EVALUATION OF WHITE-TAILED DEER RESPONSE TO PRECIPITATION AND VEGETATION IN MCMULLEN COUNTY, TEXAS

THESIS

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EVALUATION OF WHITE-TAILED DEER RESPONSE

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ABSTRACT

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The purpose of this study was to examine vegetation and white-tailed deer (*Odocoileus virginianus*) responses to precipitation in McMullen County, South Texas. Understanding how deer respond to drought is especially important in a drought-prone region. Vegetation was assessed using the Normalized Difference Vegetation Index (NDVI) from level 1 Landsat 5 imagery, and deer records were donated from seven anonymous ranches on Managed Lands Deer Permit (MLDP) programs within the county. The variables analyzed from the deer records were fawn-to-doe ratios (fawn crop/recruitment), body weights, and antler measurements. Results indicate that fawn crop was strongly related to spring NDVI ($r = 0.9$; $p \leq 0.05$) and summer ($r = 0.9$; $p \leq 0.05$), spring-summer ($r = 0.9$; $p \leq 0.05$), March-July ($r = 0.9$; $p \leq 0.05$), and July-August ($r = 0.9$; $p \leq 0.05$) rainfall. This positive relationship may be attributed to enhanced nutrition and fawning cover. Mature male body weights were related to summer ($r = 0.9$;

$p \leq 0.05$), spring-summer (r = 0.9; $p \leq 0.05$), March-July (r = 0.9; $p \leq 0.05$), and July-August (r = 0.9; $p \leq 0.05$) rainfall. Additionally, mature males demonstrated a connection between Boone and Crockett score and summer (r = 1.0; $p \leq 0.01$) and July-August (r = 1.0; $p \leq 0.01$) rainfall. Spring NDVI was related to spring rainfall (r = 0.9; $p \leq 0.05$), though summer NDVI did not indicate a relationship with summer rainfall. Spring NDVI was also strongly correlated to mature male body weights (r = 0.9; $p \leq 0.05$) and main beam length (r = 1.0; $p \leq 0.01$). Because of incomplete harvest records, analysis of physiological characteristics such as body weights and antler measurements was limited to the combined ranch averages. Also because of a low number of time-series, five years, a nonparametric statistical analysis using the Spearman r was the analysis performed for every relationship. The Spearman calculated strength of relationship by using ranks of values. Understanding how deer respond to periods of drought or periods of high rainfall in this part of Texas may provide landowners and land managers a more accurate assessment of what their herds will look like months in advance.

1.0 INTRODUCTION

1.1 Background

The white-tailed deer (*Odocoileus virginianus,* WTD) is the most studied and widespread ungulate in North America. Understanding how deer populations respond to environmental factors such as drought has important consequences for conservation and management. This animal's importance as a keystone species is noted by Waller and Alverson (1997) where they describe the role of white-tailed deer and their impacts on community structure and species composition within an ecosystem. The state of Texas is home to more white-tailed deer than any other state. Management and management related research are both needed in order to preserve and enrich this precious natural resource for future generations.

A primary reason why white-tailed deer research is important is the economic impact deer have on the state of Texas. This impact is summarized in the results of 2006 survey data in which 813,000 deer hunters in Texas spent about $1.2 billion on retail purchases and were responsible for creating more than 25,000 jobs Higginbothom (2009). Texas deer hunting contributes more than $142 million in state and local sales tax revenue each year (Higginbothom 2009). Moreover, ranch managers often use academic research to guide management efforts and conservation plans. Implementing these management recommendations typically involves investing a good amount of money that contributes to the economic impact white-tailed deer directly and indirectly have on the state of Texas.

1.2 Problem Statement

Collecting and analyzing data on white-tailed deer populations can be very time-consuming and labor intensive. The management of these populations would be aided with a technique that provides insight into the current and future condition of a population through the use of a proxy in the form of timely precipitation or satellite imagery. Because it is not feasible to take measurements from every member of a deer population, landowners and wildlife managers can both benefit from a time-saving and economical technique that offers an accurate representation of the site-specific population.

1.3 Research Objectives

1.3.1 Is there a relationship between precipitation and white-tailed deer recruitment/fawn crop survival (fawn: doe ratio) in McMullen County, TX?

1.3.2 Is there a relationship between precipitation and white-tailed deer physiological characteristics, which include body weight and antler measurements in McMullen County, TX?

1.3.3 Is there a relationship between NDVI and precipitation, NDVI and deer variables, or NDVI and vegetation response?

1.4 Justification

The prediction of antler and body characteristics from environmental factors can aid in preparing a wildlife manager for future decisions. For instance, decisions may include when to start or stop supplemental feeding based on body condition or another one could be making specific harvest guidelines for what type of deer is going to be classified as a trophy or management buck. This type of research has great implications for managing and planning wildlife populations around environmental factors.

This research is a place-based study focused on temporal variations in precipitation and the effects on white-tailed deer population characteristics (characterized by body weight and antler measurements) in McMullen County, south Texas. An additional component to this research involves the use of remotely sensed data to characterize vegetation response to variation in rainfall through the examination of changes in NDVI over time (Kerr and Ostrovsky 2003). A strong statistical relationship between the datasets suggests that accurate white-tailed deer population dynamics may be predicted given simple analysis of widely available meteorological and satellite data. It is important to remember that the results of this study are only applicable to this region of Texas and to the appropriate ranch scale of about four hundred to eight thousand hectares.

2.0 LITERATURE REVIEW

2.1 WTD Characteristics: Morphology and Life Cycles

White-tailed deer (*Odocoileus virginianus*) are members of the *Cervidae* family, which include black-tailed deer (*Odocolieus hemionus columbianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), moose (*Alces alces*), and caribou (*Rangifer tarandus*). These family members share specific characteristics such as hoofed feet with four toes (ungulates), four-chambered stomachs (ruminants), and they grow and shed antlers annually (Higginbothom 2009).

The life cycle of white-tailed deer is particularly relevant to this study: 1) White-tailed deer in south Texas breed or rut in December and birth (fawn) in July, and 2) the average buck grows a complete hardened set of antlers in six to seven months from the time they shed their previous antlers in March or April to September. These cycles are important with regard to management implications and the analysis undertaken in this study.

Body weights, fawn-to-doe ratios, and antler measurements were used as health indicators in this study. The percentage between does and fawns in any given year is referred to as the fawn crop. It is also known as recruitment since we are examining the level of new additions to the population without any regards to immigration or emigration. The fawn crop is used as an indicator of health, because when nutrition is high, does are more likely to produce and care for strong singles, twins, or even triplets. Increased health would therefore raise the doe to fawn ratio in favor of fawns.

There are three factors that go into producing a buck's set of antlers: age, nutrition, and genetics. Antlers are secondary appendages that have grown from the excess nutrition not needed in primary bodily functions; therefore, a buck will not grow his largest set of antlers until he is mature and fully grown. At this time, since the growth of his body is no longer demanding the amount of resources it once did, he is now able to express his full genetic potential through his antlers. Therefore, antler measurements can be used as indicators of health; however, we must consider in our analysis the impacts of age and genetic diversity between ranches.

2.2 Meteorological Associations with Ungulate Morphological Characteristics

This academic subfield has taken on diverse routes in recent years with ungulate studies from Africa (Owen-Smith 1990) to Spain (Torres-Porras et al. 2009). Ginnett et al. (2000) recently split Texas into 8 precipitation zones and examined the spatial variation in whitetail recruitment along these environmental gradients. Gilbert and Raedke (2004) examined seasonal temperatures along with precipitation in relation to Columbian black-tailed deer recruitment while Strickland and Demarais (2010) found a strong landscape composition influence on deer reproduction when rainfall was present. Not all relationships with precipitation are positive (Lay 1969, Shea et al. 1992), and understanding what makes these relationships either positive or negative will provide a context for understanding the results of this study.

2.2.1 Effects of Precipitation on WTD

2.2.1.1 Precipitation and Antler Quality

Precipitation can be correlated with deer physiological characteristics, such as body weight and antler quality, on the basis of nutrition. As rainfall increases, so does the production of annual vegetation (Smith and Lecount 1979, Bozzo et al. 1992). Increasing forage quantity may have more effect in resource-limiting environments. Whereas body mass may be a direct indicator for nutrition, antler quality is equally viable as it is a measure of immediate nutritional excess during the growing period.

The first white-tailed deer study focusing on antler characteristic relationships appears to focus on the relationship between antler beam diameters and range condition (Severinghaus et al. 1950). This study presented evidence that variations in antler development are related to forage adequacy. Other than this article from 1950, the literature revealed very little data on rainfall and white-tailed antlers except for the unpublished data of Stuart Stedman from his 40,000 acre Faith ranch. Stedman inspected past records from a buck capture program on the Faith ranch and noticed a constant shift in the year-to-year antler averages. He suspected this fluctuation was nutritionally related; more specifically, he assumed rainfall might be a substantial factor. Upon closer inspection, no relationships were found between April-August rainfall and antler development; however, when broken down by months, Stedman found positive correlations with March and April rains. Stedman also found evidence proving that rainfall and nutrition during a deer's birth year had an effect on future development (Schreiger 2010).

2.2.1.2 Precipitation and Fawn Recruitment

Annual herbaceous production in similar semi-arid environments has been positively correlated with rainfall (Smith and Lecount 1979, Bozzo et al. 1992). Forb biomass is also directly correlated with deer population performance (Strickland 1998). Higher nutritional levels would arguably lead to better fetal development and higher quality lactation, resulting in higher survival.

After dividing Texas into eight precipitation zones or gradients, Ginnett et al. (2000) found that positive correlation between March-July precipitation and white-tailed deer recruitment was strongest in the more arid western and southern portions of the state. Correlations then grew weaker with wetter environments as the gradients went east until they finally switched to negative correlations in the wettest portions of east Texas. Forage quantity ended up being the main factor of influence for the positive relationships in the arid western regions whereas forage quality was found to be the main factor for the negative relationships because of the dilution of nutrients with excess rainfall. Positive precipitation impacts are therefore strongest on deer populations in the arid regions of Texas where quantity of forage may be a limiting factor. Hence, increases in productivity because of timely rainfall would reduce effects of resource limitation, and result in better nutrition and enhanced hiding cover.

One study occurring on the Welder Wildlife Refuge in eastern south Texas (Kie and White 1985) examined relationships between white-tailed deer recruitment, deer density, and rainfall. At lower densities, recruitment was not affected in the same way as it was during times of higher densities. Recruitment was also positively correlated with rainfall during the gestation period and early post birth survival was primarily determined by coyote predation (Kie and White 1985). Teer (1984) also found positive relationships between rainfall and recruitment in the Llano Basin of the Texas Hill Country. Although the sites are separated geographically, they both fall under similar low annual precipitation gradients for the purpose of grouping them together and comparing with the results of Ginnett et al. (2000).

Though evidence of positive relationships between precipitation and recruitment are noted above, this is not always the case. Several studies have reported contradictory findings, where precipitation exhibits a negative relationship with recruitment. It appears that there are a few possible reasons as to why precipitation might have negative effects on recruitment. One is the type of precipitation. Unlike rain, snowfall is commonly associated with negative effects on wildlife as it usually stunts or impedes access to forage (Mech et al. 1987, Smith and Anderson 1998). Excess precipitation can also reduce forage quality (Russell 1962, Bell 1982, Meyer et al. 1984) that may be of greater influence than forage quantity when not in forage limiting environments; therefore, the type of forage is more important than the amount in this case. Reduced forage quality would result in a lowered nutritional environment that could affect milk production and growth rates.

In a study carried out in South Texas, Meyer et al. (1984) suggested that in addition to coyote predation, poor summer nutrition could be a strong factor in low fawn survival. Two examples from east Texas (Lay 1969, Ginnett et al. 2000) suggest recruitment is greatly influenced by forage quality over quantity in areas with high rainfall. Both relationships were negative with excessive rainfall resulting in the dilution of forage nutrients.

Similar results on the importance of forage quality have been reported on Florida deer in pine flatwood habitats. Shea et al. (1992) used linear regression analyses to test the relationship of annual density estimates with the mean physiological indices of whole mass, antler beam length, and number of points for yearling bucks. The density of the herd was decreased by 75% from the years 1980 to 1989. An increase in the mean physiological indices was expected to coincide with decreased density; however, body and antler measurements did not increase and no significant relationships were found, as the nutritional plane appears to not have increased as expected. It was concluded that poor forage quality in the pine flatwoods was most responsible for the results or lack thereof. Pine flatwood habitats have very little high quality forbs and browse to begin with, and if deer are edging to stay alive by consuming the bare minimum nutritional requirements, it makes sense that antler measurements would not show consistent results because antlers are secondary appendages resulting from excess nutrition. Because the physiological indices of this study were insensitive to changes in density, Shea et al. (1992) warn their use in population management on poor quality habitats may be limited.

2.2.2 Effects of Precipitation and Temperature on Non-WTD

Positive correlations between recruitment and precipitation have previously been reported for North American as well as African ungulates like the bontebok (*Damaliscus dorcas dorcas*, Novellie 1986) and the greater kudu (*Tragelaphus strepsiceros*, Owen-Smith 1990). Greater kudu is a browser like white-tailed deer and its resource-limiting environment may be similar to that of semi-arid south Texas. Owen-Smith (1990) attributes the positive correlation to increased forage quantity, which reduced the effects of resource limitation.

In North America, strong relationships between spring lamb production and previous fall-winter precipitation were found for desert populations of bighorn sheep (*Ovis canadensis nelsoni* and *O. c. cremnobates*, Berger 1982, Douglas and Leslie, 1986) and mountain sheep (*O. c. canadensis*, Wehausen et al. 1987) in California. Picton (1978) describes a positive correlation for grizzly bear reproduction and climate in Yellowstone National Park followed by a study in which he used a climate index that included both temperature and precipitation to examine correlations between climate and recruitment for mule deer (*Odocoileus hemionus*, Picton 1979). Furthermore, a joint study on three ungulates: mule deer, bighorn sheep, and wapiti (*Cervus elaphus*) conducted by Picton (1984) used the Lamb climate index to compare temperature and precipitation data to long-term population recruitment data. Precipitation was found to be of great importance to the survival of bighorn sheep. For wapiti, climate-young/female correlations were only observed during years at which the population was at capacity (Picton 1984). Specifically, the wapiti were not influenced by April and May weather like the mule deer were. Mule deer, which are very similar to white-tailed deer, revealed a positive correlation ($r = +0.649$, $P < 0.01$) between the climate index and fawn per doe ratios. Smith and LeCount (1979) also found Arizona mule deer fawns to be positively correlated with precipitation because of increases in April forb and small shrub production resulting from rain during the previous October-April period.

Negative correlations between recruitment and precipitation have previously been reported for North American as well as African ungulates such as wildebeest (*Connochaetes taurinus*, Walker et al. 1987) and zebra (*Equus burchelli*, Whyte and Joubert 1988). In a study conducted on wildebeest, zebra, and white rhinoceros

(*Ceratotherium simum*, Owen-Smith 1990), precipitation had a negative response as a result of dilution of forage nutrients that lowered the quality of vegetation. A negative relationship for snow accumulation resulting in nutritional stress has been reported for elk (Smith and Anderson 1998).

Smith (1998) found that antler size in Wyoming elk was correlated with March and April temperatures during the year they grew. Early warm temperatures would result in an early growing season and a positive nutritional affect. Torres-Porras et al. (2009) found that drought strongly affected both body and antler size negatively among red deer on the Iberian Peninsula. Azorit et al. (2002) also had a drought-related result for their study in that they sampled the lowest quality animals in a drought year and the highest quality animals in the wettest year.

2.3 Influence of Predation on WTD Fawn Recruitment

Although nutrition might be the leading factor in recruitment in a nutrient limiting environment, there is evidence that enhanced fawning cover contributes greatly to the fawn crop number. Recently born fawns need cover to hide from predators. Studies throughout the range of white-tailed deer indicate the majority of fawn mortalities are because of predation (Knowlton 1964, Cook et al. 1971, Carroll and Brown 1977, Bartush and Lewis 1981, Brown 1984, Meyer et al. 1984, Epstein et al. 1985, Huegel et al. 1985, Nelson and Woolf 1987). Cook et al. (1971) found that within the first ninety days after birth, over 70% of fawns died, with coyotes (*Canis Latrans*) and bobcats (*Lynx rufus*) contributing to 82% of the deaths. Coyotes may be the main predator as Blankenship (2000) and Ballard et al. (2001) say bobcats are not an important factor in fawn predation. Nutrition and enhanced cover most likely work together, making determining their individual contributions difficult.

2.4 Influence of Population Density on WTD Morphological Characteristics and Fawn Recruitment

Deer density is another factor to consider as every individual in the population is competing for resources. A highly concentrated population over the carrying capacity might over-use resources such as high-quality forbs and browse while at the same time encouraging lower quality vegetation.

Other white-tailed deer studies have focused on the impact of density on physiological characteristics such as body mass and antler development. In the article, How to Manage for Deer Food (Nelle 2009), Nelle presents a case study performed by the Texas Parks and Wildlife Department that focused on explaining the noticeable decline in deer quality seen around the state in the 1960's. TPWD initiated an intensive deer population and deer quality record-keeping system from 1970 to 1984 in Webb County, south Texas. Yearling body weights and two-year old basal circumferences of antlers measured deer quality. When the deer data were compared with countywide cattle and rainfall data over the same time period, results indicated when rainfall is high, quality is better, and when rainfall is low, quality is low. With the exception of a few years, as deer numbers (density) increased, quality decreased. This was also the case for cattle numbers. It is important to note that cattle numbers seemed to have the most direct effect on deer quality.

Kie et al. (1983) found that Texas deer kept in an enclosure with artificially high density exhibited lower body weights and number of antler points than deer outside the enclosure. Teer (1984) found a strong relationship between previous year's rainfall and deer densities, particularly in the context of severe drought years. Shea et al. (1992) used linear regression analyses to examine relationships between annual density estimates and mean physiological indices in the form of whole mass, antler beam length, and number of points for yearling bucks. No significant correlations were found as a result of poor forage quality in the pine flatwoods habitat.

2.5 Normalized Difference Vegetation Index (NDVI) to Assess Forage Density and Quality

2.5.1 General Description of NDVI

Deer and animals in general are affected by seasonal variations in climate in many ways. One of these ways is through climate's indirect influence on vegetation. Until recently, it has been hard to objectively quantify vegetative response. In the past, researchers like Smith and Lecount (1979) measured vegetative response by visually assessing the forage weights from the same hoop plot samples. Now we can use satellite imagery and simple mathematical calculations to determine vegetation vigor. One commonly used spectral vegetation index is the Normalized Difference Vegetation Index (NDVI; Birth & McVey, 1968) to measure vegetation greenness. The NDVI is essentially measuring greenness as it is derived from the red:near-infrared reflectance ratio [NDVI=(NIR-RED)/(NIR+RED), where NIR and RED are the amounts of near-infrared and red light, respectively, reflected by the vegetation and recorded by the sensor (Pettorelli et al. 2005).

In their review of ecological applications for remote sensing, Kerr and Ostrovsky (2003) state that when coupled with meteorological and soil data, NDVI serves as a good indicator of net primary production (NPP). Despite NDVI's benefits, it is subject to errors and false information in the form of the satellite scanning equipment not being able to penetrate through canopies, especially thick ones. This was one of the reasons for a difference of results from a study on the same species but in two different environments, one open and one closed canopy forest (Pettorelli et al. 2006). It was determined that the forested study site served as a problematic environment for NDVI because there was too much biomass and NDVI is not sensitive at high levels of biomass.

2.5.2 Previous Research using NDVI as a measure of forage quality/quantity

Because of NDVI's strong association with primary production, it has also been used to explore climate impacts on food availability for primary consumers (Pettorelli et al., 2005, Pettorelli et al., 2006, Martinez-jauregui, 2009). A study comparing NDVI, Real Bioclimatic Index (RBI), and North Atlantic Oscillation (NAO) as climatic determinants for red deer weight across three European countries, found substantial differences in the pattern of weight change over time in adult female red deer between study areas (Martinez-Jauregui et al., 2009). The RBI Index estimates vegetation productivity based on local climatic and geographic processes, and Martinez-Jauregui et al. (2009) used it because it provides an estimate of local growing conditions summarized over many local weather data. Different environmental drivers were also found to have different effects on variations of weight in the three countries: Spain, Scotland (UK), and Norway.

For instance, many of these differences were between the Spanish study site, Quintos de Mora, which has a Mediterranean climate and the other three northern latitude sites (there were two sites in Norway). The populations in Norway were also migratory so it made distinguishing climatic impacts somewhat difficult; nonetheless, weighs increased with increasing spring RBI (*p* = 0.003) and with decreasing summer RBI (*p* = 0.039) in one population whereas a significant negative effect for spring RBI (*p* = 0.015) was found for the other Norwegian population. The weights of the population on Rum Island, Spain, increased with increasing winter NAO (*p* < 0.001) and decreased with increasing spring RBI (*p* = 0.012). Weight at Quintos de Mora, Spain, was negatively associated with spring RBI (*p* < 0.001), and positively associated with autumn RBI (*p* <0.001) and spring NDVI (*p* < 0.001) (Martinez-Jauregui et al. 2009). Because of increased herbaceous vegetation growth in the spring, the NDVI curve for Quitos de Mora showed a maximum during this time period with NDVI values being similar throughout the remainder of the year because of evergreen trees and shrub species.

Pettorelli et al. (2006) examined the objective use of NDVI, as a proxy for plant productivity, to find key time periods in the growing season that had the most influence on the following winter body mass of roe deer (Capreolus capreolus) in France. Two populations were sampled from two different habitats. One population was from an oceanic climate on the Chize reserve in southwestern France and the other was from Trois Fontaines, a rich forest in a continental climate in east France. NDVI values for the spring months of April and May were positively correlated with the following winter body mass only at the Chize reserve. Pettorelli et al. (2006) concluded that the high canopy in the Trois Fontaines forest prevented the NDVI from accurately characterizing plant productivity at ground level.

3.0 METHODOLOGY

3.1 Study Area

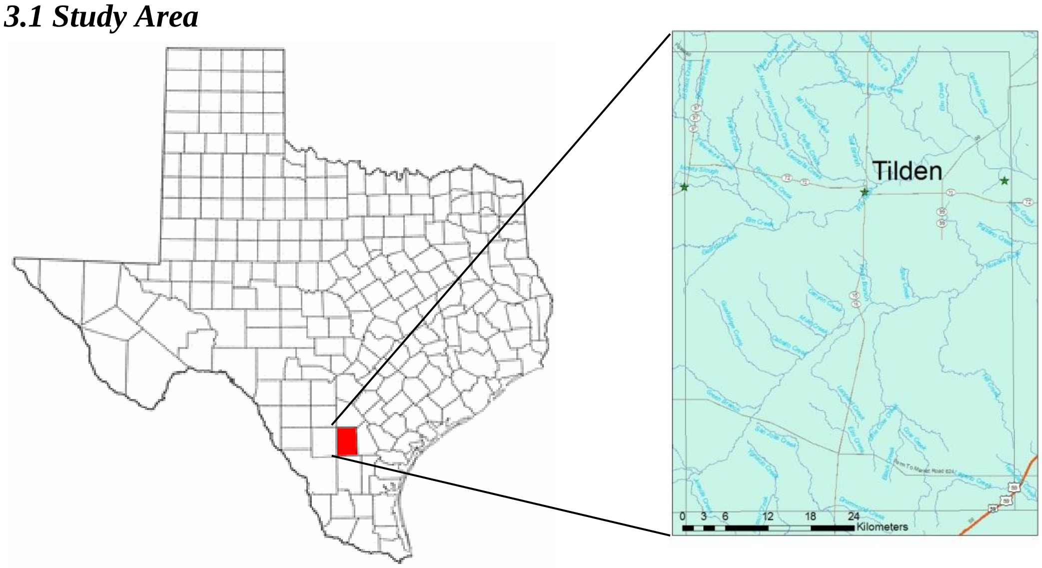

Figure 1. Map of the study area; McMullen County, TX

McMullen County is in southern Texas; bordered by Atascosa County to the north, Live Oak to the east, Duval to the south, and La Salle to the west (Fig. 1). Tilden, the county seat, is located at 28° 27' 42" N, 98° 32' 57". McMullen County falls entirely under the Texas-Tamaulipan Thornscrub sub-ecoregion of the Southern Texas Plains ecoregion (Griffith et al., Ecoregions of Texas 2004). The topography consists of gently undulating plain dipping toward the Gulf of Mexico with elevations ranging from 40 to 209 meters above sea level (USDA, Soil Survey 2010). Most of the county's 3,002 square km are drained in a west to east direction by the Fio River and Nueces River. The soils of this flat to rolling terrain are dominantly dark-colored clayey and light-colored loamy soils with many of the clayey soils being either sodic or saline (USDA, Soil Survey 2010).

Caliche outcroppings and gravel ridges are common here, and they contribute to the rich flora and fauna diversity of the region. According to the vegetation types of Texas classification scheme, a typical Mesquite-Blackbrush brush community exists throughout the county that is comprised of a mix between Mesquite and a very large diversity of scrub brush, cacti, chaparral, and grass species (TPWD, Vegetation Types 1984).

Temperatures in McMullen County range from an average of 30° C in July to an average of 13° C in January whereas the average annual temperature is 22° C (Leffler 2011). Despite common drought, McMullen County receives an average of about 58 to 60 centimeters of rain per year. This rain falls in a bimodal fashion with the peaks of rainfall occurring around May and September. The growing season typically lasts for 290 days from the month of February through November.

3.2 Site Selection

The study area was comprised of 7 separate ranches that totaled 7,845 hectares within McMullen County, TX. These sites were selected based on the availability of white-tailed deer harvest data for the years of interest.

3.3 Field Data

Table 1. Datasets for this study and their sources.	
Dataset	Source
Annual Climatological Summary: 2006 - 2010	U.S. National Climate Data Center
Population Summary - density, Doe:Buck, and Doe:Fawn recruitment: 2006 – 2010 every Fall	Helicopter Census
MLDP Harvest Logs – Age, Weight, and Antler Data sheets Hunting Seasons: 2006 - 2011	Canyon Creek Ranch and 6 other anonymous ranches
Level 1 Landsat 5 Data: 2006 – 2010 every spring and summer	U.S. Geological Survey

3.3.1 Population Survey Datasets

Population Survey datasets for each ranch were collected every fall from 2006 through 2010 by helicopter. These surveys are fast and often considered the most accurate method available in low-to-medium height brush. Normally a ranch is surveyed in a single flight over adjacent transects 200-300 meters wide (DeYoung 1985). The surveys were performed around the same date and canopy cover every year; therefore, the information derived from them provides a consistent record of yearly hectares/deer (density), does/bucks (doe to buck), and fawns/does (recruitment) ratios for each ranch.

3.3.2 Managed Land Deer Permits

The Managed Lands Deer Permits (MLDP) dataset was a compilation of 5 hunting seasons (2005/2006 through 2010/2011) of deer harvest data. Every ranch was on the same program (MLDP) with Texas Parks and Wildlife Department (TPWD); resulting in a uniform format for harvest logs. Data recorded on the harvest logs include: *Age, Field-Dressed Weight (kg), #of points, Inside Spread (cm), Basal Circ. (cm), Main*

Beam Length (cm), and Total Boone and Crocket Score (cm). Descriptions for these variables are displayed in Table 2, and the values of the survey and harvest records for all of the ranches combined are shown in Table 3.

Table 2. Definitions for survey and harvest variables.

Variable	**Definition**
Density	Hectares to deer ratio
Fawn crop	Fawns to does ratio
Body Weight	Weight after field dressing
Points	# of points with a length over 2.5 centimeters
Basal Circumference	Minimum circ. b/w pedicle (base) & 1st point
Inside Spread	Maximum width inside beams
Main Beam Length	Length from pedicle to the end of main antler stem
Total Boone and Crocket Score	Sum of measurements of entire rack

Table 3. Survey and harvest averages for all ranches combined.

All Ranches	**06'/07'**	**07'/08'**	**08'/09'**	**09'/10'**	**10'/11'**	***5-year Average***
Acres/Deer	22.61	14.78	14.74	17.77	16.75	*17.33*
Does/Buck	1.27	1.52	1.22	1.07	1.38	*1.29*
Fawns/Doe	0.45	0.94	0.81	0.39	0.87	*.69*
Does (n)	**20**	**231**	**223**	**54**	**91**	
Age	4.8	4.02	3.96	4.2	3.94	*4.18*
Body Weight (kg)	34.31	32.96	33.08	35.04	34.38	*33.95*
Mature Bucks (n)	**24**	**87**	**70**	**51**	**82**	
Age	5.5	5.76	5.67	6.28	5.96	*5.83*
Body Weight (kg)	60.88	66.06	65.98	62.54	64.09	*63.91*
Points	8.58	8.89	9.2	8.82	9.1	*8.92*
Spread (cm)	40.72	41.1	42.06	40.36	41.63	*41.17*
Basal Circ. (cm)	11.25	11.13	10.72	10.06	10.9	*10.81*
Mainbeam (cm)	50.5	54.33	52.78	51.71	53.62	*52.59*
B&Cscore (cm)	299.95	330.66	324.08	298.27	323.95	*315.38*

3.3.3 Meteorological Data

Precipitation quantities for the study period were acquired from the U.S. National Climate Data Center (NCDC) weather stations close to the ranches. Table 4 provides information for the two closest NCDC climate stations from which annual precipitation data were obtained. Tilden 4 SSE was the primary source whereas Tilden 10 S served to fill in record gaps and missing information. The time period of this study includes periods of drought along with spans of high precipitation. These extremes may express themselves more readily in the data than years with average weather.

Table 4. NCDC weather stations.

Station Name	Start Date	Stop Date	COOP ID	TYPE
Tilden 10 S	10/01/1954	8/01/2010	419030	Land Surface COOP B
Tilden 4 SSE	3/01/1958	Present	419031	Land Surface COOP COOP-A AB

3.3.4 Remote Sensing Datasets

Remotely sensed imagery used in this study were acquired from the USGS Earth Explorer (website). Level 1 Landsat 5 Thematic Mapper data were downloaded from 2006 to 2010, with emphasis on cloud-free images around March/April/May and July/August periods.

The spring imagery was selected to aid in determining nutritional effects on bucks and does, whereas the summer imagery was selected to provide information necessary to evaluate fawn survival through enhanced hiding/fawning cover. Because imagery acquired during different time periods exhibits varying solar illumination characteristics, the imagery was converted to top-of-atmosphere (TOA) reflectance to account for varying sun angles and time of year. To accomplish this, raw imagery was stacked and converted to TOA reflectance using the Erdas 2011 Model Maker and radiometric calibration coefficients published in Chander et al. (2009).

NDVI was calculated for all images used in the analysis. After NDVI was calculated, each study unit was clipped based on the boundary of the study unit. The boundaries of the remaining study units were provided by Macy Ledbetter, wildlife biologist from Spring Creek Outdoors, L.L.C., and will remain anonymous.

4.0 ANALYSIS

The two NCDC stations closest to the study sites were used to create an accurate depiction of precipitation in recent years (Table 5). Precipitation was grouped as previous fall (September-November), previous winter (December-February), spring (March-May), summer (June-August), spring-summer (March-August), March-April, March-July, and July-August total rainfall for every year of the study. A seasonal lag analysis was performed for each research objective and its rainfall periods included the previous fall, previous winter, spring (of development), and summer (of development) for each year. The resulting precipitation data were used for comparison with the field, survey, and remote sensing data.

Table 5. NCDC precipitation (cm).

Rainfall	**2006**	**2007**	**2008**	**2009**	**2010**
Total	47.09	98.5	45.42	52.78	109.63
Previous Fall	10.52	21.89	13.08	0.76	24.08
Previous Winter	0.51	21.44	1.88	0.89	21.56
Spring	4.62	31.88	17.22	16.08	42.55
Summer	12.35	39.93	24.87	6.35	17.78
Spring&Summer	16.97	71.81	42.09	22.43	60.33
March&April	3.48	11.71	11.89	8.31	30.99
March-July	15.44	69.62	30.78	22.17	60.33
July-August	9.07	25.83	24.87	3.18	11.76

Nonparametric statistical analyses were performed using the SPSS statistical program. Spearman correlation coefficients were calculated to determine statistical relationships. Spearman R assumes that the variables under consideration were measured on at least an ordinal (rank order) scale; that is, the individual observations (cases) can be ranked into two ordered series (Hill and Lewicki 2005). Similar to the Pearson R, the Spearman correlation coefficient determines the strength of relationship between two variables; however, the Spearman is calculated from ranks of the values. The target *p* value that would indicate significance in the relationship was equal to or less than 0.05.

Objective 1: Is there a relationship between precipitation and white-tailed deer recruitment/fawn crop survival (fawn: doe) in McMullen County, TX?

Fawn survival rates of every ranch were combined into one average for each year. Following the methodology of Ginnett et al. (2000), recruitment values were compared to the March-July rainfall totals of every year. Precipitation and recruitment relationships were also examined for the previous fall, previous winter, spring, summer, spring-summer, March-April, and July-August rainfall totals. The March-April time period is during the middle part of the gestation period and will provide information primarily on the nutritional condition of the mother. On the other hand, the July-August time period is one of late gestation and birthing. The analysis of this time period is designed to focus also on nutrition but with a greater focus on the effects of rainfall on fawning cover. Infant deer are very vulnerable to predators if they do not have adequate cover in the form of grasses and forbs.

Objective 2: Is there a relationship between precipitation and white-tailed deer physiological characteristics, which include body weight and antler measurements in McMullen County, TX?

The harvest log data measurements were translated from 1/8 inch to centimeter decimal points. Antler measurements considered for analysis were: the total number of points, inside spread, basal circumference, main beam length, and total Boone and

Crockett score. Antler measurements and body weights were combined into averages for all of the ranches combined and each of the seven individual ranches in the study. Body weights and antler measurements were also grouped according to maturity. Information used for all male deer was from mature animals only. Deer reach physical maturity at four and a half years of age. Body weight averages were taken from female deer of all ages.

Correlation analyses were performed between these averages and precipitation totals for previous fall, previous winter, spring, summer, spring-summer, and March-April rainfall. The March-April time period is one that has yielded positive correlations with antler measurements from a study area (Schreiger 2010) near to mine. This time period is a time of year in a white-tailed buck's life when he is recovering from the previous winter's rut and building up new mineral reserves to jumpstart his new set of antlers.

Objective 3: Is there a relationship between NDVI and precipitation, NDVI and deer variables, or NDVI and vegetation?

The polygons for all 7 ranches were clipped from every NDVI image. Only one image was chosen to analyze for each spring and summer of every year based on similar dates and cloud-free cover. The mean pixel values of all 7 NDVI clippings were averaged together for every season. A simple Spearman correlation analysis was then run with spring image values and March-April total rainfall along with additional analysis on summer image values and July-August total rainfall. Both image values were also analyzed with previous fall, previous winter, spring, summer, and spring-summer rainfall.

The spring and summer image values were also compared with body weights, antler measurements, and fawn survival ratios.

5.0 RESULTS

5.1 Precipitation and Fawn Crop

Objective 1: Is there a relationship between precipitation and white-tailed deer recruitment/fawn crop survival (fawn: doe) in McMullen County, TX?

Table 6. Precipitation and Fawn Crop correlation coefficients (r). Bold indicates significance: 0.9 ($p \leq 0.05$) and 1.0 ($p \leq 0.01$). N = 5.

Precipitation / **Ranch**	Previous Fall	Previous Winter	Spring	Summer	Spring-Summer	March-July	July-August	March-April
A	**1.0**	**0.9**	**0.9**	0.7	0.8	0.8	0.7	0.8
B	0.8	**0.9**	**0.9**	0.8	**1.0**	**1.0**	0.8	0.7
C	0.5	0.3	0.3	0.4	0.1	0.1	0.4	0.6
D	0.6	0.7	0.7	**0.9**	**0.9**	**0.9**	**0.9**	0.6
E	0.6	0.7	0.7	**0.9**	**0.9**	**0.9**	**0.9**	0.6
F	0.7	0.6	0.6	**1.0**	0.8	0.8	**1.0**	0.5
All Ranches	**0.9**	0.8	0.8	**0.9**	**0.9**	**0.9**	**0.9**	0.6

Among the seven ranches, ranch G lacked 5 years of complete survey data; therefore, the individual analysis for it was statistically unavailable. The years ranch G did have fawn crop data were absorbed into the overall average. The correlation (r) values for ranches A through F are provided in Table 6. All significant correlations ($p \leq 0.05$) are denoted in bold font. The relationship between precipitation and fawn crop was significant ($p \leq 0.05$) for ranch A during the rainfall periods of previous fall (r = 1.0), previous winter (r = 0.9), and spring (r = 0.9). Ranch B had significant fawn crop relationships with the previous winter (r = 0.9), spring (r = 0.9), spring-summer (r = 1.0), and March-July (r = 1.0) periods. Ranch C had no significant relationships whereas ranch D and E both had significant relationships with summer (r = 0.9), spring-summer (r = 0.9), March-July (r = 0.9), and July-August (r = 0.9). The results for Ranch F suggest strong correlations between precipitation and fawn crop for the summer (r = 1.0) and July-August (r = 1.0) analysis periods.

Fawn survival rates were combined for every ranch into one average for each year and analyzed with precipitation. The results of this analysis are presented in the 'All Ranches' row of Table 6. With all the ranches combined together, statistically significant relationships are reported for the previous fall (r = 0.9), summer (r = 0.9), spring-summer (r = 0.9), March-July (r = 0.9), and July (r = 0.9) analysis time periods.

5.2 Precipitation and Physiological Characteristics

Objective 2: Is there a relationship between precipitation and white-tailed deer physiological characteristics, which include body weight and antler measurements in McMullen County, TX?

A 5-year set of physiological characteristics was compiled where all of the ranches were combined and averaged. Table 7 summarizes combined ranch correlation coefficients. Correlation coefficients of 0.9 had p values equal to or less than 0.05, and coefficients of 1.0 had p values equal to or less than 0.01. Because of incomplete records to some extent and antler growth patterns, analysis was limited to the antler measurements and body weights of mature male deer (age $\geq$ 4.5 years). The female body weight averages were recorded for all does.

Table 7. Spearman rank correlation coefficients for precipitation and physiological characteristics. Analysis results are reported for combined study units. Bold indicates significance: 0.9 ($p \leq 0.05$) and 1.0 ($p \leq 0.01$). N = 5**.**

Precipitation	Previous Fall	Previous Winter	Spring	Summer	Spring-Summer	March-July	July-August	March-April
Body Weight								
Female	-0.4	-0.2	-0.2	**-0.9**	-0.5	-0.5	**-0.9**	-0.1
Male	0.6	0.7	0.7	**0.9**	**0.9**	**0.9**	**0.9**	0.6
Antler Measurements								
# of points	0.6	0.7	0.7	0.6	0.6	0.6	0.6	**0.9**
Inside Spread	0.7	0.6	0.6	0.7	0.5	0.5	0.7	0.8
Basal Circ.	0.3	-0.1	-0.1	0.3	0	0	0.3	-0.3
Main Beam	0.8	**0.9**	**0.9**	0.8	**1.0**	**1.0**	0.8	0.7
B&C Score	0.7	0.6	0.6	**1.0**	0.8	0.8	**1.0**	0.5

Analysis of female body weights resulted in negative correlations for the summer (r = -0.9) and July-August (r = -0.9) rainfall periods. Male body weights exhibited highly positive relationships for the summer (r = 0.9), spring-summer (r = 0.9), March-July (r = 0.9), and July-August (r = 0.9) periods.

Among the antler measurements, the numbers of points were highly related to March-April (r = 0.9) rainfall. Inside spread and basal circumference had no significant relationships whereas the main beam length had relationships with the previous winter (r = 0.9), spring (r =0.9), spring-summer (r = 1.0), and March-July (r = 1.0) rainfall periods. Finally, the total Boone and Crockett score exhibited a strong statistical relationship with summer (r = 1.0) and July-August (r = 1.0) rainfall.

5.3 NDVI, Precipitation, and Deer Variables

Objective 3: Is there a relationship between NDVI and precipitation, NDVI and deer variables, or NDVI and vegetation response?

5.3.1 Precipitation and Spring NDVI

Spring NDVI values (Table 8) were calculated for each ranch and as a combined ranch dataset. The precipitation and spring NDVI relationship values are provided in Table 9.

Table 8. Spring NDVI values.

Spring	May'06	April'07	April'08	April'09	May'10
A	0.18	0.59	0.33	0.23	0.54
B	0.23	0.50	0.33	0.28	0.51
C	0.20	0.52	0.28	0.21	0.49
D	0.24	0.56	0.34	0.27	0.52
E	0.21	0.55	0.31	0.24	0.57
F	0.20	0.60	0.31	0.22	0.59
G	0.18	0.67	0.22	0.21	0.62
All Ranches	0.21	0.57	0.30	0.24	0.55

Table 9. Precipitation and spring NDVI correlation coefficients (r). Bold indicates significance: 0.9 ($p \leq 0.05$) and 1.0 ($p \leq 0.01$). N = 5

Precipitation **Ranch**	Previous Fall	Previous Winter	Spring	Summer	Spring-Summer	March-July	July-August	March-April
A	0.8	**0.9**	**0.9**	0.8	**1.0**	**1.0**	0.8	0.7
B	0.8	**0.9**	**0.9**	0.8	**1.0**	**1.0**	0.8	0.7
C	0.8	**0.9**	**0.9**	0.8	**1.0**	**1.0**	0.8	0.7
D	**0.9**	**1.0**	**1.0**	0.6	**0.9**	**0.9**	0.6	**0.9**
E	0.8	**0.9**	**0.9**	0.8	**1.0**	**1.0**	0.8	0.7
F	0.8	**0.9**	**0.9**	0.8	**1.0**	**1.0**	0.8	0.7
G	**0.9**	**1.0**	**1.0**	0.6	**0.9**	**0.9**	0.6	**0.9**
All Ranches	0.8	**0.9**	**0.9**	0.8	**1.0**	**1.0**	0.8	0.7

Ranches A, B, C, E, and F all had the same significant relationships with the previous winter (r = 0.9), spring (r = 0.9), spring-summer (r = 1.0), and March-July (r = 1.0) rainfall periods. Ranches D and G both had significant relationships with previous fall (r = 0.9), previous winter (r = 1.0), spring (r = 1.0), spring-summer (r = 0.9), March-July (r = 0.9), and March-April (r = 0.9) periods.

When all of the spring NDVI values were combined into the 'All Ranches' row, significant relationships were found with previous winter (r =0.9), spring (r = 0.9), spring-summer (r = 1.0), and March-July (r = 1.0) rainfall periods.

5.3.2 Precipitation and Summer NDVI

Summer NDVI values (Table 10) were calculated for each ranch and also averaged to derive a single value for the combined study units. Spearman rank correlations for precipitation and summer NDVI are provided in Table 11.

Table 10. Summer NDVI values.

Summer	**July'06**	**July'07**	**July'08**	**August'09**	**August'10**
A	0.36	0.20	0.38	0.24	0.46
B	0.28	0.42	0.40	0.25	0.42
C	0.36	0.39	0.43	0.25	0.44
D	0.36	0.45	0.42	0.25	0.45
E	0.33	0.46	0.47	0.27	0.49
F	0.27	0.42	0.45	0.24	0.50
G	0.28	0.48	0.44	0.24	0.57
All Ranches	0.32	0.40	0.43	0.25	0.48

Spearman rank correlations indicated that ranches A and B had the same significant relationships with the previous fall (r = 1.0), previous winter (r = 0.9), and spring (r = 0.9) rainfall periods. Ranches C, D, and G all exhibited strong positive correlations with previous fall (r = 0.9) and March-April (r = 0.9) periods. Ranch E had no high correlation coefficients whereas ranch F was significantly related to previous fall (r =0.9), summer (r = 0.9), spring-summer (r = 0.9), March-July (r = 0.9), and July-August (r = 0.9).

Combined summer NDVI values for all ranches indicated positive relationships for previous winter (r = 0.9), spring (r = 0.9), spring-summer (r = 0.9), and March-July (r = 0.9) rainfall periods.

Table 11. Precipitation and summer NDVI correlation coefficients (r). Bold indicates significance: 0.9 (P<≤0.05) and 1 (P≤0.01). N = 5.

Precipitation Ranch	Previous Fall	Previous Winter	Spring	Summe r	Spring-Summer	March-July	July-August	March-April
A	**1.0**	**0.9**	**0.9**	0.7	0.8	0.8	0.7	0.8
B	**1.0**	**0.9**	**0.9**	0.7	0.8	0.8	0.7	0.8
C	**0.9**	0.8	0.8	0.6	0.6	0.6	0.6	**0.9**
D	**0.9**	0.8	0.8	0.6	0.6	0.6	0.6	**0.9**
E	0.4	0.3	0.3	-0.1	-0.1	-0.1	-0.1	0.6
F	**0.9**	0.8	0.8	**0.9**	**0.9**	**0.9**	**0.9**	0.6
G	**0.9**	0.8	0.8	0.6	0.6	0.6	0.6	**0.9**
All Ranches	**0.9**	0.8	0.8	0.6	0.6	0.6	0.6	**0.9**

5.3.3 NDVI and Fawn Crop

Table 12. NDVI and fawn crop correlation coefficients (r). Bold indicates significance: 0.9 (P≤0.05) and 1 (P≤0.01). N = 5.

Ranch	NDVI Spring	NDVI Summer
A	0.8	**1.0**
B	**1.0**	0.8
C	0.1	0.8
D	0.7	0.5
E	**0.9**	-0.2
F	0.8	**0.9**
All Ranches	**0.9**	0.7

The fawn crops for ranches A (r = 1.0) and F (r = 0.9) were related to the summer NDVI values (Table 12) whereas fawn crops for ranches B (r = 1.0) and E (r = 0.9) were related to the spring NDVI values. Spearman rank correlations indicated no strong relationships for ranches C and D, and ranch G was excluded from analysis because of an incomplete set of survey data.

When the ranches were combined into a single dataset, the average fawn crop was compared to the average spring and summer NDVI values for each year. The combined fawn crop numbers had a significant relationship with the combined spring NDVI values (r = 0.9).

5.3.4 NDVI and Physiological Characteristics

Table 13. NDVI and physiological characteristic correlation coefficients (r) for the ranches combined together. Bold indicates significance: 0.9 ($p \leq 0.05$) and 1.0 ($p \leq 0.01$). N = 5.

Body Weight	NDVI Spring	NDVI Summer
Female	-0.5	-0.3
Male	**0.9**	0.5
Antler Measurements		
# of points	0.6	0.8
Inside Spread	0.5	**0.9**
Basal Circ.	0	0.1
Main Beam	**1.0**	0.6
B&C Score	0.8	0.6

A 5-year set of spring and summer NDVI (Tables 8 and 9) and deer physiological data (Table 3) was combined, averaged, and compared. The regional average was compared with average NDVI extracted from each study unit. An analysis on individual ranches was not possible because of incomplete records. However, the combined ranch averages had enough consecutive years of data for comparison with NDVI. Spearman rank correlations are reported in Table 13. Similar to the combined ranch precipitation and physiological analyses, only mature male deer were included. The female body weight averages were calculated for all does regardless of age.

The combined ranch male body weights exhibited a strong positive relationship (r = 0.9) with spring NDVI values. Among the antler measurements, inside spread was positively correlated (r = 0.9) with summer NDVI values whereas main beam length was found to have a strong relationship (r = 1.0) with spring NDVI. Female body weights, number of points, basal circumference, and total Boone and Crocket score exhibited no statistical relationships with averaged NDVI over all time periods of analysis.

6.0 DISCUSSION

6.1 Precipitation and Fawn Crop

Of the six individual ranches with complete survey records, the majority of the significant fawn crop and precipitation relationships focused around the summer, spring-summer, March-July, and July-August time periods. Other than one different relationship found with previous fall ($r = .9$) the results of the combined ranch numbers matched perfectly with the majority of individual ranch relationships; therefore, there was little variation between the combined ranch and individual ranch relationships.

The spring-summer (March-August) and March-July time periods are very similar because they have only one month of rainfall difference between them. This is also the case with the summer (June-August) and July-August periods. Although they may be similar, these four time periods are relevant to fawn crop production in slightly different ways. Because the majority of fawns in McMullen County are born in mid- to late-July, the March-July period is the best representation of gestation influence on fawn crop and the July-August period is best suited for explaining fawning cover influence. The statistical relationships were the same for both rainfall periods; therefore, it is difficult to determine the specific influence between nutrition and enhanced fawning cover on fawn survival rates. The March-July rainfall period was modeled after the Ginnett et al. (2000) study on deer recruitment. Ginnett et al. (2000) reported a similar relationship between fawn crop and precipitation.

There are a number of sources of uncertainty for the survey data. It is assumed that precipitation was evenly distributed across the ranches when this was likely not the case. The small number of years analyzed is also a source of uncertainty. Additionally, differences in canopy cover and helicopter survey dates may contribute to inconsistent survey records. Furthermore, inconsistent and over harvest of female deer before the survey could have artificially pushed the fawn to doe ratio up because of an abundance of orphan fawns.

6.2 Precipitation and Physiological Characteristics

Because of incomplete harvest records, analysis of physiological characteristics and rainfall was limited to the combined ranch averages. Because the ranch values were combined into averages for each of the five years, the extant of the incomplete data became evident when limited observations were included as the measurement. Some ranches lacked records for a particular year whereas other ranches had incomplete records with less than 6 observations of a particular measurement. If there were less than 6 measurements in a particular category, that category was deleted from the overall average. Certain ranches and measurements were therefore not represented among the yearly averages. The years that were limited to data from only a few ranches were biased towards the different harvest strategies of those ranches. In turn, the type of buck represented in the average for that year could then be misleading and biased towards a difference in management strategy. This is a major source of uncertainty for this section of the study.

Amongst the body weights of the total ranch averages, female body weight had the only significantly negative correlations of all the results in the study. There were negative relationships with every time period; however, the only significant relationships were with the summer (r = -0.9) and July-August (r = -0.9) periods. Negative correlations may be attributed to the fact that during drought years, harvest records indicate that fewer and older female deer were harvested. The results may have been different if there were a consistent harvest of female deer from year to year and if only mature female deer were analyzed such as with the male deer measurements. On the contrary, male body weight was positively correlated (r = 0.9) with the same time periods in addition to spring-summer (r = 0.9) and March-July (r = 0.9). The spring-summer time period corresponds to when the majority of antler development occurs, and when the majority of vegetation in a deer's diet will be grown; therefore, it is not unexpected to observe relationships with spring-summer and the temporally-similar periods of summer, March-July, and July-August.

The March-April time period is one that has previously yielded positive correlations with antler measurements in this region (Schreiger 2010). This time period is relevant as it represents recovery from the previous winter and building up mineral reserves to facilitate new antler growth. March-April rainfall did yield a significant relationship (r = 0.9) with the number of points.

Main beam length exhibited significant relationships with previous winter (r = 0.9), spring (r = 0.9), spring-summer (r = 1.0), and March-July (r = 1.0). The relationship between seasonal precipitation and main beam length was expected because of the timing of precipitation (i.e., during antler growth). A lag relationship with previous winter rainfall during pre-antler development was observed. This may demonstrate a spillover effect from the condition of the deer during the previous season while the previous set is still attached. Finally, the Boone and Crockett score was the only other measurement to exhibit strong positive relationships, but only for the summer (r = 1.0) and July-August (r = 1.0) analysis periods. These analysis periods are coincident with the second half of antler development.

6.3 NDVI, Precipitation, and Deer Variables

Analysis between precipitation and spring NDVI included ranch averages for both variables. Strong, positive correlations were observed for all ranches combined and the previous winter (r = 0.9), spring (r = 0.9), spring-summer (r = 1.0), and March-July (r = 1.0) rainfall periods. These results were similar to the values found for the individual ranches. Spring NDVI images were used from the months of March, April, and May. Therefore it is not surprising that the spring rainfall period was significant. It is, however, interesting that there is a significant lag effect from the previous winter rainfall to spring green-up. This finding may be explained by simple statistical chance or it implies that there is soil moisture build-up in the months leading up to the spring green-up.

Analysis of precipitation and summer NDVI resulted in only one ranch (Ranch F) with a significant relationship with summer (r = 0.9) or July-August (r = 0.9) rainfall totals. Summer NDVI images were acquired during the months of July or August. All other ranches exhibited weak, non-significant relationships between summer NDVI and precipitation. Combined summer NDVI values for all ranches indicated positive relationships for previous winter (r = .9), spring (r = .9), spring-summer (r = .9), and March-July (r = .9) rainfall periods.

There were an equal amount of individual ranches with significant fawn crop relationships to spring and summer NDVI numbers; however, when ranches were combined, fawn crop only had a significant relationship (r = 0.9) to the combined spring NDVI values. Though there was not a majority between fawn crop and NDVI, the spring NDVI continued to have greater significance among its relationships than the summer NDVI. One interpretation of this relationship is that ranchers and landowners of the area may anticipate a relative increase or decrease in the upcoming deer population based on spring NDVI values.

Of the NDVI and deer physiological relationships for the combined ranch dataset, spring NDVI was strongly correlated with male body weight (r = 0.9) and main beam length (r = 0.9) whereas summer NDVI was correlated with inside spread (r = 1.0). However, the remaining variables did not exhibit statistical relationships with NDVI. One source for this could be because of the inconsistency of the harvest records that made up the combined averages for the physiological characteristics. Ranchers and landowners within the study area may consider incorporating spring and summer NDVI data to aid in their deer population management. Higher spring NDVI values may result in higher male body weights and main beam length. Greater body weights are directly related to larger antler sizes and longer main beams usually give room for extra tines. Larger summer NDVI values were indicative of a wider inside spread.

7.0 CONCLUSION

Fluctuations in rainfall affect vegetation response, which in turn affects the general health of white-tailed deer. This was the assumption behind the expected results to come out of this study. Because fawn crop was positively correlated with rainfall, landowners and wildlife managers may further examine the influence of precipitation on deer forecasts and general management decisions related to harvest intensity. A direct indicator of nutrition is body weight and male body weight proved to have a strong relationship with rainfall during the vegetation growing season. Total Boone and Crockett score, which is what most deer hunters are interested in, did have a strong relationship with rainfall during the summer time period; however, because of incomplete data, it is difficult to speculate how consistent the antler measurement data are.

Vegetation response was characterized by NDVI. Spring NDVI, thus spring vegetation response, was positively correlated with rainfall during and before the satellite image acquisition dates. However, summer NDVI was unexpectedly not related to rainfall. Spring NDVI also indicated a greater statistical correlation with fawn crop and physiological characteristics than summer NDVI. The spring NDVI values generally had stronger statistical relationships than the summer NDVI values. Spring, spring-summer, and March-July rainfall were correlated with spring NDVI and spring NDVI was strongly correlated with fawn crop. However, fawn crop only demonstrated a statistically significant relationship with spring-summer and March-July rainfall. Results also indicate that spring rainfall is related to spring NDVI, which in turn also exhibited a strong correlation with main beam length.

In conclusion, landowners and wildlife managers in this area of Texas may consider using the NDVI coupled with precipitation data to predict fawn crop for the following hunting season. This type of predictive information is especially useful in managing herd population as it gives the manager time to assess habitat and herd condition and decide if harvest numbers should increase or decrease and to what degree. The small landowner who does not keep survey records or does not have a full-time biologist on staff would most likely be the greatest beneficiary of this research because of its supplementary nature to large-scale surveys. Even though measurements such as body weight, main beam length, and total Boone and Crockett score had significant relationships with precipitation and NDVI, future work should expand this analysis with more complete harvest records spanning a longer time period.

8.0 FUTURE WORK

Future related research could include a study with larger sample sizes or more consecutive years of analysis. A similar study with a more spatial component to it could examine rainfall relationship with deer among the different precipitation gradients or ecoregions of Texas. There is even variation in rainfall from the western to the eastern side of south Texas that can be examined. In general, understanding how deer, wildlife, and their habitats respond to rainfall is very important.

APPENDIX

Appendix. A. Deer Physiological Characteristic Averages for Individual Ranches and All Ranches combined. Blank spots indicate where there was incomplete or not enough data.

All	Fawn/Doe	Weight (does)	Weight (bucks)	Points	Inside Spread	Basal circ.	Main beam	B&C score
06'/07'	0.45	34.31	60.88	8.58	40.72	11.25	50.5	299.95
07'/08	0.94	32.96	66.06	8.89	41.1	11.13	54.33	330.66
08'/09'	0.81	33.08	65.98	9.2	42.06	10.72	52.78	324.08
09'/10'	0.39	35.04	62.54	8.82	40.36	10.06	51.71	298.27
10'/11'	0.87	34.38	64.09	9.1	41.63	10.9	53.62	323.95
A	**Fawn/Doe**	**Weight (does)**	**Weight (bucks)**	**Points**	**Inside Spread**	**Basal circ.**	**Main beam**	**B&C score**
06'/07'	0.46	-	-	-	-	-	-	
07'/08	0.77	31.82	61.66	8.93	43.54	10.97	56.13	317.37
08'/09'	0.69	30.81	62.72	8.83	40.97	11.02	54.33	306.71
09'/10'	0.31	32.13	59.54	8.65	39.22	9.91	51.49	294.36
10'/11'	1.03	31.86	61.57	9.61	40.51	10.52	55.58	322.68
B								
06'/07'	0.45	-	-	-	-	-	-	-
07'/08	1.41	33.89	73.48	8.74	42.93	10.92	53.98	349.89
08'/09'	0.92	35.14	69.02	9.63	43.36	10.41	52.86	348.08
09'/10'	0.56	36.76	67.28	9.42	44.3	10.24	52.86	-
10'/11'	1.1	33.66	64.61	8.33	42.67	11.46	53.24	-
C								
06'/07'	0.49	33.82	68.1	9.38	41.78	12.42	52.22	348.56
07'/08	0.48	33	69.68	9.89	42.39	11.63	54.79	360.45
08'/09'	0.9	31.4	66.15	9.53	39.8	10.87	45.24	340.21
09'/10'	0.44	-	-	-	-	-	-	-
10'/11'	0.68	-	69.44	9.25	44.35	11.94	54.38	341.58
D								
06'/07'	0.22	-	60.84	8.29	39.47	9.88	48.49	281.76
07'/08	0.93	35.44	67.94	8.56	39.34	10.72	48.46	305.97
08'/09'	0.87	35.07	66.22	8.71	46.81	10.11	52.35	292.05
09'/10'	0.43	-	-	-	-	-	-	-
10'/11'	0.86	38.61	66.97	8.64	40.64	10.67	49.96	315.93

Appendix A. Continued

E	Fawn/ Doe	Weight (does)	Weight (bucks)	Points	Inside Spread	Basal circ.	Main beam	B&C score
06'/07'	0.66	35.04	54.48	8.11	-	-	-	273.3
07'/08	1.03	34.2	59.68	7.93	30.63	-	-	-
08'/09'	0.84	34.17	65.24	8.57	41.33	-	-	-
09'/10'	0.29	38.88	62.65	8.4	38.58	10.36	50.5	309.58
10'/11'	0.79	-	61.35	9.13	41.33	9.86	50.39	327.76
F								
06'/07'	0.41	-	-	-	-	-	-	-
07'/08	1.03	-	-	-	-	-	-	-
08'/09'	0.83	-	-	-	-	-	-	-
09'/10'	0.44	-	-	-	-	-	-	-
10'/11'	0.81	-	-	-	-	-	-	-
G								
06'/07'	-	-	-	-	-	-	-	-
07'/08	-	-	-	-	-	-	-	-
08'/09'	0.61	-	-	-	-	-	-	-
09'/10'	0.27	-	-	-	-	-	-	-
10'/11'	0.84	-	-	-	-	-	-	-

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