SEASONAL EFFECTS OF FORAGE QUANTITY, QUALITY AND DIETARY COMPOSITION OF PRONGHORN (*Antilocapra americana*) IN A SEMI-ARID ENVIRONMENT

BY

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ABSTRACT

SEASONAL EFFECTS OF FORAGE QUANTITY, QUALITY AND DIETARY COMPOSITION OF PRONGHORN (*Antilocapra americana*) IN A SEMI-ARID ENVIRONMENT

BY

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Pronghorn (*Antilocapra americana*) populations throughout the arid southwest have declined as a result of environmental pressures associated with human-induced and climate-related stressors. A population of pronghorn on White Sands Missile Range (WSMR) has declined since 1980 despite little to no hunting pressure or competition for forage with livestock. While this decreasing trend coincided with intermittent periods of severe drought, the exotic South African gemsbok (*Oryx gazella*) is presumed to be contributing to the pronghorn decline. Less is known regarding the effects that precipitation has on quantity and quality of forage selected by pronghorn. Thus the goal of this study was to characterize

seasonal changes in forage quantity and quality in areas where pronghorn were observed foraging on WSMR and relate these seasonal changes to diet composition and dietary quality of available forage in both pronghorn and gemsbok. Diet composition using microhistological methodology revealed forbs, comprised over half the pronghorn diet in the warm-wet (55%), and warm-dry (68%) seasons of 2010. Diet composition of pronghorn and gemsbok overlapped 17% in the warm-dry season of 2010 and 31% during the drought of the warm-dry season of 2011.

I quantified above-ground biomass in pronghorn habitat across three seasons to determine forage availability and to compare biomass with seasonal trends in precipitation. The majority of the annual precipitation (12.6 cm) coincided with above-ground biomass in the warm-wet season (89.8 g/m^2) compared to the warm-dry (63.9 g/m^2) and cool-dry (68.9 g/m^2) seasons which received 3.7 cm and 0.5 cm precipitation, respectively. Across all three seasons, the majority of above-ground biomass consisted of grasses (47.6 g/m^2) followed by shrubs (14.6 g/m^2), and forbs (12.1 g/m^2).

Fecal nitrogen (FN) and fecal 2,6-diamonphelic acid (DAPA) were assessed as indices of diet quality. Dietary quality in the pronghorn population on WSMR was affected by seasonal differences in forage as well as severe drought as indicated by a low FN (1.44 %) and FDAPA (0.32 mg/g) in the warm-dry season of 2011. Fecal nitrogen and FDAPA did not differ for gemsbok between warm-dry seasons of 2010 and 2011 reflecting negligible effects of drought on the dietary quality of gemsbok.

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INTRODUCTION

Pronghorn (*Antilocapra americana*) are endemic to North America, roaming the ancient plains with populations estimated at 30 - 40 million before 1800 (O'Gara and McCabe 2004). After European settlement, pronghorn numbers declined to 15,000 by 1915 (Yoakum and O'Gara 2000). Range-wide management practices such as regulated hunting, restoration of historical range and habitat resulted in a remarkable turnaround of pronghorn populations with more than one million animals by 1983 throughout North American (O'Gara and McCabe 2004). Despite altered management practices, populations continued to exhibit fluctuations throughout their range due to environmental pressures such as drought, malnutrition, disease epizootics, hunter harvest, parturition problems, poisonous plants, and predation (Martinka 1967, Barrett 1982).

Seasonal variations in species abundance, phenology, and nutrient quality of range plants can alter pronghorn diets which lead to nutritional deficiencies. Pronghorn are selective feeders and will modify their diet depending upon forage availability. In arid environments, pronghorn diets vary among seasons and years, with forbs being a critical component due to their higher nutrient content (Buechner 1950, Stephenson et al. 1985a, Howard et al. 1990, Smith et al. 1998). Key forage species were characterized in a number of studies for pronghorn in New Mexico (Howard et al. 1982, Stephenson et al. 1985a, Stephenson et al. 1985b, Smith et al. 1998). These include dropseed grasses (*Sporobolus spp*.), plains bristle grass (*Setaria leucopila*), soaptree yucca (*Yucca elata*), prickly-pear (*Opuntia spp.),* feather delea

(*Dalea formosa*), Mormon tea (*Ephedra trifurca*), yellow salsify (*Tragopogon dubius*), annual sunflower (*Helianthus annuus*), four-wing saltbush (*Altriplex canescens*), Wrights buckwheat (*Eriogonum wrightii*), winterfat (*Eurotia lanata*), globemallow (*Sphaeralcea spp.*), fireweed summer cypress (*Kochia scoparia*), phacelia (*Phacelia spp.),* and wooly white (*Hymenopappus flavescens*). On White Sands Missile Range (WSMR) over a decade ago, Smith et al. (1998) found shrubs to be an important dietary component in pronghorn with an average annual diet composition of 58% shrubs, 20% grasses, 17% forbs, and 5% unknown. The authors noted that shrubs were the largest part of the diet (83%) during the cool-dry (November –February) when precipitation was relatively low compared to 55% in the warm-wet (July – October).

Pronghorn populations throughout the arid Southwest face additional strain of variable forage production due to low and patchy precipitation compared to the midwest regions of North America. While water availability is the most important physical factor that limits primary production in arid ecosystems (Noy-Meir 1973, Hadley and Szarek 1981), the lag time between precipitation and its influence on herbivores has a profound biological impact on population dynamics (McKinney and Smith 2007). There is a positive relationship between forage production and precipitation in the Chihuahuan Desert (Cable and Martin 1975, Pieper et al 1971, Whitford 1986, Khumulo and Holechek 2005) with variability in forage production extreme among years (Herbel and Gibbens 1996, Khumalo and Holechek 2005). Despite the variability, precipitation has been correlated with nutritional quality of forage and body condition of wild herbivores (Marshal et al. 2005, Simpson et al. 2007, Marshal et al. 2008, McKinney et al. 2008).

Knowledge of wild herbivores diet is critical for efficient management. This information will aid in option forage allocation to different herbivores. Several methods exist to evaluate the botanical composition of the herbivores including: observation of the animal, utilization techniques, stomach analysis, fecal analysis and fistula techniques (Holechek et al. 1982c). Fecal analysis is preferred with wild herbivores because it is non-invasive. While multiple herbivores may co-exist in the same area, accurate assessment of diet composition of individual ungulates can be conducted through visual surveys.

Two commonly used metrics for assessing dietary quality in pronghorn include fecal nitrogen (FN) and fecal 2,6-diaminopimelic acid (FDAPA) (Schwartz et al. 1977, Dennehy 2000, Robinson et al. 2001, Miller and Drake 2004). Fecal N and FDAPA are two of the most common indices preferred in wildlife field studies because they are non-invasive, less labor intensive, and relatively inexpensive. Fecal nitrogen is positively correlated with dietary nitrogen, forage intake, dietary protein and digestibility (Holechek et al. 1982a, Leslie and Starkey 1985, Brown et al. 1995, Osborn and Ginnett 2001). The reliability of FN as an index of diet quality may be compromised by secondary plant compounds such as tannins, which can decrease N absorption and hence elevate N content of the feces. In contrast, DAPA is a cell wall component of nearly all rumen bacteria that pass unabsorbed through the digestive track with no measurable loss (Czerkawski 1974, Davitt and Nelson 1984). As an index, fecal DAPA represents rumen bacterial populations and thus the status of digestible energy (Davitt and Nelson 1984). Together, FN and FDAPA are assessed in the event that consumption of tannins compromises nitrogen absorption.

Gemsbok were released onto WSMR from 1969 to 1977 by New Mexico Department of Game and Fish to bring a Safari experience to the Southwest. Since their initial release of seven animals (Saiz 1975), the population has increased to 3,000-6,000 and expanded their range throughout 15,000 km^2 of WSMR and surrounding areas (Burkett et al. 2002, Bender et al. 2003). Similarities of temperature, rainfall, and vegetation exist between southern New Mexico and the Kalahari desert that made the transition and range expansion of the gemsbok possible (Saiz 1975).

Precipitation has an effect on forage quantity and quality of ungulates in arid-lands. However, only the study of Smith et al. (1998) described the effects of precipitation on dietary composition of pronghorn in the Chihuahuan Desert. However, neither seasonal trends of precipitation on forage quantity or quality were described. Thus my primary goal was to relate seasonal changes in forage quantity to dietary composition and dietary quality of pronghorn on WSMR in south-central New Mexico. While pronghorn and gemsbok appear to coexist on WSMR despite similar habitat use (Hoenes and Bender 2010), little dietary overlap was observed between the two species (Smith et al. 1998). Thus, a secondary goal was to evaluate the influence gemsbok have on pronghorn through dietary overlap.

My objectives were to:

1. Characterize seasonal effects on diet composition of pronghorn;
2. Evaluate the seasonal effects of diet overlap between pronghorn and gemsbok;
3. Quantify the seasonal effects on above ground biomass throughout pronghorn habitat to estimate forage availability and forage preference; and
4. Evaluate the seasonal effects on the nutritional well being of pronghorn and gemsbok using fecal N and fecal DAPA.

The study began in 2009 at the start of the cool-dry season (November-February) with dietary composition and quality for pronghorn which continued through the cool-dry season of 2010 to obtain at least two of the same seasons for comparison (Appendix A). Dietary composition and quality was assessed for gemsbok during cool-dry 2009 and warm-dry 2010 and 2011. Above-ground biomass was characterized beginning warm-dry 2010 and continued through the warm-wet (July-October) and ended with the cool-dry season (2010).

STUDY AREA

The study was conducted within the northern portion of White Sands Missile Range in the Tularosa Basin of south-central New Mexico. White Sands Missile Range, a Department of Defense research and testing installation, encompassing approximately 800,000-ha within the Chihuahuan Desert (Figure 1). The installation is bordered by the Sacramento Mountains to the east and the San Andres and Organ Mountains to

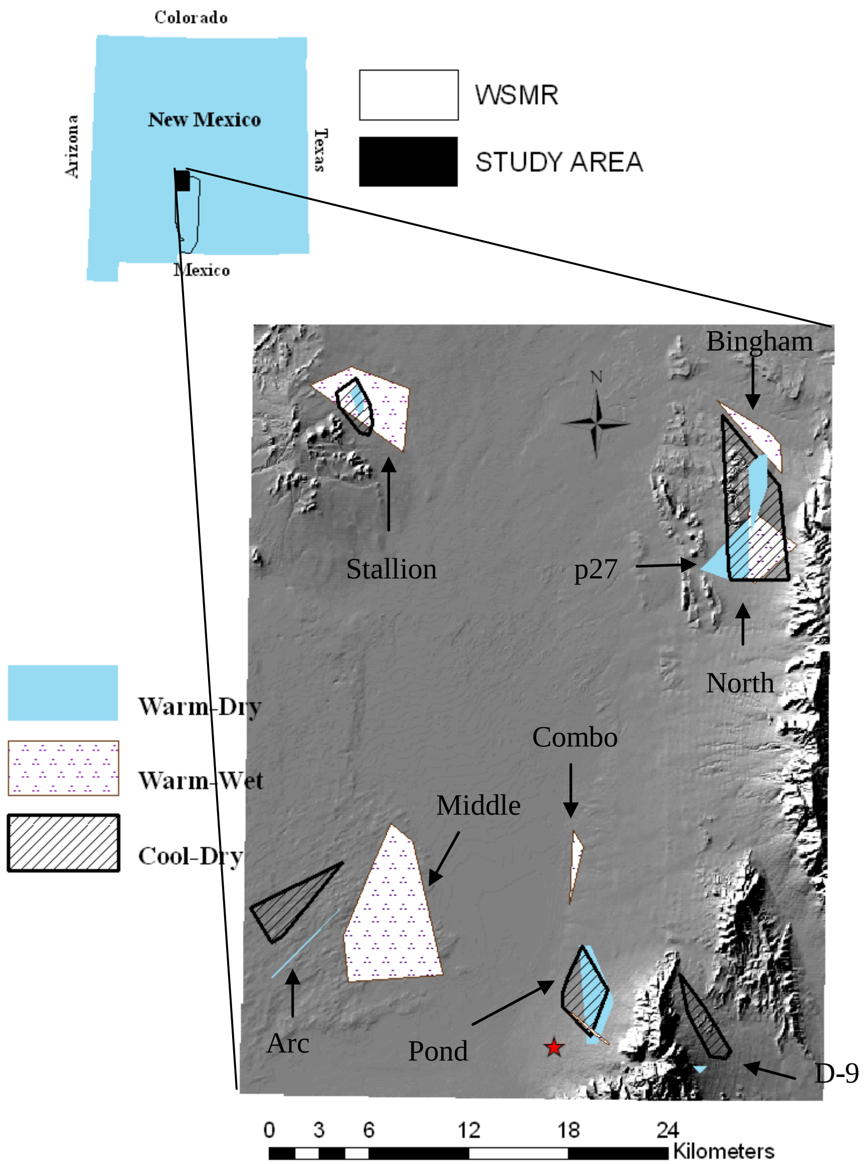

Figure 1. Study area in south-central New Mexico. Minimum convex polygons were built from seasonal locations of pronghorn in 2010. Seasons are represented by warm-dry (March-June), warm-wet (July-October), cool-dry (November-February). Star is represented by focal burn location that occurred in the warm-wet of 2008.

the west. Annual rainfall averages 20-23 cm with the majority of the precipitation occurring during the summer monsoon season (July-October) (Hoenes 2008).

Precipitation delineates the seasons of this semi-arid landscape and includes warm-dry (March-June), warm-wet (July-October), cool-dry (November-February) (Hoenes 2008), but may vary slightly through time due to decadal climate patterns (i.e., El Niño and La Niña). Beginning January 2011, the study area experienced one of the worst droughts on record (http://www.droughtmonitor.unl.edu/archive.html, accessed on August 5, 2012).

The terrain includes open grasslands, dry lakebeds, lava flows, gypsum dunes, shrublands, and canyons. The dominant ecotonal vegetation is represented by Chihuahuan desert scrub, while other vegetation types include closed basin scrub, alkali sink scrub, and desert grassland (Dick-Peddie 1993). Common grasses include grama grasses (*Bouteloua spp*.), dropseeds (*Sporobolus spp*.), tobosa (*Pleuraphis mutica*.), and fluff grass (*Erioneuron pulchellum*). Common shrubs include a variety of yucca (*Yucca spp.)*, prickly-pear (*Opuntia spp*.), Mormon tea (*Ephedra spp.)*, tarbush (*Flourensia cernua*), snakeweeds (*Gutierrezia spp*.), creosote bush *Larrera tridentata*), and honey mesquite (*Prosopis glandulosa*). Common forbs included spiny golden aster (*Xanthisma spinulosum*), tahoka daisy (*Machaeranthera tanacetifolia*), field bahia (*Bahia absinthifolia*), and bristle clinchweed (*Pectis papposa*). Livestock grazing does not occur on WSMR and populations of ungulates such as mule deer (*Odocoileus hemionus*) are incidental. Predators including coyotes (*Canis latrans*), mountain lions (*Puma concolor)*, bobcats (*Lynx rufus*), and golden eagles (*Aquila chrysaetos*) have been reported in the area, but were not observed during the study.

METHODS

Precipitation- Monthly precipitation (cm) was averaged across three meteorological stations (WeatherMeasure 8" tipping bucket gauges with 0.01" resolution model 6010) distributed across WSMR: Mockingbird Gap (Latitude 33.4027 and Longitude 106.364, elevation 1303 m), Arc (Latitude 33.561 and Longitude 106.647, elevation 1442 m), and Stallion Range Center (Latitude 33.8192 and Longitude 106.665, elevation 1498 m) from 2009 through 2011 (White Sands Missile Range, Meteorology Branch).

Pronghorn Population- Twenty nine pronghorn (two fawn males, five adult males, 22 adult females) were captured April 2007 and December 2008 throughout the northern area of WSMR by chemical immobilization (Halbritter and Bender 2011) and fitted with VHF mortality-sensitive radio collar (Advanced Telemetry Systems, Isanti, MN, USA). Capture and treatment methodology was approved by New Mexico State University Institutional Animals Use and Care Committee (IACUC No. 2009-025). Radio-collared pronghorns were located from the ground with a R-1000 telemetry hand-held receiver (148-174 MHZ telemetry receiver, Communications Specialists, Inc., Orange, CA, USA). Locations were recorded weekly using a hand-held Geographic Positioning System (GPS) and plotted using the Geographic Information System (GIS) software package ArcGIS 9.3 (Environmental Systems Research

Institute, Redlands, CA, USA). Females were monitored at least twice a week during parturition and lactation for observational monitoring of fawn survival and recruitment.

Seasons associated with trends in precipitation included warm-dry (March-June), warm-wet (July-October), cool-dry (November-February) (Hoenes 2008). The study began in 2009 at the start of the cool-dry season (November-February) with dietary composition and dietary quality and continued through the warm-dry season of 2011 (March-June) (Appendix A). Above-ground biomass was characterized beginning warm-dry 2010 and continued through the warm-wet (July-October) and ended with the cool-dry season (2010) (Appendix A).

For the warm-dry season, pronghorn were located weekly from 6 March to 15 April 2010 and sampling for above ground biomass occurred from 17 April to 8 June 2010. In the warm-wet season, pronghorn were located weekly from 10 June 2010 to 29 August 2010 and sampling for above ground biomass occurred from 6 September to 15 October 2010. For the cool-dry season, pronghorn were located weekly from 4 November to 2 January 2011, and sampling for above ground biomass occurred from 4 January to 17 January 2011. Sightings and the respective GPS coordinates for each animal were used to build multi-convex polygons in ArcGIS 9.3 within each season to subsequently assess above-ground biomass. Each multi-convex polygon was built from animal sightings in the same area (i.e., animal sightings from one area were not combined with animal sightings within an adjacent area) from a total of 146 pronghorn observations.

Microhistology, Diet Composition, and Preference Ratings- Slide preparation for microhistological analysis of diet composition followed the method of Sparks and Malechek (1968) as modified by Holechek (1982) and Alipayou et al. (1992). Additional modifications included filtering fecal material through a Whatman No. 4 filter paper and using plastic mounting medium (Johnson et al. 1983). Each slide was examined systematically viewing 20 fields per slide to insure high repeatability (Holechek and Vavra 1981) at 100x magnification using a compound microscope (Leica DME) (Sparks and Malechek 1968). When particles representative of diagnostic characteristics were unclear, magnification of 200x was used (Holechek and Valdez 1985). Microhistological analysis will result in considerable variation between technicians despite training. As a result, a single observer (the author) was trained using procedures of Holechek and Gross (1982a) and conducted all microhistological assessments. Reference plant slides were prepared in the same manner as the fecal samples to facilitate identification of plant fragments in fecal samples with the exception of four species: croton, prickly-pear, yucca, and *Plantago patagonia* (plantago) required an alternative method for identification of epidermal characteristics. Briefly stated, this method required soaking 1 g of plant tissue in boiling 10% nitric acid until the epidermal layer separated from the dermal layers of the sample. This layer was gently placed on a glass slide, coated with plastic mounting medium and covered by a glass cover slip.

Prior research was used as a guide to identify diagnostic micro-anatomical characteristics from epidermal cells of plant references (Metcalfe and Chalk 1950, Metcalfe 1960, Johnson et al. 1983, Dabo et al. 1986). Drawings and pictures of the epidermal cell characteristics were critical when identifying plant species in fecal samples. Diagnostic characteristics of micro-anatomical epidermal cells for grasses included parallel veins, silica, cell size and shape, shape of cell wall, stomata size, stomata shape and orientation, and associated companion cells (Metcalfe and Chalk 1950, Metcalfe 1960, Sparks and Malechek 1968, Johnson et al. 1983). Diagnostic characteristics of micro-anatomical epidermal cells for forb or shrub species included stomata shape, number of epidermal cells that surround the stomata, shape and number of cells making up the base of the trichome, and the presence of crystals (Metcalfe and Chalk 1950, Sparks and Malechek 1968, Johnson et al. 1983). When identifying a grass species in fecal material, two micro-epidermal anatomical diagnostic characteristics were required, while one or two micro-anatomical epidermal feature in forbs or shrubs was required for positive confirmation (Johnson et al. 1983).

Percent composition (PC) was determined for each plant species identified in fecal matter using the method of Holechek and Gross (1982b):

$$PC = A \times (100/B),$$

where A is the occurrence of each plant species and B in the occurrence of all plant species. Percent composition of each species of grass, forb and shrub were combined into forage classes.

To evaluate how the animals utilized forage in proportion to availability, preference ratings were calculated by dividing the percent composition of the individual plant in the diet by the percent availability of the plant on the landscape (Krueger 1972, Hansen et al. 2001, McDonald 2005). Percent forage availability of individual plant species was determined by dividing the weight (g) of the individual species by the total weight of all species present. Preference ratings of pronghorn and gemsbok for individual plants were determined seasonally. Plants with preference ratings greater than 1.0 were considered 'preferred'.

Dietary Overlap- The selection of an index that describes dietary overlap should be based on its biological interpretation (Hulbert 1978). Kulcyznski's similarity index (Oosting 1956) was selected to assess dietary overlap of the two ungulates because it provides quantitative evaluation of similarity and overlap of herbivore diets, it is easy to use and interpret, allows statistical analysis, and provides a direct measure of common proportionality between diets (Holechek et al. 1984).

$$S = [(2)\ W\ \ *100\ ] / (A+B),$$

where W is the sum of the quantity of each plant species that the two animals (A and B) have in common in their respective diets; A represents the total of all plant species in diet A, and B represents the total of all plant species in diet B. For the purpose of this study, the similarity index represented the percentages of two diets that were identical for each season between pronghorn and gemsbok. The similarity index quantified dietary overlap across seasons for pronghorn and gemsbok separately. To evaluate how the animals were utilizing the forage in proportion to their availability, preference ratings were calculated by dividing the percent composition of the individual plant in the diet by the percent availability of the plant on the landscape (Krueger 1972).

Above-ground Biomass- Above ground biomass sampling occurred during 2010 beginning with the warm-dry season and followed by warm-wet and cool-dry seasons. Within each minimum complex polygon, four random points were generated using ArcGIS 9.3. Each random point was the origin for transects in four compass directions. Along each transect, two 0.5 m^2 quadrats were placed 12 meters apart. Within each quadrat, all vegetation except for shrubs and trees were clipped to the ground, separated by species, and placed into labeled paper bags. For shrubs and trees, new growth from ground level to 2.5 m above ground was clipped (Hobbs et al. 1982). All harvested material was oven dried at 60°C for 24 h and weighed ($\pm$ 0.1 g) (Beck and Peek 2004). Mass of individual plant species were added together to obtain total forage availability (g/m^2). Succulent vegetation (i.e., prickly-pear, Mormon tea, yucca) required additional time (3-14 days) for drying. During the warm-dry season, harvested material was returned to the laboratory where the material was carefully processed to separate last years dead material from the current seasons new growth. During the warm-wet and cool-dry seasons, dead material was easily separated in the field prior to bagging. At each sampling point, the area was examined throughout approximately 250 m radius for extensive grazing and homogeneity of the soil and vegetation.

Nutritional Indicators –Fecal collections began in cool-dry 2009 and continued through cool-dry 2010 to obtain two of the same seasons for an additional comparison of a dry season. Beginning in 2011, however, the Southwest experienced one of the worst droughts in decades (http://www.droughtmonitor.unl.edu/archive.html, accessioned August 5, 2012). Thus, an additional season (warm-dry) was added in 2011 to compare the effects of drought on diet composition and quality of pronghorn and gemsbok.

Radio-collared pronghorn were located and observed from a distance. After the majority of animals had defecated and moved on, approximately 2 g of fresh fecal pellets were collected from each defecation and composited. Numbers of animals within each group varied and included both radio-collared and non-collared pronghorn. Fresh fecal samples were collected from gemsbok observed in the same areas as pronghorn using the same collection methodology. Due to time constraints, however, fecal samples were collected only during the cool-dry (2009), warm-dry (2010 and 2011) seasons because these seasons represented limited resources. Fecal sample areas for pronghorn and gemsbok overlapped throughout the seasons (Appendix A).

Feces were obtained from a captive population of pronghorn (The Living Desert Zoo, Palm Desert, California, USA) for nutritional comparisons with the WSMR wild population throughout the warm-dry, warm-wet, and cool-dry seasons. The captive population presumably represented a nutritionally healthy and stable population from which to compare wild population on WSMR. Feces were collected from one male and one female pronghorn every three days resulting in a two week collection within each season. The captive population was fed a pelleted diet (Mazuri®/PMI Nutrition International LLC) and supplemented daily with alfalfa.

Fecal samples were oven dried at 55^{o}C for 48 h, then ground using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) through a 1 mm sieve. A portion of the sample was evaluated for FN using the combustion method of Verheyden et al. (2011) (Leco LP 520) at New Mexico State University in the Department of Animal and Range Science Nutrition Laboratory (Las Cruces, New Mexico). A second portion was analyzed for FDAPA by the Wildlife Habitat and Nutrition Lab at Washington State University (Seattle, WA) using the method of Davitt and Nelson (1984). Composited fecal samples produce a value equal to the mean of the represented individuals and were deemed appropriate for the purpose of FN and FDAPA (Jenks et al. 1989).

Statistical Analysis for Dietary Overlap- The Kruskal-Wallis test was used to assess similarity of diet for pronghorn and gemsbok during the cool-dry season of 2009 and warm-dry season of 2010 and 2011. The Kruskal-Wallis was also used to compare similarities of diet for gemsbok across seasons (cool-dry 2009, warm-dry 2010 and 2011). Differences were considered detectably different when $P \leq 0.05$. When differences were detected, the Mann-Whitney test was used to assess differences and Bonferroni corrections were used to control for type 1 error. All statistical analyses were conducted in SAS (version 9.3) (SAS Institute, Inc., Cary, NC).

Statistical Analyses for Above Ground Biomass- Assumption of Normality for total forage availability was unlikely to be met due to the small sample size within each area (n=4) as well as mosaic distribution of vegetation. Thus a non-parametric analysis was selected to analyze differences in total forage availability among areas within each season. To confirm my assumption, total forage availability was assessed within each season and found to be non-normally distributed ($P<0.05$). The non-parametric Kruskal-Wallis test was conducted to detect differences for total forage availability among areas within each season (Kuehl 2000). If differences were found among areas, the Mann-Whitney test was conducted between individual areas selected *a priori* to confirm areas where total forage availability were different. Bonferroni corrections were used to control for type 1 error. As such, a series of *a priori* tests were conducted among areas for both seasons using Mann-Whitney followed by Bonferroni correction in the warm-wet ($P=0.01$) and cool-dry ($P=0.008$) seasons.

Statistical Analysis for Nutritional Indices-The assumptions for Normality were not met for either FN ($P=0.002$) or for FDAPA ($P=0.024$). Thus, the non-parametric Kruskal-Wallis test was conducted to detect differences for FN and for FDAPA among seasons (warm-dry, warm-wet, and cool-dry) (Kuehl 2000). In addition, differences in FN and FDAPA were assessed for season between years (cool-dry 2009 vs. cool-dry 2010 and warm-dry 2010 vs. warm-dry 2011) using the Wilcoxon signed-rank test. The Kendall's Tau coefficient was used to determine seasonal association between FN and FDAPA (Kruskal 1958). The Mann-Whitney test was used to assess differences in FN and FDAPA between the captive and WSMR pronghorn populations.

RESULTS

Precipitation- Cumulative average rainfall throughout the northern portion of WSMR exhibited seasonal patterns in 2010 with the greatest precipitation recorded during the seasons of warm-wet (12.6 ± 0.85 cm), followed by cool-dry (6.5 ± 1.4 cm), and warm-dry (3.7 ± 0.51 cm) (Figure 2). During the drought of 2011, average cumulative rainfall during the warm-dry season was 0.15 ± 0.22 cm (Figure 2). According to the Palmer Drought Index, seasonal precipitation throughout the Southwest region was classified as 'normal' at the beginning of the study (cool-dry 2009) and continued through to the end of 2010 (cool-dry 2010). Beginning in 2011 with the warm-dry season, precipitation was negligible resulting in moderate to severe drought. By the end of the study (May 2011), the southwest was experiencing 'exceptional' drought (http://www.droughtmonitor.unl.edu/archive.html, accessioned August 5, 2012).

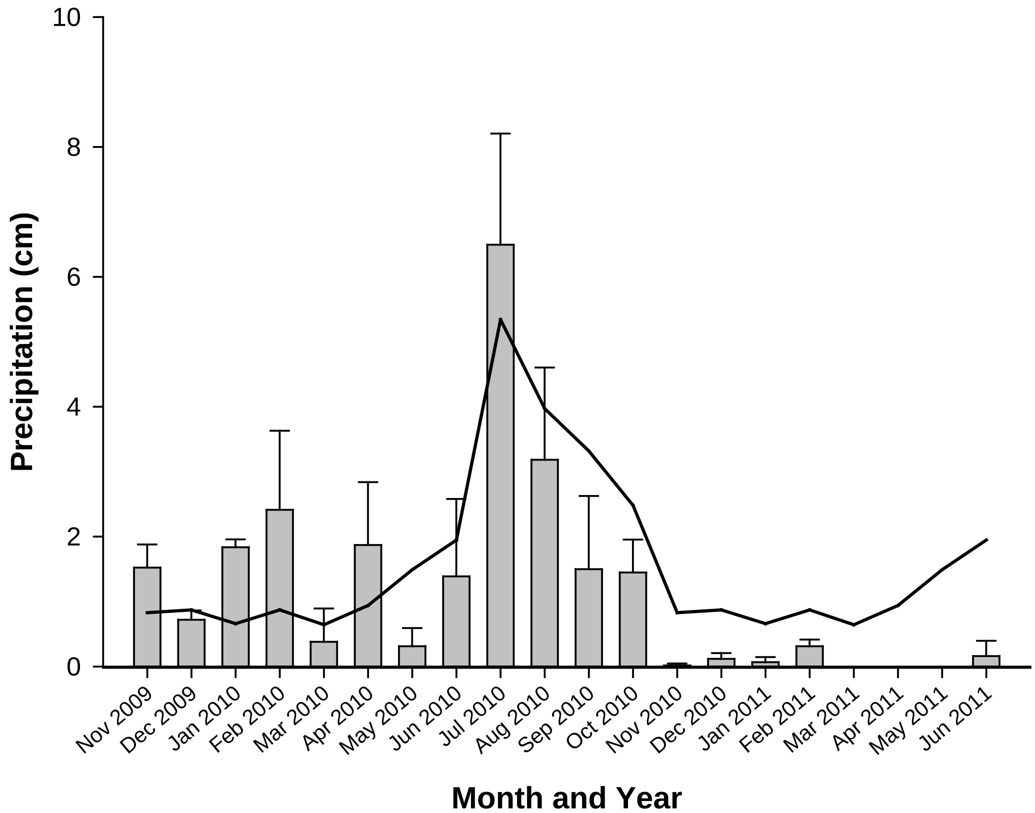

Figure 2. Average cumulative precipitation (cm) with standard deviation recorded at three weather stations (D-9, Arc, Stallion) located within the northern area of White Sands Missile Range, south-central New Mexico. Seasons are represented by cool-dry (November-February), warm-dry (March-June), warm-wet (July-October). Solid line represents the long term precipitation trend for WSMR. Source: White Sands Missile Range Environmental Stewardship Branch.

Diet Composition for Pronghorn and Gemsbok- Microhistological analysis of fecals revealed pronghorn consumed a total of 75 identifiable species (13 grasses, 24 shrubs, 38 forbs) (Appendix B). Pronghorn diet varied seasonally throughout the study with key forage species in the cool-dry season (2009) consisting of prickly-pear (21%), horse nettle (8%), three-awn grasses (7%), globemallow (6%), and Bigelow sage (5%) (Table 1). Key forage species during the warm-dry season (2010) consisting of yucca (11%), croton (7%), blazingstar (7%), hog potato (6%), and prickly-pear (4%) (Table 1). During the warm-wet season (2010), key forage species included globemallow (10%), croton (8%), skunk bush (7%), prickly-pear (7%), annual sunflower (5%), and Bigelow sage (5%). Key forage species during the cool-dry season (2010) included prickly-pear (21%), horse nettle (14%), yucca (8%), scrub oak (6%), Mormon tea (7%), and 4-wing (5%). Despite the drought, (warm-dry 2011) pronghorn were finding and selecting forbs and were presumably selecting succulents for the needed moisture. Key forage species shifted in the warm-dry 2011 to include prickly-pear (24%), yucca (11%), horse nettle (10%), hog potato (10%), globemallow (7%), and Bigelow sage (5%). During the warm-dry (2011) pronghorn diet consisted of 2% African rue (*Peganum harmala)*, which is a toxic exotic species. Forbs predominated in pronghorn diets (68% warm-dry 2010 and 55% warm-wet 2010) during the warm-wet season. When precipitation decreased pronghorn altered their diet to consume more shrub species (66% cool-dry 2010 and 51% warm-dry 2011) (Table 1).

Table 1. Seasonal average percent diet composition of pronghorn from White Sands Missile Range in south-central New Mexico. Seasons are represented by cool-dry (November-February), warm-dry (March-June), warm-wet (July-October). "T" represents less than 1% of the diet consisting of the species and is not included in the total percent of the diet composition. "-" represents absence from the diet within that season.

	2009		2010		2011
	Cool-dry	Warm-dry	Warm-wet	Cool-dry	Warm-dry
Grasses					
Aristida spp.	7	T	3	T	1
Total Grasses	21	6	12	2	7
Shrubs					
Opuntia spp.	21	4	7	21	24
Yucca spp.	3	11	4	8	11
Artemisia bigelovii	5	3	6	4	5
Quercus turbinella	4	T	T	6	T
Rhus microphylla	T	T	7	-	1
Rumex hymenosepalus	7	-	-	-	-
Atriplex canescens	1	2	T	5	2
Ephedra spp.	-	-	T	7	T
Total Shrubs	50	26	33	66	51
Forbs					
Solanum elaeagnifolium	8	2	4	14	10
Sphaeralcea spp.	6	4	10	4	7
Croton spp.	1	10	8	2	1
Hoffmannseggia glauca	4	6	4	-	10
Lesquerella gordonii	1	3	5	1	T
Aphanostephus ramosissimus	1	5	4	1	T
Helianthus petiolaris	-	2	5	2	T
Mentzelia spp.	-	5	1	2	T
Peganum harmala	-	T	-	-	2
Total Forbs	29	68	55	32	42

A total of 50 species (19 grasses, 16 shrubs, 15 forbs) (Appendix C) were detected in fecal samples of gemsbok. During the cool-dry (2009) season, gemsbok diet consisted of 66% grasses, 32% shrubs, and 2% forbs (Table 2). During the warm-dry (2010) season, the gemsbok diet consisted of 54% grasses, 30% shrubs and 16% forbs (Table 2). In the drought during the warm-dry season (2011), the gemsbok diet consisted of 47% grasses, 35% shrubs, and 18% forbs (Table 2).

Preference Ratings for Pronghorn and Gemsbok- Throughout all three seasons, pronghorn preferred forbs over grasses or shrubs (Table 3). During the warm-dry season, preferred species were hog potato, followed by horse nettle, plantago and globemallow (Table 3). In the warm-wet season, preference ratings for hog potato, horse nettle, and globemallow, while lower, were still highly preferred (Table 3). In addition, pronghorn selected grasses such as three-awn, deer grass and vine mesquite. In the cool-dry season, preference ratings were greatest for horse nettle followed by globemallow, annual sunflower, and yucca (Table 3). During the warm-dry season , gemsbok preferred globemallow, grama grasses, and dropseeds (Table 3).

Table 2. Mean seasonal diet composition of pronghorn and gemsbok during cool-dry 2009 (November-February), warm-dry 2010 and 2011 (March-June) on White Sands Missile Range in south-central New Mexico. “T” represents less than 1% of the diet and not represented in the total. “-“ represents absence from the diet. “P” represents Pronghorn and “G’” represents Gemsbok.

	Cool-dry (2009)		Warm-dry (2010)		Warm-dry (2011)	
	P	G	P	G	P	G
Grasses						
Bouteloua spp.	3	11	1	9	1	10
Bouteloua gracilis	2	8	T	8	T	2
Aristida spp.	7	8	T	5	1	3
Bouteloua curtipendula	3	7	T	4	T	1
Bouteloua eriopoda	T	7	T	3	-	3
Sporobolus spp.	T	5	1	7	1	8
Sporobolus cryptandrus	T	4	T	4	T	5
Other grasses	1	1	T	8	1	6
Unknown grasses	4	4	4	6	3	8
Total Grasses	21	66	6	54	7	47
Shrubs						
Opuntia spp.	21	9	4	2	24	6
Yucca spp.	3	10	11	10	11	23
Krascheninnikovia lanata	T	2	1	10	T	T
Artemisia bigelovii	5	-	3	T	5	T
Other Shrubs	2	1	4	3	5	3
Unknown Shrubs	6	2	T	1	T	2
Total Shrubs	50	32	26	30	51	35
Forbs						
Sphaeralcea spp.	6	2	T	2	7	9
Solanum elaeagnifolium	8	T	T	-	10	4
Hoffmannseggia glauca	4	-	5	1	10	1
Croton spp.	1	-	10	1	1	1
Lesquerella gordonii	1	-	3	5	T	-
Marrubium vulgare	3	-	5	-	T	-
Aphanostephus ramosissimus	1	-	5	-	T	-
Other Forbs	2	T	31	3	7	3
Total Forbs	29	2	68	16	42	18

Table 3. Preference ratings for pronghorn and gemsbok on White Sands Missile Range in south-central New Mexico. Seasons are represented by warm-dry (March-June), warm-wet (July-October) and cool-dry (November-February). Values greater than 1.0 are preferred.

	Warm-dry 2010		Warm-wet 2010	Cool-dry 2010
	Pronghorn	Gemsbok	Pronghorn	Gemsbok
Grasses				
Aristida spp.	0.2	1.4	3	
Bouteloua curtipendula	-	2.5	-	-
Bouteloua gracilis	0.5	3	0.06	1
Muhlenbergia spp.	-	-	1	-
Panicum obtusum	-	0.8	1	-
Sporobolus spp.	0.2	2.3	0.13	-
Bouteloua eriopoda	0.02	0.1	-	-
Pleuraphis spp.	0.02	0.1	-	-
Bouteloua barbata	-	-	0.4	-
Bouteloua spp.	-	-	0.3	-
Shrubs				
Yucca spp.	-	-	1.2	3
Opuntia spp.	-	0.02	0.1	0.8
Artemisia bigelovii	0.8	-	-	-
Ephedra spp.	-	-	0.02	0.5
Artemesia filifolia	-	-	0.03	-
Forbs				
Sphaeralcea spp.	99	6.3	33.6	7
Solanum elaeagnifolium	152	-	4.2	112
Hoffmannseggia glauca	176	-	4.8	-
Plantago patagonia	135	-	-	-
Helianthus spp.	6.1	-	0.1	6
Psilostrophe tagetina	10.6	-	-	-
Physaria fendleri	7	-	-	-
Zinnia grandiflora	-	3.9	-	-
Acourtia nana	.3	3.1	-	-
Mentzelia albicaulis	0.4	-	2.1	-
Aphanostephus ramosissimus	0.2	-	-	-
Cryptantha angustifolia	-	0.3	-	-

Dietary Overlap of Pronghorn- The similarity index revealed that pronghorn exhibited differences between seasons that were detectable (P=0.039). Dietary overlap was lowest during warm-dry (2010) and cool-dry (2010) seasons (21.8 ± 2.36%) (Table 4) and highest during the lower precipitation of the cool-dry (2009) and warm-dry (2011) seasons (44.6 ± 5.10%) (Table 4). As such, *a priori* assumptions of seasonal precipitation were tested , however, none of the comparisons were statistically different with the Bonferroni correction at 0.01.

Dietary Overlap of Gemsbok- The similarity index revealed gemsbok diet exhibited moderate dietary overlap across seasons that varied from 39.1 when comparing warm-dry 2011 with warm-dry 2010 to 42.9 in the warm-dry 2011 seasonal and cool-dry 2009 season (Table 4). Differences were not detected between seasonal dietary overlap for gemsbok (P = 0.840).

Table 4. Average seasonal dietary overlap for pronghorn on White Sands Missile Range in south-central New Mexico from November 2009 to July 2011. Seasons are represented by cool-dry (November-February), warm-dry (March-June), warm-wet (July-October). Only estimates in the same column for Pronghorn followed by the same superscript were tested using Mann-Whitney two sample t-test and are not significantly different after Bonferroni correction (P>0.01). Estimates in the same column for gemsbok followed by the same superscript are not significantly different using Kruskal-Wallis and Bonferroni correction (P>0.05).

Comparison	Overlap (%)	Standard Error
Pronghorn		
Cool-dry 2009 vs. warm-dry 2010	23.0	4.72
Cool-dry 2009 vs. warm-wet 2010	36.1^{BC}	4.83
Cool-dry 2009 vs. cool-dry 2010	34.4	1.18
Cool-dry 2009 vs. warm-dry 2011	44.6^{AD}	5.09
Warm-dry 2010 vs. warm-wet 2010	28.6	5.35
Warm-dry 2010 vs. cool-dry 2010	21.8^{ABE}	2.36
Warm-dry 2010 vs. warm-dry 2011	26.4	2.99
Warm-wet 2010 vs. cool-dry 2010	23.2	4.90
Warm-wet 2010 vs. warm-dry 2011	26.9^{CD}	2.62
Cool-dry 2010 vs. warm-dry2011	37.3^{E}	4.48
Gemsbok		
Cool-dry 2009 vs. warm-dry 2010	45.5^{F}	1.57
Cool-dry 2009 vs. warm-dry 2011	42.9^{F}	5.33
Warm-dry 2010 vs. warm-dry 2011	39.1^{F}	7.07

Dietary Overlap of Pronghorn and Gemsbok- Of the total 85 species and genera (19 grasses, 26 shrubs, 40 forbs) consumed by both pronghorn and gemsbok, 45 species and genera (13 grasses, 17 shrubs, 15 forbs) were shared (Appendix C). Dietary overlap between the two ungulates was 37% in the cool-dry season (2009), 17% in the warm-dry season (2010), and 31% during extreme drought of 2011 in the warm-dry season. Dietary overlap, however, was not detectably different among the three seasons (P = 0.220). Surprisingly, there were no detectable differences of dietary overlap between warm-dry (2010) and warm-dry (2011) (P = 0.313). Common key forage species for both pronghorn and gemsbok during cool-dry 2009 included prickly-pear, yucca, and three-awn grasses. During the warm-dry 2011 drought, key forage species shared between pronghorn and gemsbok included yucca, prickly-pear, globemallow, and horse nettle. Cumulatively, these four species consisted approximately 50% of the pronghorn diet and approximately 40% of gemsbok diet.

Above Ground Biomass- Throughout the three seasons in 2010, 29 species of grasses, 81species of forbs, and 16 species of shrubs for a total of 126 species of plants was collected throughout the study areas (Appendix D). Briefly stated, predominant species among areas during the warm-dry season included grama grasses, dropseeds, prickly-pear and plains doze daisy. Predominant species among areas during the warm-wet season included grama grasses, dropseeds, yucca, Mormon tea, and snakeweed. Predominant species among areas during the cool-dry season included grama grasses, yucca, prickly-pear, and dropseed. Grasses represented the dominant functional group (64%), followed by shrubs (19%) and forbs (17%) in above ground biomass for all three seasons (Table 5). During the warm-dry season, above ground biomass was not detectably different among areas (P = 0.418) (Table 6). In contrast, above ground biomass of total forage was detectably different among areas during the warm-wet (P = 0.004) and cool-dry (P = 0.028) seasons (Table 6). Differences in above ground biomass among areas within the warm-wet and cool-dry seasons were most likely due to patchy rainfall as well as topography and varying soil characteristics. Pair-wise comparisons using a Mann-Whitney two sample t-tests were compared for the following areas during the warm-wet season (Pond with Stallion, North and Combo; Stallion with Bingham and Combo) and resulted in a Bonferroni correction factor of 0.01. Pair-wise comparisons using a Mann-Whitney two sample t-tests were compared among the cool-dry season (Pond with Stallion, Arc, D-9, and North; Arc with Stallion and D-9) and resulted in a Bonferroni correction factor 0.008. These selections were selected *a posteriori* due to ecological differences among the areas that were considered noteworthy. No detectable differences were detected after pair-wise comparasions were made.

Nutritional Indicators for Pronghorn and Gemsbok- From December 2009 through June 2010, a total of 73 fecal composites were collected from radio-collared and un-collared pronghorn throughout the study areas. Detectable differences in 2010 were observed for FN among warm-dry, warm-wet, and cool-dry seasons (P=0.037 Chi-square=6.57) (Table 7). Two independent comparisons (with a Bonferroni correction

Table 5. Average percent of major forage categories and ± standard error from obtained from above ground biomass across study areas throughout White Sands Missile Range, south-central New Mexico. Above ground biomass was collected seasonally throughout 2010 during warm-dry (March-June), warm-wet (July-October), cool-dry (November-February).

Season	Grasses (%)	Shrubs (%)	Forbs (%)
Warm-dry	59 ± 8.9	14 ± 5.9	26 ± 8.2
Warm-wet	68 ± 3.5	17 ± 2.4	15 ± 3.1
Cool-dry	64 ± 2.4	26 ± 3.0	10 ± 1.2
Average	64 ± 2.6	19 ± 3.6	17 ± 4.7

Table 6. Average (± standard error) of above ground biomass across study areas throughout White Sands Missile Range, south-central New Mexico. Above ground biomass was collected seasonally throughout 2010 during warm-dry (March-June), warm-wet (July-October), cool-dry (November-February). "-" indicates pronghorn were not observed within the area and thus above-ground biomass was not sampled. There were no detectable differences detected among areas within season.

Area	Warm-dry (g/m^2)	Warm-wet (g/m^2)	Cool-dry (g/m^2)
Stallion	53.6 ± 5.39	139.3 ± 31.33	93.2 ± 38.48
Pond	55.0 ± 7.71	50.8 ± 8.70	32.3 ± 5.21
D-9	75.4 ± 16.63	-	96.8 ± 16.24
Bingham	84.0 ± 16.82	61.0 ± 11.89	-
Arc	53.0 ± 7.37	-	32.9 ± 4.20
North	62.2 ± 5.69	113.1 ± 6.39	80.9 ± 21.81
Combo	-	89.8 ± 15.32	-
Middle	-	116.4 ± 12.08	-
Average	63.9 ± 5.30	95.1 ± 14.0	67.2 ± 14.40

Table 7. Average concentrations of fecal nitrogen % (FN) and fecal 2,6-diaminopimelic acid (mg/g) (FDAPA) for pronghorn (standard error and sample size in parenthesis) on White Sands Missile Range, south-central New Mexico. Fecal indices were analyzed seasonally from 2009 to 2011 during cool-dry (November-February), warm-dry (March-June), warm-wet (July-October). "-" indicates samples were not collected. There were no detectable differences noted among years and within years.

	2009		2010		2011	
Season	FN (%)	FDAPA (mg/g)	FN (%)	FDAPA (mg/g)	FN (%)	FDAPA (mg/g)
Cool-dry	1.43 (0.13,4)	0.31 (0.04,4)	1.57 (0.05,4)	0.28 (0.016,4)	-	-
Warm-dry	-	-	2.01 (0.13,6)	0.43 (0.055,6)	1.44 (0.07,12)	0.33 (0.03,12)
Warm-wet	-	-	1.55 (0.08,6)	0.36 (0.035,6)	-	-

factor of 0.025) showed no detectable differences between warm-dry and cool-dry (P=0.048) or warm-dry and warm-wet seasons (P=0.206).

There was no detectable differences during 2010 across warm-dry, warm-wet and cool-dry seasons for FDAPA (P=0.067, Chi-square=5.41) (Table 7). There were no detectable differences between years (cool-dry 2009 and cool-dry 2010) for either FN (P=1.0) or FDAPA (P=0.5). Surprisingly, there were no detectable differences for FN (P=0.062) and FDAPA (P=0.188) between years of normal precipitation and drought (warm-dry 2010 vs. warm-dry 2011).

Fecal N and FDAPA were positively correlated with one another within warm-dry (2010) (P=0.003, Taub=0.50), and cool-dry (2010) seasons (P=0.036, Taub=0.54), reflecting that secondary plant metabolites did not affect FN values of pronghorn within these seasons. In contrast, FN and FDAPA were moderately correlated with one another during the cool-dry (2009) (P=0.292, Taub=0.286), and warm-dry (2011) seasons (P=0.112 Taub=0.36) reflecting that secondary plant metabolites may have been impacting digestibility of dietary nitrogen (Figure 3). FDAPA may be more representative of dietary quality during cool-dry 2009 and warm-dry 2011 when shrubs consisted of 50% of the pronghorn diet and presumably causing a tannin-nitrogen interaction.

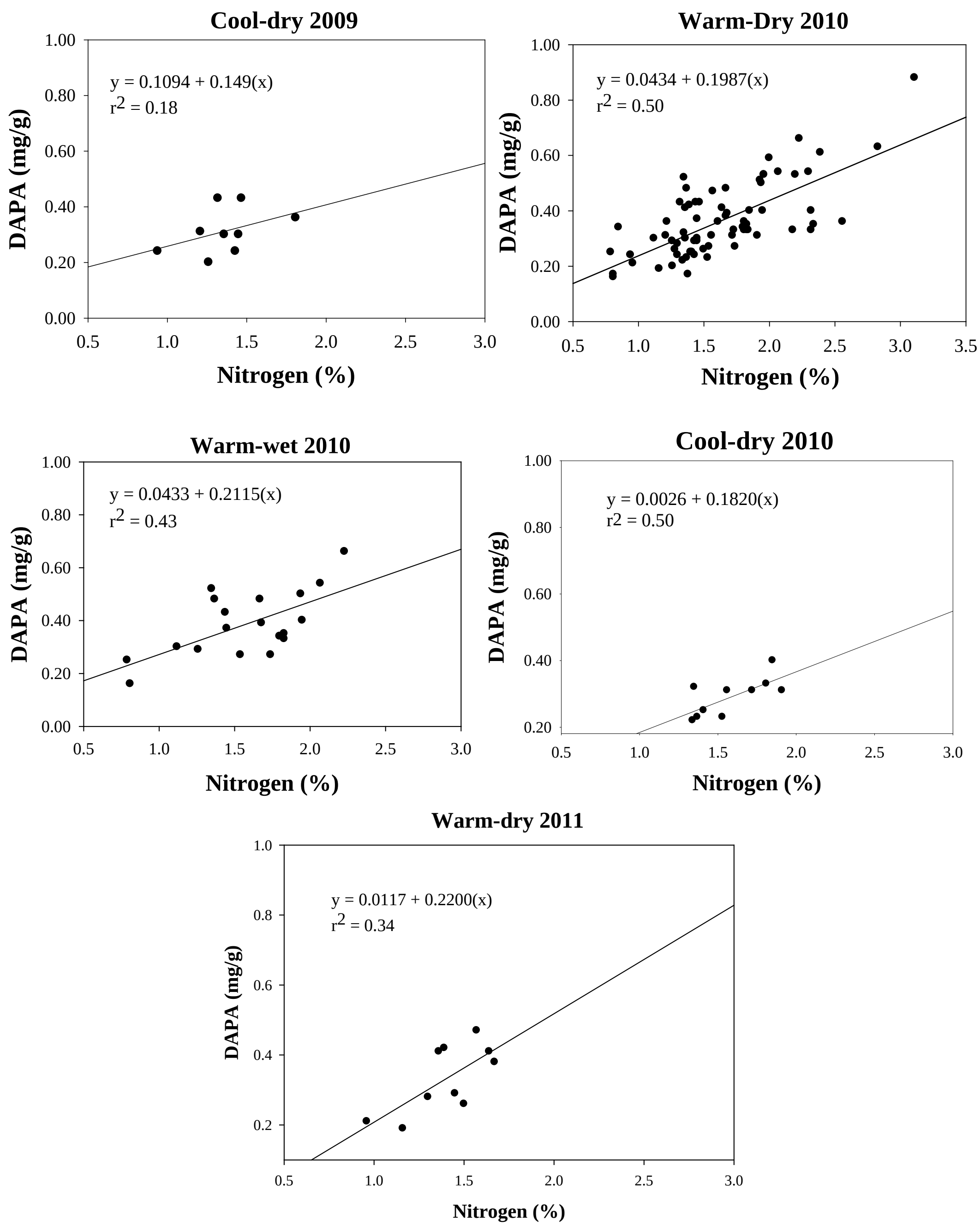

Figure 3. Pronghorn fecal Nitrogen (%) correlated with fecal DAPA (mg/g) from cool-dry 2009 through warm-dry 2011. The relationshiop between fecal DAPA and fecal Nitrogen are described within each season comparison. Seasons are represented by warm-dry (March-June), warm-wet (July-October), cool-dry (November-February).

A total of 14 fecal samples were collected from gemsbok observed foraging in the same areas as the radio-collared pronghorn throughout the warm-dry seasons of 2010 and 2011. There were no detectable differences in FN between warm-dry 2010 (1.5 ± 0.21%) and warm-dry 2011 (1.5 ± 0.05%) (P = 0.839) (Table 8); nor were differences observed in FDAPA between warm-dry 2010 (0.47 ± 0.08 mg/g) and warm-dry 2011 (0.34 ±0.03 mg/g) (P = 0.142) (Table 8).

Nutritional Differences between WSMR and Captive Pronghorn Populations- A total of 18 fecal samples were obtained from the captive population of pronghorn and analyzed for FN and FDAPA throughout warm-dry (n=10), warm-wet (n=4) and cool-dry (n=4) seasons. During the warm-dry season 2010, FN values were detectably greater in the WSMR population (2.36 ± 0.14%) compared to the captive population (2.06 ± 0.04%) (P=0.04) (Figure 4). In contrast, FN during the warm-dry season 2011 was detectably lower in the WSMR population (1.44 ± 0.07%) compared to the captive population (2.06 ± 0.04%) (P<0.0001). During the warm-wet season (2010), FN was not detectably different between WSMR (1.61 ± 0.17%) and the captive (2.03 ± 0.06%) population (P=0.191). During the cool-dry season (2010), FN was detectably different between WSMR (1.60 ± 0.08) and the captive (2.08 ± 0.06%) population (P=0.016). During the warm-dry season 2010, FDAPA was not detectably different between WSMR (0.54 ± 0.04 mg/g) and the captive (0.53 ± 0.04 mg/g) population (P=0.513) (Figure 5). During the warm-dry season of 2011, FDAPA was detectably different between WSMR (0.33 ± 0.03 mg/g) and captive

Table 8. Average concentrations of fecal Nitrogen (%) (FN) and fecal 2,6-diaminopimelic acid (mg/g) (FDAPA) for gemsbok (standard error and sample size in parenthesis) on White Sands Missile Range, south-central New Mexico. Fecal indices were analyzed warm-dry (March-June) 2010 and 2011. Shared superscripts between years for each dietary variable indicate no detectable differences.

2010	2011	2010	2011
FN (%)	FN (%)	FDAPA (mg/g)	FDAPA (mg/g)
1.5[a] (0.21, 4)	1.5[a] (0.05, 10)	0.47[b] (0.08, 4)	0.34[b] (0.03, 10)

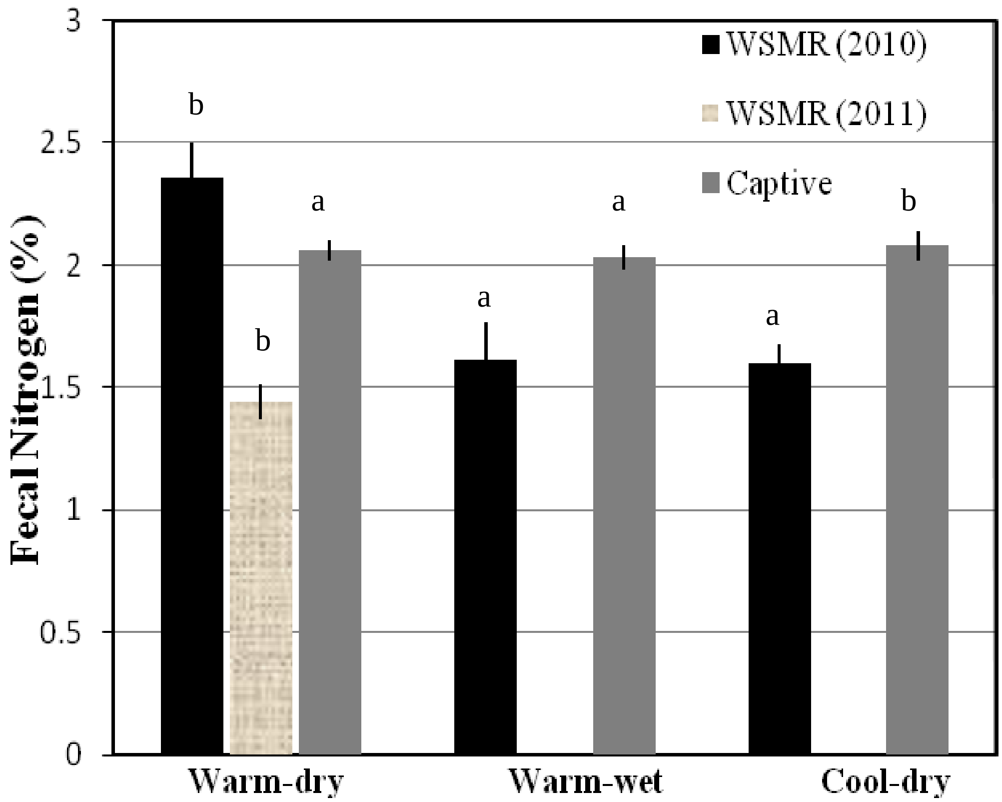

Figure 4. Average percent fecal nitrogen (%) collected from pronghorn on WSMR in 2010 and 2011 and from pronghorn from the Living Desert Zoo in Palm Desert, California (Captive). Seasons are represented by warm-dry (March-June), warm-wet (July-October), cool-dry (November-February). Standard error bars are presented. Shared superscripts within season for WSMR and Captive populations indicate no detectable differences.

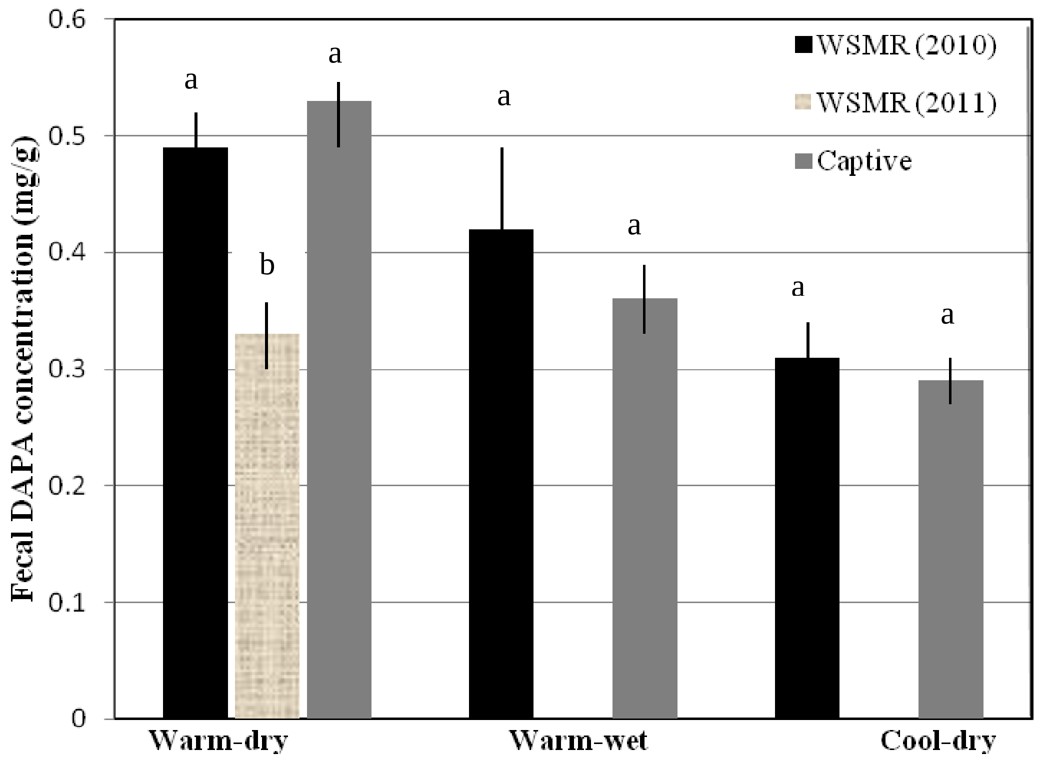

Figure 5. Average concentration of fecal 2,6-diaminopimelic acid (mg/g) (DAPA) collected from pronghorn on WSMR in 2010 and 2011 and from pronghorn from the Living Desert Zoo in Palm Desert, California (Captive). Seasons are represented by warm-dry (March-June), warm-wet (July-October), cool-dry (November-February). Standard error bars are presented. Shared superscripts within season for WSMR and Captive populations indicate no detectable differences.

populations (0.53 ± 0.04 mg/g) (P=0.003). During the warm-wet season 2010, FDAPA was not detectably different between WSMR (0.42 ± 0.07 mg/g) and the captive populations (0.35 ±0.03 mg/g) (P=0.905). During the cool-dry 2010 season, FDAPA was not detectably different between WSMR (0.31 ± 0.03 mg/g) and captive populations (0.29 ± 0.02 mg/g) (P=1.0). FDAPA decreased in the captive population throughout the three seasons likely a result of a decrease in the digestibility of the local alfalfa.

DISCUSSION

Variable cumulative precipitation occured throughout WSMR, impacting production of forage in areas selected by pronghorn. Throughout areas where pronghorn were observed foraging, above-ground biomass varied throughout the warm-wet (41-170 g/m^2), cool-dry (29-113 g/m^2), and warm-dry seasons (46-100 g/m^2). The variability in above-ground biomass within season was likely due to patchy precipitation patterns resulting in vegetation patchiness characteristic of Chihuahuan desert grasslands (Muldavin et al. 2008). These estimates were lower than those reported for grassland systems throughout the Chihuahuan desert (51-184 g/m^2) (Muldavin et al. 2008). Production estimates were greatest for grasses (62-83%), followed by forbs (7-27%) across all seasons. Despite the lower production across season and areas, forbs represented the greatest percentage (68%) and the greatest diversity in pronghorn diet which supports other research that pronghorn will select forbs when available (Beale and Smith 1970, Mitchell and Smoliak 1971, Koerth et al. 1984, Stephenson et al. 1985a, Howard et al. 1990, Hansen et al. 2001, Brown et al. 2008). While grasses represented the greatest percentage of above ground biomass throughout all three seasons (28-93%), grasses were represented the least within pronghorn diets (6-21%). Shrubs increased in the diet during an exceptionally dry season (warm-dry 2011) when prickly pear and yucca were observed in their diet.

Studies of diet composition in ungluates are valuable for wildlife managers in evaluating forage preference. Diet composition of pronghorn throughout their range was variable in this study because pronghorn were opportunistic, preferring forbs followed by shrubs but only during dry seasons. Pronghorn selected forb species disproportionately to their availability (Hansen et al. 2001, McDonald 2005). Pronghorn modified their diet seasonally with dietary overlap varying from 23-45%. During seasons of low precipitation, dietary overlap was moderate (45%) (warm-dry 2011 vs. cool-dry 2009). In contrast, pronghorn exhibited low dietary overlap (23%) between seasons of higher precipitation (warm-wet 2010 vs. cool-dry 2009). Gemsbok seasonal dietary overlap was higher (39-45%) than pronghorn throughout the study indicating a diet not affected by precipitation patterns.

When more than one large herbivore shares the same habitat, the potential for negative consequences can occur and is dependent upon behavioral ecology, the landscape, and climatic conditions. The Jarman-Bell principle states that larger herbivores can sustain themselves on poorer quality diets because of the lower metabolism /gut capacity ratio (Bell 1971, Jarman 1974). As a large herbivore, gemsbok (180-225 kg) can consume lower quality forage. Smaller bodied ungulates such as pronghorn (40-50 kg) must consume a higher quality diet and can exploit their habitat as a consequece of their mouth and gut morphology. The results of this research were similar to the study of Smith et al. (1998), who observed low dietary overlap between pronghorn and gemsbok on WSMR ranging from 0.02-0.19. The authors observed pronghorn and gemsbok shared yucca, plains bristlegrass, and dropseed. In this study, the ungluates shared yucca, prickly-pear, and globemallow. Yucca and prickly pear were highly selected for by pronghorn (15-25%) and gemsbok (12-19%). However, during the drought of 2011 (warm-dry 2011), yucca and prickly-pear increased in their diet, making up 35% of pronghorn diet and 28% of gemsbok diet. Prickly-pear was a critical component of the pronghorn diet throughout the study appearing as a key species every season. While prickly-pear and yucca were not limiting on the landscape, globemallow was limited during the drought of warm-dry (2011) compared to the previous warm-dry (2010) season. When shared key forage species are limited on the landscape, the pontential for competition arises. Despite the scarcity of key forb species, pronghorn selected other forbs as indicated by their varied diet composition of forbs.

Diet quality is an important indicator of the health of wildlife populations that can be monitored easily through fecal indices (Holechek et al. 1982b, Gates and Hudson 1981, Robinson et al. 2001). During the warm-dry seasons, diet composition of forbs was the greatest (68%) and may explain elevated FN and FDAPA values when compared to other seasons. McDonald (2005) compared dietary quality of pronghorn among similar environmental conditions throughout Arizona and observed FN values similar to those reported in this study (0.86 - 1.60%). In contrast, FDAPA values reported here (including those collected during the drought of 2011) were lower (0.21 - 0.48 mg/g) than values deemed necessary for survival and reproduction of pronghorn in the Southwest (0.82 - 1.80 mg/g) (McDonald 2005). The same authors stated that FDAPA values from 0.3 to 0.8 mg/g reflected 'fair' to 'good' forage quality similar to values obtained in this study throughout WSMR. It should be noted that the study began during 'normal' or what was considered average precipitation and ended during one of the worse droughts for the Southwest in recorded history. During stressful environmental periods, such as drought, wild populations experience conditions that impact their nutritional condition. Thus, a captive population from the California Zoo was used as a reference to compare with the WSMR population because the captive population presumably represented a nutritionally healthy population. Captive populations of herbivores are typically maintained on manufactured diets and supplemented with browse. Throughout warm-dry and warm-wet (2010) seasons, the Southwest received average precipitation which was reflected in similar fecal indices between WSMR and captive populations of pronghorn. During the drought of 2011, however, fecal indices were lower for WSMR pronghorn compared to the captive population.

This research represents the first characterization of dietary quality in gemsbok using FN and FDAPA. Dietary quality of gemsbok was not impacted by severe drought. Gemsbok have a clear advantage over pronghorn during low precipitation and thus poor production years because gemsbok utilize forage of lower nutritional quality. Pronghorn are more dependent upon precipitation than gemsbok which may be important to consider in light of climate change and the potential increase in frequency of drought. While gemsbok may have a greater potential to survive drought conditions when compared to pronghorn, further research describing dietary quality for both herbivores throughout multiple years of varied precipitation is needed to better evaluate how well these herbivores respond to shifts in forage quantity and quality across time.

MANAGEMENT IMPLICATIONS

Pronghorn population dynamics are affected by the quantity and quality of available forage consumed (Yoakum and O'Gara 2000, Hansen et al. 2001, McDonald 2005). Throughout their range on WSMR, pronghorn were selective and selected forage in an attempt to meet nutritional needs. The complexity of habitat requirements (e.g., forage quantity, quality, precipitation), however, can limit our capacity to manage pronghorn populations in arid environments. Dietary composition varies across habitats in semi-arid environments due to patchy rainfall. Thus, a better understanding of local habitat and its response to seasonal effects will aid in management decisions. While managers cannot control climate, they can modify hunting regulations, initiate predator control, reduce competition, and identify factors that contribute to population declines in arid ecosystems which is key to restoring and sustaining populations.

Monitoring the nutritional well-being of free-ranging ungulates is an essential component of all big game management plans (Smith and Shandruk 1979, Hodgman et al. 1996). Pronghorn managers can easily monitor trends in diet quality through FN and FDAPA. It is important to note that these indices may not always be directly related to the availability of forage at the time of the collections. Thus, caution is required when interpreting the influence the forage has on fecal indices. Managers of pronghorn populations throughout the Southwest have long known that forbs are key to survival of pronghorn populations. My research has demonstrated that no only production but forb diversity is important to pronghorn and that when forb production and diversity was greatest, dietary quality was measureably improved over other seasons when forb production and diversity were low.

On WSMR, pronghorn have been coexisting with a large exotic herbivore for over 40 years. Since the introduction, only two studies have evaluated the impact of gemsbok on the pronghorn population. Hoenes and Bender (2010) observed that generally pronghorn and gemsbok utilized the same habitat and Smith et al. (1998) found little dietary overlap between pronghorn and gemsbok. My results revealed low to moderate dietary overlap between the two ungulates. These differences in diet overlap were likely the result of precipitation differences which are patchy and varied across an arid landscape. However, a changing climate with a trend toward extreme seasonal variation in precipitation such as severe drought could result in an increase in overlap of key forage items and thus competition during environmentally stressful times. It should be noted that this study ended shortly after the onset of severe drought which has continued to persist at the time of the publication of this thesis. Thus, population abundance and recruitment of gemsbok should be monitored in areas where both animals exist and additional research is needed to quantify if gemsbok have had a negatively influenced on pronghorn forage selection and habitat preference.

This short term study did not address factors regarding predation and long term climatic effects. Future research should include predator impact, disease, and fawn recruitment and continue to include above-ground forage within permament or long-term monitoring stations. In addition to poor forage quantity and quality, predation can affect fawn recruitment and thus population productivity as well (O'Gara and Yoakum 2000). While predator control can be costly, Smith et al. (1986) found that selective, time-specific application of aerial gunning in areas of high coyote density was an economically beneficial means of increasing fawn survival in a desert environment.

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APPENDICES

Appendix A. Timeline of pronghorn and gemsbok fecal collections throughout forage areas on the northern range of White Sands Missile Range, south-central New Mexico. Fecal samples were collected seasonally during cool-dry (November-February), warm-dry (March-June), warm-wet (July-October). “X” indicates samples were collected when animals were observed in the areas. “-“ indicates samples were not collected due to absence of animals from the areas.

	2009		2010				2011	
	Cool-dry		Warm-dry		Warm-wet	Cool-dry	Warm-dry	
	Pronghorn	Gemsbok	Pronghorn	Gemsbok	Pronghorn	Pronghorn	Pronghorn	Gemsbok
North	X	X	X	X	X	X	X	X
D-9	X	X	X	X	X	X	X	X
Pond	X	X	X	X	X	X	X	X
Arc	-	-	X	X	X	X	X	X
Stallion	X	-	X	-	X	-	X	X

Appendix B. Seasonal average percent diet composition of pronghorn on White Sands Missile Range in south-central New Mexico. Seasons are represented by cool-dry (November-February), warm-dry (March-June), warm-wet (July-October). "T" (trace) represents less than 1% of the plant in the diet and is not included in the total percent of the diet composition. "-" represents absence from the diet within that season.

	2009		2010		2011
	Cool-dry	Warm-dry	Warm-wet	Cool-dry	Warm-dry
Grasses					
Aristida spp.	6.8	T	3.0	T	1.0
Bouteloua curtipendula	2.6	T	1	-	T
Bouteloua eriopoda	T	T	-	T	-
Bouteloua gracilis	1.7	T	1.0	T	T
Bouteloua spp.	3.1	1.3	1.0	T	1.0
Panicum obtusum	T	-	T	-	T
Setaria leucopila	1.1	T	0.1	-	T
Sporobolus cryptandrus	T	T	T	T	T
Sporobolus spp.	1.0	T	1.3	-	1.2
Unknown grasses	3.2	1.9	3.5	1.0	3.5
Total Grasses	21.1	5.6	11.5	2.0	7.6
Shrubs					
Atriplex canescens	1.3	1.8	T	5.1	1.9
Aloysia wrightii	-	1.4	T	-	-
Fallugia paradoxa	4.2	1.2	1.9	4.1	2.9
Artemisia bigelovii	4.5	2.6	5.0	3.7	5.4
Artemisia filifolia	-	-	1.5	-	T
Dalea spp.	-	T	T	T	T
Ephedra spp.	-	-	T	7.2	T
Flourensia cernua	-	T	-	0.4	T
Juniperus spp.	3.6	-	T	4.0	1.0
Krascheninnikovia lanata	T	1.0	0.5	1.6	T
Opuntia spp.	20.9	3.8	7.4	21.3	24.2
Parthenium incanum	T	-	-	-	T
Prosopis glandulosa	-	T	2.2	-	T

Appendix B Continued.

	2009		2010		2011
	Cool-dry	Warm-dry	Warm-wet	Cool-dry	Warm-dry
Quercus turbinella	3.6	T	T	6.1	T
Rhus microphylla	T	T	7.0	-	1.0
Rhus spp.	-	1.0	1.6	T	T
Rumex hymenosepalus	6.9	-	-	-	-
Rumex spp.	-	T	-	2.5	-
Yucca spp.	2.6	11.1	3.7	8.4	10.8
Unknown shrub	-	0.2	0.5	-	T
Total Shrubs	49.5	26.8	33.3	65.9	50.8
Forbs					
Allionia incarnata	1.4	T	-	-	-
Ambrosia spp.	1.7	1.7	1.0	1.6	4.0
Aphanostephus ramosissimus	1.3	5.0	3.6	1.2	T
Bahia neomexicana	-	T	T	T	T
Castilleja spp.	-	T	T	T	-
Croton spp.	1.0	9.5	8.3	1.8	1.0
Garrya spp.	-	3.8	2.0	-	-
Gutierrezia sarothrae	-	T	1.2	1.3	1.1
Helianthus petiolaris	-	2.0	5.3	1.8	T
Hoffmannseggia glauca	3.9	5.5	4.1	-	10.1
Hymenopappus flavescens	T	-	T	T	-
Lepidium spp.	T	3.3	-	-	T
Lesquerella gordonii	1.4	3.3	4.6	1.1	T
Lesquerella fendleri	-	2.9	T	T	-
Machaeranthera pinnatifida	-	1.0	-	T	1.0
Machaeranthera tanacetifolia	-	1.5	1.0	T	T
Machaeranthera spp.	-	2.7	-	-	-
Marrubium vulgare	2.6	4.6	1.7	T	T
Mentzelia spp.	-	5.4	1.4	1.5	T

Appendix B Continued.

	2009	2010			2011
	Cool-dry	Warm-dry	Warm-wet	Cool-dry	Warm-dry
Peganum harmala	-	T	-	-	1.6
Plantago patagonia	-	3.2	-	-	-
Psilostrophe tagetina	-	T	T	-	-
Solanum elaeagnifolium	8.3	2.2	3.6	14.2	9.8
Sphaeralcea spp.	6.3	3.8	9.9	4.1	6.8
Tiquilia canescens	-	1.0	-	1.0	T
Tidestromia lanuginosa	T	1.3	2.0		-
Unknown forb	-	-	3.7	1.0	1.7
Total Forbs	29.4	67.6	55.2	32.1	41.6

Appendix C. Seasonal average percent diet composition of pronghorn and gemsbok on White Sands Missile Range in south-central New Mexico. Seasons are represented by cool-dry (November-February), warm-dry (March-June), warm-wet (July-October). "T" (trace) represents less than 1% of the plant in the diet and is not included in the total percent of the diet composition. "-" represents absence from the diet within that season.

	Cool-dry (2009)		Warm-dry (2010)		Warm-dry (2011)	
	Pronghorn	Gemsbok	Pronghorn	Gemsbok	Pronghorn	Gemsbok
Aristida spp.	6.9	8.2	T	4.9	1.0	2.8
Bothriochloa barbinodis	-	T	-	2.2	T	1
Bouteloua barbata	-	T	-	T	-	T
Bouteloua curtipendula	2.7	7.2	T	4.0	T	1
Bouteloua eriopoda	T	6.8	T	3.0	-	2.6
Bouteloua gracilis	1.7	8.0	T	8.0	T	1.5
Bouteloua spp.	3.1	11.1	1.3	8.8	1.0	9.8
Muhlenbergia emersleyi	-	-	-	T	-	-
Muhlenbergia porteri	-	T	-	1.6	-	T
Muhlenbergia spp.	-	-	-	1	-	-
Panicum obtusum	1.0	T	-	-	T	T
Pleuraphis mutica		T	-	1.3	T	2.4
Schizachyrium scoparium	T	T	-	-	-	1.8
Setaria leucopila	1.1	3.8	T	T	T	1

Appendix C continued.

	Cool-dry (2009)		Warm-dry (2010)		Warm-dry (2011)	
	Pronghorn	Gemsbok	Pronghorn	Gemsbok	Pronghorn	Gemsbok
Sporobolus airoides	-	-	-	-	-	T
Sporobolus flexuosus	-	-	-	-	T	T
Sporobolus contractus	-	-	-	-	-	T
Sporobolus cryptandrus	T	4.5	T	3.6	T	4.8
Sporobolus spp.	1.0	4.9	T	7.4	1.2	7.5
Unknown grasses	3.2	4.4	1.9	6.6	3.5	8.4
Total Grasses (%)	21.1	61.2	5.6	55.5	7.6	46.7
Shrubs						
Aloysia wrightii	-	-	1.4	-	-	-
Artemisia bigelovii	4.5	-	2.6	T	5.4	T
Artemisia filifolia	-	-	-	T	T	T
Artemisia frigida	-	-	-	-	T	-
Artemisia spp.	-	-	-	-	T	-
Atriplex canescens	1.3	2.7	1.8	T	1.9	T
Cercocarpus montanus	T	T	-	T	-	T
Cercocarpus spp.	-	T	-	T	-	-
Dalea formosa	-	T	-	T	T	-
Dalea spp.	-		T	-	T	-
Ephedra spp.	-	-	-	-	T	1
Fallugia paradoxa	4.2	T	1.2	2.0	2.9	T
Flourensia cernua	-	T	T	T	T	-
Juniperus spp.	3.6	T	-	-	1.0	T

Appendix C continued.

	Cool-dry (2009)		Warm-dry (2010)		Warm-dry (2011)	
	Pronghorn	Gemsbok	Pronghorn	Gemsbok	Pronghorn	Gemsbok
Krascheninnikovia lanata	T	2.2	1.0	9.9	T	T
Larrea tridentata	-	-	-	-	T	-
Opuntia spp.	20.9	9.5	3.8	1.7	24.2	5.7
Nolina microcarpa	-	-	-	-	T	T
Parthenium incanum	T	-	-	T	T	-
Pinus spp.	-	-	-	-	T	-
Prosopis glandulosa	-	3.7	T	-	T	1
Quercus turbinella	3.6	3.7	T	1.7	T	T
Rhus microphylla	T	-	T	-	1.0	-
Rhus spp.	-	-	1.0	-	T	T
Rumex hymenosepalus	6.9					
Rumex spp.	-	-	T	-	-	-
Yucca spp.	2.6	10.6	11.1	10	10.8	22.5
Unknown shrubs	-	1.8	0.2	1.4	T	1.7
Forbs						
Acourtia nana	-	-	T	T	T	-
Allionia incarnata	1.4	-	T	-	-	-
Ambrosia spp.	1.7	-	1.7	1.6	4.0	T
Aphanostephus ramosissimus	1.3	-	5.0	-	T	-
Astragalus spp.	-	-	T	-	-	-
Bahia neomexicana	-	-	1	-	T	-
Castilleja spp.	-	-	T	-	-	-
Croton spp.	1.0	-	9.5	1	1	1.1

Appendix C continued.

	Cool-dry (2009)		Warm-dry (2010)		Warm-dry (2011)	
	Pronghorn	Gemsbok	Pronghorn	Gemsbok	Pronghorn	Gemsbok
Cryptantha angustifolia	-	-	-	1.7	T	-
Erysimum capitatum	-	-	-	-	T	-
Erysimum spp.	-	-	-	-	T	-
Garrya spp.	-	-	3.8	-	-	-
Gutierrezia sarothrae	-	-	-	-	1.1	-
Gutierrezia spp.	-	-	-	-	T	-
Helianthus petiolaris	-	-	2.0	-	T	-
Hoffmannseggia glauca	3.9	-	5.5	1.2	10.1	1.2
Hymenopappus flavescens	T	-	-	-	-	-
Lepidium spp.	T	-	3.3	2.2	T	T
Lesquerella gordonii	1.4	-	3.3	4.5	T	-
Lesquerella fendleri	-	-	2.9	-	-	-
Machaeranthera pinnatifida	-	-	1.0	-	1.0	-
Machaeranthera tanacetifolia	-	-	1.5	T	T	-
Machaeranthera spp.			2.7			
Marrubium vulgare	2.6	-	4.6	-	T	-
Mentzelia spp.	-	-	5.4	-	T	-
Peganum harmala	-	-	T	-	1.6	-
Plantago patagonia	-	-	2.2	-	T	-
Portulaca oleracea	-	-	T	-	-	-
Psilostrophe tagetina	-	-	T	-	-	T

Appendix C continued.

	Cool-dry (2009)		Warm-dry (2010)		Warm-dry (2011)	
	Pronghorn	Gemsbok	Pronghorn	Gemsbok	Pronghorn	Gemsbok
Salsola tragus	-	-	T	-	-	-
Scutellaria resinosa	-	-	1	-	-	-
Senecio douglasii	-	-	-	-	T	-
Solanum elaeagnifolium	8.3	T	2.2	-	9.8	4.3
Solanum rostratum	-	2.5	-	T	T	1
Sphaeralcea spp.	6.3	-	3.8	1.9	6.8	9.4
Tiquilia canescens	-	-	1.0	-	T	-
Tiquilia condenia	-	-	1.0	T	T	-
Tidestromia lanuginosa	T	T	1.3	-	-	-
Viguiera spp.	T	-	T	-	-	-
Zinnia grandiflora	T	-	-	T	-	-
Unknown forbs	-	T	-	T	1.7	T
Total Forbs (%)	29.4	3.4	67.6	15.64	41.6	18.17

Appendix D. Mean percent composition of forage availability on the northern range of White Sands Missile Range in New Mexico throughout 2010. Seasons are represented by warm-dry (March-June), warm-wet (July-October), cool-dry (November-February). (Species with *italics* under vegetative composition are known to be comsumed by pronghorn).

Scientific Name	Common Name	Vegetative Composition (%)		
Grasses		Warm-dry	Warm-wet	Cool-dry
Achnatherum perplexum	New Mexico needle grass	0.06	-	-
Aristida spp.	three-awns	*1.13*	*0.35*	*1.69*
Aristida adscensionis	six-week grama	-	*1.96*	*2.86*
Aristida purpurea	purple three-awn	*2.01*	*2.80*	-
Bouteloua spp.	grama grass	*0.02*	*0.17*	-
Bouteloua aristidoides	needle grama	-	*0.53*	-
Bouteloua barbata	six-weeks grama	-	*1.31*	*3.04*
Bouteloua curtipendula	sideouts grama	*0.07*	*0.09*	-
Bouteloua eriopoda	black grama	*28.64*	*23.75*	*27.86*
Bouteloua gracilis	blue Grama	*0.93*	*5.23*	*6.81*
Bouteloua hirsuta	hairy grama	-	-	*0.10*
Buchloe dactyloides	buffalo grass	-	*0.01*	-
Bromus anomalus	nodding brome	0.02	-	-
Dasyochloa pulchella	fluff grass	2.99	4.08	1.14
Digitaria californica	Arizona cottontop	-	-	0.06
Enneapogon desvauxii	nine-awn pappusgrass	-	0.96	0.42
Hordeum murinum	wall barley	*0.02*	-	-
Muhlenbergia spp.	deer grass	-	0.02	-
Muhlenbergia porteri	bush muhly	-	*1.86*	*0.75*
Muhlenbergia torreyi	ring muhly	*0.36*	-	-
Panicum hallii	Hall's panicgrass	0.14	0.39	0.05
Panicum obtusum	vine mesquite	*0.09*	*0.06*	-
Pleuraphis jamesii	James Gelleta	*3.10*	*1.73*	-
Pleuraphis spp.	galleta	*6.53*	*1.10*	*5.89*
Scleropogon brevifolius	burro grass	*1.55*	*3.44*	*0.03*
Setaria leucopila	Plains bristlegrass	*0.01*	*0.02*	*0.32*
Sporobolus airoides	alkali sacaton	*1.44*	*8.71*	
Sporobolus contractus	spike dropseed	-	*0.62*	*0.14*
Sporobolus flexuosus	mesa dropseed	*1.74*	*3.65*	*2.68*
Sporobolus nealleyi	Neally dropseed	-	*0.19*	
Sporobolus spp.	dropseed	*7.85*	*5.32*	*10.15*
Tragus berteronianus	spike burgrass	-	-	0.09
Tridens muticus	slim tridens	0.04	-	-
Vulpia octoflora tenella	six- week fescue	0.0002	-	-
Total Grasses (%)		62.56	71.73	83.32

Appendix D continued.

Scientific Name	Common Name	Vegetative Composition (%)		
		Warm-dry	Warm-wet	Cool-dry
Shrubs				
Artemisia filifolia	sandsage	-	*2.55*	*1.810*
Artemisia bigelovii	bigelow sage	*0.25*	-	-
Cylindropuntia imbricata	Tree cholla	*0.02*	-	*1.0*
Dalea formosa	featherplume	*0.49*	-	-
Ephedra viridis	Mormon tea	*2.52*	*4.64*	*3.75*
Fallugia paradoxa	Apache plume	*0.91*		-
Gutierrezia spp.	snakeweed spp.	*3.46*	*5.21*	*5.31*
Krascheninnikovia lanata	winterfat	*0.27*	*0.15*	*0.09*
Larrea tridentata	creosote bush	3.12	-	2.31
Lorandersonia baileyi	baileys rabbitbrush	*0.35*	-	*0.07*
Nolina microcarpa	Bear grass	*0.004*	-	-
Opuntia spp.	Prickly pear spp.	*1.0*	*0.40*	*0.02*
Opuntia phaeacantha	Tulip prickly pear	*3.02*	*1.27*	*4.41*
Opuntia polyacantha	Plains prickly pear	-	-	*3.32*
Opuntia santa rita	Santa rita prickly pear	-	-	*0.62*
Parthenium incanum	mariola	0.02	-	0.05
Yucca elata	Soaptree yucca	-	*2.62*	*4.70*
Total Shrubs (%)		11.80	13.25	9.98
Forbs				
Acalphya neomexicana	New Mexico copperleaf	0.001	-	0.03
Acleisanthes chenopodioides	moonpod	0.0008	0.02	
Acourtia nana	dwarf desert holly	0.11	-	0.01
Allionia incarnata	trailing windmills		0.21	
Allium macropetalum	Large flower wild onion	*0.0007*	-	*0.01*
Amaranthus spp.	pigweed	-	*0.05*	
Amaranthus palmeri	Palmer's amaranth	-	-	*0.54*
Anemone tuberosa	desert anemone	0.002		
Aphanostephus ramosissimus	plains doze daisy	3.57	0.02	0.04
Asclepias brachystephana	bract milkweed	-	*0.17*	-
Astragalus spp.	milkvetch	*0.03*	*0.05*	-
Astragalus allochrous	Wooton milkvetch	*0.01*	-	-
Astragalus nuttallianus	Nutall's milkvetch	*0.95*	-	-
Astragalus missouriensis	Missouri loco	*0.47*	-	-
Bahia spp.	Bahia	*0.02*	-	*0.08*
Bahia absinthifolia	hairyseed bahia	*0.05*	-	-
Bahia pedata	bluntscale bahia	-	-	*0.62*
Baileya multiradiata	Desert marigold	*0.007*	*0.08*	*0.04*
Bidens spp.	Beggars tick	-	0.72	-
Boerhavia torreyana	creeping spiderling	-	0.06	-

Appendix D continued.

Scientific Name	Common Name	Vegetative Composition (%)		
		Warm-dry	Warm-wet	Cool-dry
Chaetopappa ericoides	baby aster	0.14	0.28	0.01
Chamaesarcha coniodes	grey 5-eyes	0.04	0.21	-
Chamaesarcha sordida	hairy 5-eyes	-	*0.01*	-
Chamaesyce spp.	sandmat	-	0.17	0.50
Chamaesyce fendleri	Fender's spurge	*0.098*	*0.03*	*0.01*
Chamaesyce lata	hoary sandmat	*0.004*	*0.06*	-
Chamaesyce maculata	sandmat	0.0007	-	-
Chamaesyce micromera	desert spurge	*0.003*	*0.04*	-
Chamaesyce serpens	matted sandmat	-	*0.80*	-
Chenopodium fremontii	Freemont's goosefoot	*1.06*	*0.30*	*0.12*
Cirsium neomexicanum	New Mexico Thistle	-	*0.01*	
Cryptantha angustifolia	Desert hidden flower	*2.06*	*0.28*	*0.79*
Cryptantha spp.	popcorn flower	*0.002*	-	-
Cymopterus bulbosus	bulbous springparsley	0.002	-	-
Dalea jamesii	James Dalea	-	*0.03*	-
Descurainia pinnata	Western tansy mustard	*0.37*	-	-
Eriastrum diffusum	miniature woolystar	0.009	-	-
Eriogonum spp.	Buckwheat	*0.00003*	-	*0.81*
Eriogonum abertianum	Abert's wild buckwheat	*0.001*	*0.03*	-
Eriogonum rotundifolium	Roundleaf buckwheat	*0.0009*	-	-
Eriogonum wrightii	wrights wild buckwheat	-	-	*0.32*
Eschscholtzia californica	California poppy	0.13	-	0.01
Euphorbia hexagona	Six-angle spurge	-	*0.31*	-
Evolvulus sericeus	Silvery Desert morning glory	0.90	0.10	0.03
Gaura coccinea	scarlet beeblossom	0.19	0.19	0.12
Gilia flavocinta	yellow-throat gilia	0.65	-	-
Giliastrum acerosum	still leaf gilia	0.08	-	-
Glandularia bipinnatifida	Verbena	0.02	-	-
Helianthus annuus	annual sunflower	*0.03*	*0.17*	*0.04*
Hoffmannseggia glauca	hog potato	0.001	0.68	-
Houstonia humifusa	matted bluets	0.001	-	0.62
Hymenopappus flavescens	yellow wooly white	*0.42*	-	*0.06*
Kallstroemia californica	California calltrop	-	0.33	0.26
Lepidium spp.	pepperweed	-	*0.007*	*0.22*
Lepidium alyssoides	mesa pepperwort	*0.13*	*0.13*	-
Lepidium lasiocarpum	hairy-pod peppercress	*2.51*	-	-
Lepidium latifolium	broadleaf pepperweed	*1.20*	-	-
Linanthus bigelovii	Bigelow's desert trumpets	-	0.06	-
Linum aristatus	bristle flax	0.02	0.03	-

Appendix D continued.

Scientific Name	Common Name	Vegetative Composition (%)		
		Warm-dry	Warm-wet	Cool-dry
Lithospermum multiflorum	pretty stone seed	-	0.13	0.03
Machaeranthera pinnatifida	lacy tansyaster	*0.21*	*2.20*	*0.07*
Machaeranthera tanacetifolia	tansyleaf tansyaster	*2.60*	-	*0.06*
Malacothrix fendleri	Fendler's Desert Dandelion	*0.03*	-	-
Melampodium leucanthum	Blackfoot daisy	*0.01*	-	-
Mentzelia albicaulis	whitestem blazingstar	1.24	0.008	-
Mirabilis linearis	narrow 4-oclock	0.04	-	-
Nama hispidium	bristly Nama	*0.35*	-	-
Oenothera spp.	primrose	*0.16*	-	-
Pectis angustifolia	lemonweed	-	0.10	-
Phacelia spp.	scorpionweed	*0.10*	-	-
Penstemon fendleri	Fendler's penstemon	-	*0.03*	-
Physaria fendleri	Fendler's bladder pod	*0.69*	-	*0.23*
Plantago patagonica	wooly plantain	*2.23*	*0.27*	*0.09*
Portulaca pilosa	rose purslane	-	*0.32*	*0.14*
Portulaca suffrutescens	shrubby purslane	-	-	0.23
Portulaca oleracea	common purslane	-	1.24	-
Psilostrophe tagetina	paper flower	0.008	-	-
Rafinesquia neomexicana	Desert chichory	0.002	0.03	0.008
Rumex hymenosepalus	wild-rhubard	0.002	-	-
Salsola tragus	Prickly Russian thistle	0.11	1.35	1.24
Senecio longilobus	threadleaf groundsel	0.16	-	0.02
Senna bauhinioides	two-leaf desert senna	0.08	0.002	0.005
Solanum elaeagnifolium	Silverleaf nightshade	0.18	1.0	0.10
Sphaeralcea spp.	globemallow	0.23	0.51	0.28
Sphaeralcea leptophylla	scaly globemallow	-	0.04	0.03
Stephanomeria pauciflora	wire lettuce	0.09	0.02	-
Talinum aurantiacum	yellow-flame flower	0.02	0.03	-
Tetraclea coulteri	stinkweed	-	0.04	
Thymophylla acerosa	American prickly leaf	1.0	0.31	0.47
Tidestromia lanuginosa	Honeymat	-	*0.93*	*0.06*
Tiquilia hispidissima	hairy crinklemat	0.82	0.17	-
Xanthisma spinulosum	spiny golden weed	-	-	*0.55*
Zinnia spp.	zinnia	-	-	0.27
Zinnia grandiflora	Plains zinnia	*0.05*	*0.13*	-
Unknown forb		0.005	0.02	-
Total Forbs (%)		25.64	15.02	6.70