

HABITAT INTERFERENCE BY EXOTIC AXIS DEER (*AXIS AXIS*) ON NATIVE
WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) IN TEXAS

THESIS

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by

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DEDICATION

To my Dad, Steve Faas, who introduced me to hunting and the outdoors at a very young age. From the days when I tagged along to the deer stand or out to the muddy rice fields in pursuit of geese, I grew to appreciate nature and all it had to offer; but for more than just hunting. He taught me to appreciate what it meant to just be out there; to get away from everything and enjoy what God gave us. He instilled in me a work ethic that I will carry with me always and one day pass along to my children. Most of all, he has always been there for me, whether it be to offer words of advice or encouragement, a helping hand, or to set me straight when I got out of line, he shaped me into the person I am today.

To my Mom, Terese Faas, who has always guided me down the right path and never let me settle for mediocre results. She has been my council through life's trials and tribulations and is always my reassurance when times get tough. She has endured countless hours of hunting and fishing stories and always nodded and smiled as if it was the most interesting thing she heard that day. Above all she has always been supportive of me in the direction I have chosen in life. Without her support and guidance, I would not be where I am today; writing this manuscript.

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS.....	v
LIST OF TABLES.....	vii
LIST OF FIGURES	viii
ABSTRACT	ix
CHAPTER	
I. INTRODUCTION.....	1
II. STUDY AREA AND DESIGN	7
<i>Treatment Area</i>	8
<i>Control Area</i>	8
III. METHODS	9
<i>Spatial Data</i>	9
<i>Behavioral Data</i>	13
<i>Axis Deer Removal</i>	16
IV. RESULTS.....	17
<i>Habitat Use</i>	17
<i>Displacements and Time Spent at Feeder</i>	19
V. DISCUSSION	22
LITERATURE CITED.....	28

LIST OF TABLES

Tables	Page
1. Summary of the model selection for determining the detection probability of white-tailed deer and axis deer	18

LIST OF FIGURES

Figures	Page
1. Figure 1. Map of treatment and control areas with survey routes in Bandera County, Texas, USA.....	10
2. Proportion of wooded habitat used in survey seasons one and two by white-tailed deer in the treatment and control areas compared to the amount of wooded habitat available	20

ABSTRACT

HABITAT INTERFERENCE BY EXOTIC AXIS DEER (*AXIS AXIS*) ON NATIVE WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) IN TEXAS

by

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Exotic ruminants were introduced into Texas with little knowledge of how the species would interact with native white-tailed deer (*Odocoileus virginianus*). Axis deer (*Axis axis*), the most common exotic ungulate in the state, are larger and more gregarious than white-tailed deer, and there is overlap in resources used by both species. In this study, I tested if the presence of axis deer affected habitat selection of white-tailed deer by comparing habitat use of white-tailed deer in an area where axis deer were present and then after axis deer were removed (temporal control) to another area where only white-tailed deer were present (spatial control). I wanted to assess if axis deer and white-tailed deer could coexist

via each species being superior in a different form of competition (interference or exploitative). Vehicle surveys were conducted to determine locations of white-tailed deer and axis deer over two survey seasons. The data were used to evaluate possible changes in habitat selection by white-tailed deer after the removal of axis deer. I also observed animals at artificial feeding sites that were provisioned with a high quality food. At feeding sites I recorded aggressive behaviors and the amount of time each species spent at feeders alone and together. From these data I determined dominance relationships between species and estimated the amount of time each species spent at feeders alone and together. The treatment area contained 53.85% wooded habitat. White-tailed deer used wooded habitat $34.6 \pm 4.2\%$ during the first survey season and $79.7 \pm 4.5\%$ in the second survey season, suggesting that the removal of axis deer influenced the habitat selection of white-tailed deer. No changes were observed in habitat selection of white-tailed deer in the control area (34.31% wooded) during the two survey seasons ($23.1 \pm 3.6\%$ in the first survey season and 25.1 ± 3.1 in the second survey season). Axis deer were dominant to white-tailed deer at the artificial feeding sites. Although marginally significant, both species spent a significantly greater amount of time alone than at feeders together. However, the amount of time that individuals of each species spent at feeders did not differ. These results suggest that axis deer are superior at interference competition, but white-tailed deer were not superior at exploitative competition, thus the conditions for coexistence are not met. Currently, populations of axis deer in Texas may be at manageable densities. However, increases in axis deer population sizes have the potential to displace white-tailed deer over large spatial scales which may result in a subsequent decrease in their numbers.

CHAPTER I

INTRODUCTION

Exotic ruminants (hereafter exotics) were introduced into high-fenced enclosures in Texas with little knowledge of the biology of the species, or how they would adjust to the new environment. Axis deer (*Axis axis*), native to India, are the most abundant of all exotics introduced into Texas (Mungall and Sheffield 1994). Their first known release was circa 1930 in Kerr County and since that time numbers have climbed to well over 40,000 individuals (Ables 1977, Mungall and Sheffield 1994). As exotic populations increase, so does the potential for competition with native white-tailed deer (*Odocoileus virginianus*) for resources. Gabor and Hellgren (2000) stated that introduced species alter factors that affect populations, including resource distribution, abundance, and competition. One would suspect that in areas where exotics are introduced, these exotics have either monopolized resources from the native species or caused these species to change their fundamental niche (Berger 1985). Dietary overlap and competition for limited resources has often been attributed as the mechanism for competition between white-tailed deer and exotics (Demarais et al. 1998), however, competitive interactions between white-tailed deer and exotics have not been studied in detail (Bartos et al. 2002).

Understanding how large herbivore distribution is affected by habitat selection is necessary for examining resource partitioning and competition (Stewart et al. 2002). However, competitive interaction studies among cervids, especially between exotics and native species, have rarely been conducted (Bartos et al. 2002). Stewart et al. (2002)

reported that studies of competition between large herbivores are complicated because addition or removal experiments are not feasible in most cases. This is largely due to their wide-ranging distributions and the difficulty in conducting manipulative experiments that have spatial and temporal controls (White and Garrott 1990).

When examining competition, the potential for competition is predicated upon similarities in body size, life history, and resource use. Axis deer are a medium sized deer, males range from 66 – 113 kg and 74 – 100 cm at the shoulder. Females are slightly smaller at 43 – 66 kg and 67 – 84 cm. Home ranges are from 485 – 769 ha for both males and females with males wandering widely during the breeding season. Being a gregarious species, group sizes typically range from 5 – 15 individuals but may number as many 40 – 70 in some cases (Ables 1997, Mungall and Sheffield 1994). Unlike many other cervids, axis deer do not follow a specific pattern of antler growth and breeding. Hard-antlered males can be found anytime throughout the year and due to females experiencing a continuous series of diestrous cycles throughout the year, breeding can occur at any time. However, breeding is done primarily in mid-May to August with peak fawning occurring from December to mid-April in Texas. Usually only one fawn is born per female (Demarais et al. 1998, Geist 1998, Mungall and Sheffield 1994, Putman 1988).

Axis deer tend to avoid rugged terrain and are generally found in open deciduous forests and small meadows with understories consisting of grasses and forbs (Geist 1998, Mungall and Sheffield 1994). Their diet is classified as intermediate between concentrate selector and bulk forager (Geist 1998, Putman 1988). Although grass consumption can be as high as 95 %, some studies have shown browse and forb consumption as much as 52 and 39 % respectively (Ables 1977, Demarais et al. 1998, Geist 1998, Henke et al. 1988, Mungall and Sheffield 1994, Putman 1988).

White-tailed are slightly smaller than axis deer with males ranging from 56 – 75 kg (n = 24) and females ranging from 35-45 kg (n = 37, Flying A Ranch 2008). Home ranges of white-tailed deer in the Edwards Plateau of Texas are usually 400 ha or less (Thomas et al. 1964). Adult male and female white-tailed deer commonly segregate, especially during the spring and summer months. Males group into small bachelor groups and females generally form family groups consisting of her fawns from that year and female offspring from the previous year (Demarais et al. 2002). Breeding times for this region range from mid-October to the end of December, with a peak breeding date of 24 November (Texas Parks and Wildlife Department 2008). Parturition begins mid to late-April with approximately 90% of young being born before the end of June. Fawning rates were 1.3 fawns per female in utero (Texas Parks and Wildlife Department 2008).

White-tailed deer are classified as opportunistic concentrate feeders selecting primarily forbs and browse that are high in nutrients (Fulbright and Ortega 2006, Geist 1998, Henke et al. 1988). White-tailed deer often select wooded areas with 50 % or more closed canopy cover as these areas not only provide them with the necessary forbs and browse, but also with cover for shelter from predators and climatic extremes (Fulbright and Ortega 2006, McCullough 1985, Meyer et al. 1984, Weckerly and Kennedy 1992).

Interspecific competition has been classified into two types: exploitative and interference competition (Amarasekare 2002, Carothers and Jaksić 1984, Case and Gilpin 1974). Exploitative competition is an indirect competition involving one species reducing the availability of a shared and vital resource for the other. Interference competition is a more direct competition in which one species restricts access to a resource by the other species. This can be done by either directly attacking the individuals or by blocking their access to the resource (Amarasekare 2002, Brian 1956, Carothers and Jaksić 1984). Although interference competition is often thought of as direct physical confrontation

between two species resulting in a shift in habitat selection, a change in activity times may also occur (Carothers and Jakšić 1984). If a resource is highly desirable by the subordinate species, then shifting its activity times will allow that species to use the particular resource at the times when the dominant species is less active, thus minimizing the opportunity for physical confrontation to take place (Stewart et al. 2002). In the case of exotics, if the exotic species is superior in both exploitative and interference competition, exclusion or displacement of white-tailed deer is likely to occur (Amarasekare 2002). For exotics and white-tailed deer to co-exist in an area, one of two scenarios must exist: 1) the exotic species may be superior in interference competition, while the white-tailed deer is superior in exploitative competition or 2) the two species use different resources within the same habitat (Carothers and Jakšić 1984, Ziv et al. 1993). The latter possibly seems unlikely for white-tailed deer and axis deer.

Since the time of their original introduction into high-fenced enclosures, many exotics have escaped or been released and free ranging populations have continued to increase (Butts 1979, Demarais et al. 1998, Mungall and Sheffield 1998). With these increasing numbers of exotics, there is an increased need to determine negative effects on white-tailed deer. Because exotics in Texas are regulated as livestock and not game animals, there has been little done in an attempt to control numbers of animals outside of the managed herds within game ranches (Mungall and Sheffield 1998). With the largest concentration of exotics being in those areas of the state with the highest densities of white-tailed deer, the possibility of negative interactions is compounded by the increased forage demands on the habitats (McGhee and Baccus 2006).

Herein I tested if the presence of axis deer affects the habitat selection of white-tailed deer by comparing the habitat selection of white-tailed deer in an areas where axis deer were present and then after axis deer were removed (temporal control) and in another area where

only white-tailed deer were present (spatial control). I wanted to assess if axis deer and white-tailed deer could coexist via each species being superior in a different form of competition. Axis deer are larger in body size and should therefore be superior in interference competition. If axis deer were superior at interference competition then I expected 3 conditions to be met. 1) After the removal of axis deer, there should be a shift in the habitat selection of white-tailed deer. If axis deer were superior at interference competition, they would likely displace white-tailed deer from their preferred habitat thus producing a shift in their absence (Amarasekare 2002, Carothers and Jaksić 1984, Morse 1974, Stewart et al. 2002). 2) Axis deer should be socially dominant to white-tailed deer. If they are socially dominant, then they would have the ability to displace white-tailed deer (Amarasekare 2002, Carothers and Jaksić 1984). 3) At stations with a highly desired food source, each species alone (i.e. only axis deer or only white-tailed deer) should occur more frequently than both species together. If both species occurred together more frequently than each species alone, it was unlikely that a displacement would have taken place. If each species was present more frequently at the food source alone, it would suggest that they are partitioning the resource over time and one may be avoiding the other (Bartos et al. 2002, Carothers and Jaksić 1984, Case and Gilpin 1974). Conversely, if white-tailed deer were superior at exploitative competition, 3 conditions should be met. 1) After the removal of axis deer, there should be no change in habitat selection of white-tailed deer. This would suggest that white-tailed deer use the habitat and its resources the same regardless of the presence of axis deer (Amarasekare 2002, Carothers and Jaksić 1984, Morse 1974, Stewart et al. 2002). 2) Axis deer should be socially dominant to white-tailed deer. If white-tailed deer are the subordinate species, it is likely that they have to use the resource first or more efficiently than axis deer. This would allow them to obtain the benefits from the resource before the axis deer were able to interfere (Carothers and Jaksić 1984, Case and Gilpin 1974, Ziv et al.

1993). 3) At stations with a highly desired food source, white-tailed deer should occur more frequently than axis deer. If white-tailed deer are better suited to exploit the resources, I expected them to be at that food source more often (Case and Gilpin 1974, Ziv et al. 1993).

CHAPTER II

STUDY AREA AND DESIGN

I conducted this study on the Flying A Ranch, Bandera County, Texas. The ranch is approximately 3763 ha of non-contiguous land dispersed over 68 km². Temperatures range from a low of 2.2° C in January to a high of 35° C in July, with an average annual precipitation of 73.6 cm (NOAA 2007). Vegetation varies largely due to soil type and its depth and past management practices. Primary habitat types are live oak (*Quercus virginiana*) - ashe juniper (*Juniperus ashei*) woodlands, post oak (*Quercus stellata*) - elm (*Ulmus spp.*) woodlands with mixed hardwoods, and open grasslands. These grasslands are dominated by little bluestem (*Schizachyrium scoparium*), king ranch bluestem (*Bothriochloa ischaemum*), threeawns (*Aristida spp.*), gramas (*Bouteloua spp.*) and Texas wintergrass (*Nasella leucotricha*). Soils types include clay, clay loam, and silty clay. Predator control for coyotes (*Canis latrans*) is continually conducted on the ranch. Along with shooting predators when they are seen during the day, ranch employees use snares set at travel corridors on fences to remove as many possible.

A treatment area and control area were studied in two survey seasons. In the treatment area, axis and white-tailed deer were present in survey season one, but axis deer were removed prior to survey season two. This allowed me to assess any possible changes in white-tailed deer habitat use due to axis deer. Conducting surveys in both study areas, over two survey periods, provided both spatial and temporal controls (White and Garrot 1990).

Including spatial and temporal controls reduced possibilities that environmental differences between survey seasons or possible peculiarities of the treatment area influenced conclusions (White and Garrott 1990).

Treatment Area

The treatment area was approximately 130 ha and was enclosed by a 2.4 m high fence in 2001 that was a complete barrier to deer movement. Approximately 10 axis deer were trapped in the area when the fence was constructed and 15 more were added shortly after completion. The white-tailed deer found within the area were either part of the initial herd that was trapped when the fence was erected or offspring of that herd. No white-tailed deer were introduced to the area after its enclosure. During the 6 year period from fence construction to the conclusion of this study, both species were hunted through a commercial hunting operation conducted on the entire ranch.

Control Area

The control area was 360 ha of a 2023 ha pasture located 6 km south of the treatment area. The larger pasture was enclosed in a 2.4 m high fence (also a complete barrier to deer movement) that was erected immediately after the treatment area fence in 2001. The area selected as the control was not fully enclosed in game-proof fence, however it did have fencing on the north and east sides. This area was selected because of similarities to the treatment area in habitat type and topography. White-tailed deer found within the area were either part of the initial herd that was trapped when the fence was erected or offspring of that herd. Because axis deer were not present in this area, it served as an adequate representation of white-tailed deer in their native habitat. As with the treatment area, white-tailed deer in the control area were hunted through a commercial hunting operation.

CHAPTER III

METHODS

Spatial Data

Spatial data were collected over two survey seasons: July – December 2006 and 2007. In each survey season vehicle surveys were conducted on both the treatment and control areas to obtain spatial locations of white-tailed deer. Prior to the beginning of data collection, survey routes were established in both treatment and control areas for measuring habitat use of both species. These routes were selected to maximize the amount of area surveyed while minimizing the risk of double counting animals (Fig. 1). Once survey routes were established, 150 m diameter (1.77 ha) circular detection plots were designated: 21 in the treatment area and 33 in the control area. The center of these plots were set approximately 200 m apart along the entire survey route and were identified by florescent surveyors tape. Detections of animals in these plots were used to calculate detection probabilities as described later.

Each survey route was driven in the morning and evening, one day a week. Morning surveys began approximately 30 minutes before sunrise and evening surveys began 90 minutes before sunset so that surveys could be completed before dark. Each week, the order and direction in which the routes were driven were rotated so that a given area was not observed at the same time of day. Surveys were driven at 17 k/hr or less (Sanders 1963). When an animal was detected, the UTM (Universal Transverse Mercator)

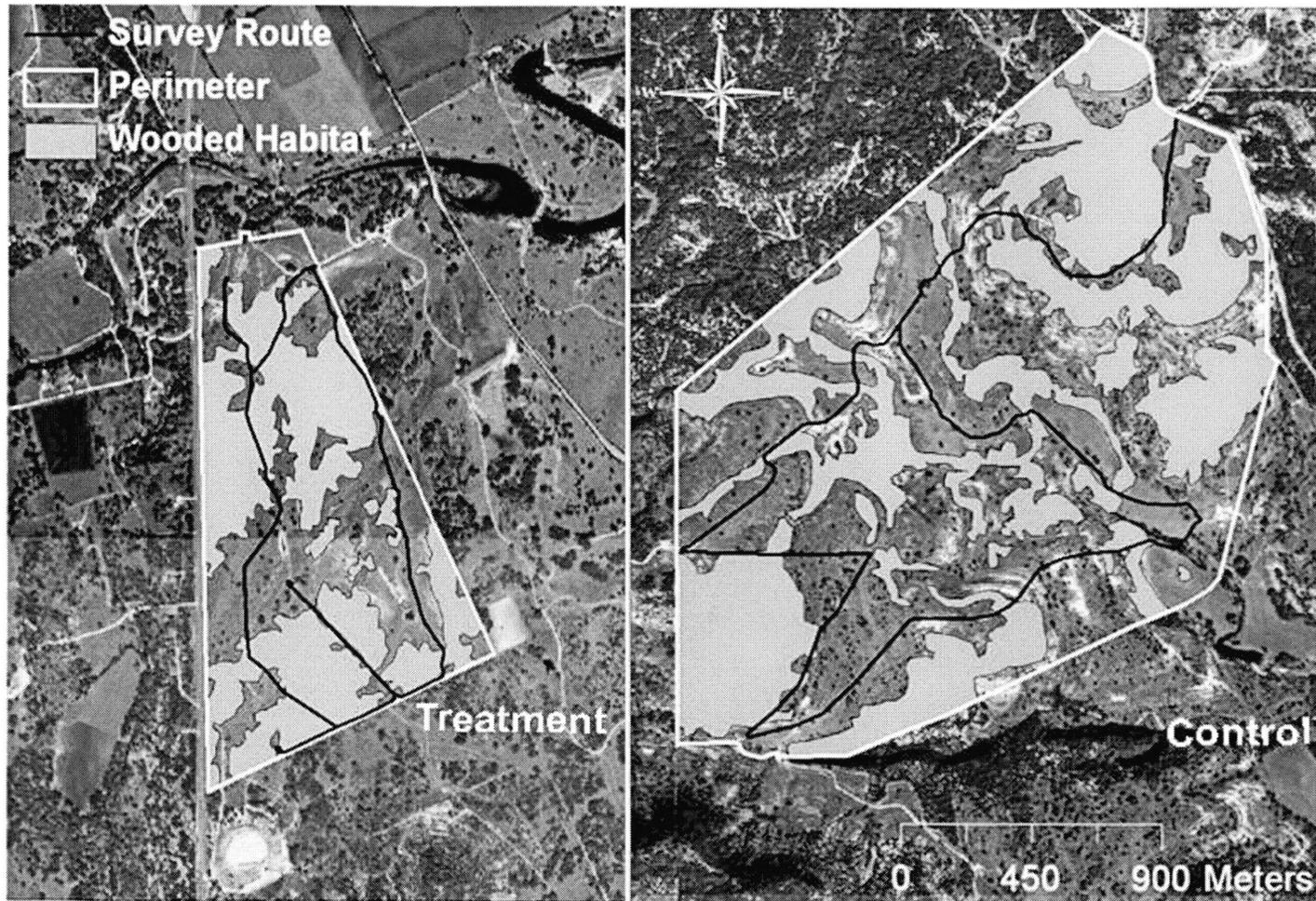


Figure 1. Map of treatment and control areas with survey routes in Bandera County, Texas, USA. Wooded habitat is represented by the shaded portions of the map.

coordinates of my location as well as a distance and compass bearing to the animal were recorded. This information was used to determine the animal's actual location (UTM coordinates). Using a GPS unit (Garmin™ eTrex Legend®) and visual observations, it was also determined whether or not the animal was located within any of the detection plots. Time of day, number of animals, species, sex and age class (juvenile { ≤ 1 year old}, adult) were also recorded.

Because it was unrealistic to assume that all animals were counted when conducting surveys, the probability of detecting an animal when in fact it was present was estimated to obtain unbiased estimates (MacKenzie et al. 2006). Occupancy models were used to calculate this detection probability using program PRESENCE (Longoria and Weckerly 2007, MacKenzie et al. 2002, MacKenzie 2005). One critical assumption of occupancy modeling was constant residence status; animals were present or not present in individual detection plots throughout an entire survey season (MacKenzie 2005). Since detection plots were smaller than the daily movements of axis and white-tailed deer, this assumption was violated. To meet this assumption, data were pooled into one-month intervals to allow time for animal movement in and out of detection plots (Kendall 1999, Longoria and Weckerly 2007). These pooled data were used for calculating the detection probability. The distance between detection plots was probably insufficient to insure that the assumption of independence was met for occupancy estimators (MacKenzie et al. 2006). Violation of independence results in inflated variances of estimates but the estimates are probably unbiased (Draper and Smith 1998). Because I used estimates of detection, procedures to correct for inflated variances were not needed.

White-tailed deer data were evaluated using 5 models. In each model, occupancy was constant. Detection probabilities (\hat{p}) were modeled as influenced by diel, habitat, season, area (treatment, control), or no covariate. Axis deer data were evaluated using 3 models where

again, occupancy was constant. Detection probability was modeled as influenced by diel, habitat, season, or no covariate. Diel was either morning or evening and season was either survey season one or two. Habitat was classified as wooded or open, with wooded habitat having at least 50% closed canopy, and site was either control area or treatment area. Models were selected based on Akaike Information Criterion corrected for small sample size (AIC_c), Akaike weights, and numbers of parameters estimated (Burnham and Anderson 2002).

Detection probabilities were used to correct data to obtain unbiased estimates of animals present (Lancia et al. 2000). To calculate this correction, I used the formula $N = C/p$, where N is the corrected count, C is the raw count and p is the detection probability (Lancia et al. 2000). If the number of animals in the corrected count, for any given day, exceeded the presumed population size, then the number of animals in the raw counts for that day were adjusted to not exceed the presumed population size. Population size was estimated by dividing the mean number of animals seen throughout the survey season by the detection probability (Lancia et al. 2000). These corrected data were used to determine habitat use.

Orthophotos (georeferenced aerial photographs) were obtained from Texas Natural Resource Information Systems (www.tnris.state.tx.us) and uploaded for analysis using ArcGIS® 9.1 by ESRI®. Habitat was classified as wooded or open. Using the orthophotos, I digitized the wooded habitat in each study area. To obtain an accurate percentage of wooded habitat, ground truthing was done based on a thorough knowledge of the study area. The digitized wooded habitat was clipped with a 150 m buffer on each side of the survey route to obtain the percent of wooded habitat on that route. This distance was chosen because it represented the furthest distance that animals could be detected during surveys. The area within the buffer was considered to be the actual portion of the study areas that were surveyed. Corrected data were then entered into ArcGIS as individual detections. The number of detections in both wooded and open habitats in each season was calculated to

determine the percentage of white-tailed deer using wooded habitat. After calculating the 95% confidence interval for this percentage, I compared it to the percent of wooded habitat on the survey route to assess white-tailed deer habitat selection; was the population using wooded habitat greater-than or less-than its availability in each survey season. If the upper or lower bounds of the confidence interval overlapped the actual percentage of wooded habitat in the area, it was concluded that white-tailed deer used the habitat consistent with its availability (Sokal and Rohlf 1995). Ninety-five percent confidence intervals were also calculated for the difference between the percentage of wooded habitat used in survey seasons one and two. This allowed me to determine if there were changes in habitat use by white-tailed deer with axis deer present and removed. If the confidence interval of the difference overlapped zero then there was no change in habitat use by white-tailed deer throughout the study (Sokal and Rohlf 1995). I expressed 95% confidence intervals as the estimate \pm one-half the confidence interval. This process was conducted for both treatment and control areas to assess differences in habitat use patterns in the two areas over the two survey seasons.

Behavioral Data

Since axis deer were present only during the first survey season, behavioral data were only collected during that time. Observations were recorded twice a day, one day a week from July-December 2006. Two deer blinds that were placed when the area was enclosed with the 2.4 m high fence were used for observations. Blinds were approximately 0.7 km apart. Each week I switched blinds. Morning observations took place for 2 hours starting approximately 0.5 hours before sunrise, and evening observations took place for 2 hours starting approximately 1.5 hours before sunset. These times were chosen to allow observations during the hours when deer are most active (Halls 1984). Each blind had a corn

feeder located within 100 m. Whole shelled corn is a desired food source because it is rapidly fermented by deer (Wheaton and Brown 1983). These feeders were set to feed each day during the times when observations were taking place and dispersed approximately 2.3 kg of corn in a 14 m diameter area. By baiting the deer to the area, there was greater potential to observe interspecific interactions for a highly desired food for an extended period of time. It is assumed that social interactions observed at artificial feeding sites are similar to those found under natural conditions (McGhee and Baccus 2006). When an animal was first observed, the time of day, number of animals, species, sex and age class (juvenile $\{\leq 1$ year old $\}$, adult) were recorded. Observations were made using 10x42 binoculars. When both axis and white-tailed deer were present at a feeder at the same time, any aggressive behavior resulting in a displacement of one species by another was recorded. Displacement was categorized as complete and incomplete (Weckerly 1999). Behavior resulting in one animal leaving the area was considered complete displacement and incomplete displacement was classified as one animal moving away from another but not leaving the area with feed. Only those times when both axis deer and white-tailed deer were present at the feeder were used for the displacement analysis since I was not concerned with intraspecific interactions. The rate of displacement was calculated as the number of displacements per animal per minute. For example, if 5 white-tailed deer were at a feeder with axis deer for 10 minutes and 2 displacements took place; the rate of displacement would be 0.04 displacements/animal/min.

Due to the non-normal distribution of the data, a randomization test was used to determine if axis deer displaced white-tailed deer to a greater extent than white-tailed deer displaced axis deer (Manly 1997). Because I predicted that most of the displacements were by axis deer, a one-tailed randomization test for paired data was conducted (Manly 1997). These randomization tests were conducted for both complete and incomplete displacements and when both displacements were pooled. Number of permutations conducted was 10,000.

The test statistic (t_s) for the randomization test was the sum of the difference between the rate of displacement of white-tailed deer and axis deer for each sampling occasion.

The length of time axis deer and white-tailed deer were at feeders alone and together was also evaluated. Time was recorded when at least one animal from either species was present. For this analysis the number of animals present was not included. Data were divided into morning and evening observations and the mean amount of time for each species alone and together was calculated. A likelihood ratio test was conducted to determine if variances differed between species composition (axis deer only, white-tailed deer only, and axis and white-tailed deer together) and across diel period (morning, evening, Sokal and Rohlf 1995). If variances were significantly different, I conducted a linear contrast in a restricted maximum likelihood ANOVA that accounted for heteroscedasticity to determine if the amount of time species spent alone at feeders differed from the amount of time both species were present together (Pinheiro and Bates 2000, Sokal and Rohlf 1995). The restricted maximum likelihood ANOVA was chosen because a standard ANOVA does not account for differences in variance (Pinheiro and Bates 2000, Sokal and Rohlf 1995).

To determine if the two species spent different amounts of time at feeders I multiplied the number of minutes a species was present at the feeder by the number of animals of that species to obtain deer-minutes. I again used a likelihood ratio test to determine if variances differed among combinations of species and diel period. If variances differed I conducted a restricted maximum likelihood ANOVA that accounted for heteroscedasticity to determine if there were differences in the amount of deer-minutes each species spent at the feeders in morning and evening. Hedeker and Gibbons (2006) suggested that likelihood ratio tests lack power and therefore recommended to increase the power of the test the P-value should be divided by two.

Axis Deer Removal

Removal of axis deer began immediately after the conclusion of the first data collection period. The first technique used for removal was a large capture facility or catch pen, a 2.4-m high fencing formed a funnel and lane leading up to the facility for capturing the animals. A field planted in oats (*Avena sativa*), wheat (*Triticum aestivum*), and triticale (*Triticale hexaploide*) was used to bait deer to the fenced area. Shelled corn was also scattered on the ground one week prior to capture in an attempt to lure the deer to the area. Once deer were observed within the fenced area, a gate was closed and the deer were pushed to a fully enclosed building for sorting. After two captures (26 January and 30 January 2007) the bait area was closed. A drop net was set up according to Rongstad and McCabe (1984) and was baited with corn one week prior to capture. The drop net was released on a group of axis deer on 27 February 2007 then removed. On 2 March, a helicopter capture team flew the area, captured axis deer with net guns (see Webb et al. 2008), and removed as many deer as possible. Remaining deer were harvested with rifles either by sitting in hunting blinds over bait or out of a vehicle at night using artificial light. Since axis deer are not regulated by Texas Parks and Wildlife Department, any legal means may be use to harvest them (Texas Parks and Wildlife Department 2007).

CHAPTER IV

RESULTS

Habitat Use

I conducted 50 total surveys (morning and evening) in both the treatment and control areas during both survey seasons. I tallied 261 (per survey: $\bar{x} = 5.22$, $s = 6.29$) axis deer and 108 ($\bar{x} = 2.16$, $s = 3.03$) white-tailed deer in the treatment area during the first survey season. In the second survey season 44 ($\bar{x} = 0.88$, $s = 1.49$) white-tailed deer were observed in the treatment area. In the control area, the number of white-tailed deer counted was 53 ($\bar{x} = 1.06$, $s = 1.61$) and 129 ($\bar{x} = 2.58$, $s = 2.86$) for the first and second survey seasons respectively. In the treatment area, 26 axis deer were located within 67% of the detection plots. Also in the treatment area, during the first survey season, 39% of the detection plots were occupied by 9 white-tailed deer in the mornings and 12 in the evenings. During the second survey season, 60% of the detection plots in the treatment area were occupied by 5 white-tailed deer in the mornings and 15 in the evenings. In the control area, I counted 4 white-tailed deer in mornings and 13 in the evenings in 62% of the detection plots during the first survey season. In the second survey season, 48% of the detection plots were occupied by 15 white-tailed deer in the mornings and 17 in the evenings.

Between survey seasons, a total of 50 axis deer were removed from the treatment area; 25 were removed using the catch pen, 3 were caught with the drop net, and 9 by the helicopter crew. Approximately 70 man-hours were spent in blinds and spotlighting at night resulting in the harvest of 10 axis deer. During the first 2 weeks of surveys, 4 axis does were

seen on the survey route. After this initial observation 3 axis does were harvested within the first two month of surveys in the second survey season. I am reasonably confident that only one axis deer remained in the treatment area.

The null model was selected for Axis deer to estimate detection probability (Table 1). The detection probability was estimated from the null model as $\hat{p} = 0.123$. The minimum population size of axis deer based on the number of axis deer removed was 51. The estimated minimum population size calculated from the product of the mean of survey counts and detection probability was similar in comparison ($5.17/0.123 = 42$). The agreement in the two estimates of population size indicates that detection probabilities were not strongly biased.

TABLE 1. Summary of the model selection for determining the detection probability of white-tailed deer and axis deer. The models that were selected are enclosed in boxes. The symbol ψ represents occupancy and p represents detection probability. Detection probabilities were modeled as influenced by diel period (diel), open or wooded habitat (hab), treatment or control area (site), survey season (yr) and as not influenced by outside factors (.). Model selection was based on Akaike information criterion coefficients (AIC_c), Akaike weights (w), number of parameters (nPar), and two times the negative log likelihood (-2LogLike).

White-tailed deer				
Model	AIC_c	w	nPar	-2LogLike
$\psi(\cdot), p(\cdot)$	631.30	0.33	2	627.06
$\psi(\cdot), p(\text{diel})$	631.69	0.30	3	625.21
$\psi(\cdot), p(\text{hab})$	632.80	0.17	3	626.32
$\psi(\cdot), p(\text{site})$	633.13	0.15	3	626.65
$\psi(\cdot), p(\text{yr})$	635.15	0.05	3	628.67
Axis deer				
$\psi(\cdot), p(\cdot)$	171.15	0.51	2	166.48
$\psi(\cdot), p(\text{diel})$	173.72	0.20	3	166.31
$\psi(\cdot), p(\text{hab})$	173.74	0.20	3	166.33

The null model was also selected for white-tailed deer (Table 1). From this model, I obtained a detection probability estimate of $\hat{p} = 0.0693$. From the detection probability and mean of survey counts, estimated population sizes were 21 white-tailed deer in the treatment area and 26 in the control area.

The treatment area was 53.85 % wooded habitat. White-tailed deer used wooded habitat 34.6 ± 4.2 % during the first survey season, and 79.7 ± 4.5 % during the second survey season (Fig. 2). The difference between proportional habitat use in the two survey seasons was -44.8 ± 4.5 %. In survey season one white-tailed deer used wooded habitat less than its availability and in survey season two they used wooded habitat greater than its availability. Axis deer used wooded habitat 30.4 ± 2.6 % of the time in the first survey season which was less than its availability.

The control area consisted of 34.31 % wooded habitat. White-tailed deer used wooded habitat 23.1 ± 3.6 % and 25.1 ± 3.1 % during survey seasons one and two respectively (Fig. 2). There was no difference in habitat use between the two survey seasons (-2 ± 4.8 %). During both seasons white-tailed deer used wooded habitat less than its availability.

Displacements and Time Spent at Feeder

I spent a total of 48 hours during 29 occasions observing feeders. On 19 occasions white-tailed deer or axis deer, but not both species, were observed (65.5 %). Only during 8 occasions were both white-tailed deer and axis deer present at a feeder at the same time. During these sampling occasions, axis deer completely displaced white-tailed deer 17 times resulting in a mean rate of displacement of 0.140 ($s = 0.123$). A complete displacement of axis deer by white-tailed deer was not observed. Incomplete displacements of white-tailed deer by axis deer were observed 22 times (mean rate of displacement = 0.086, $s = 0.046$)

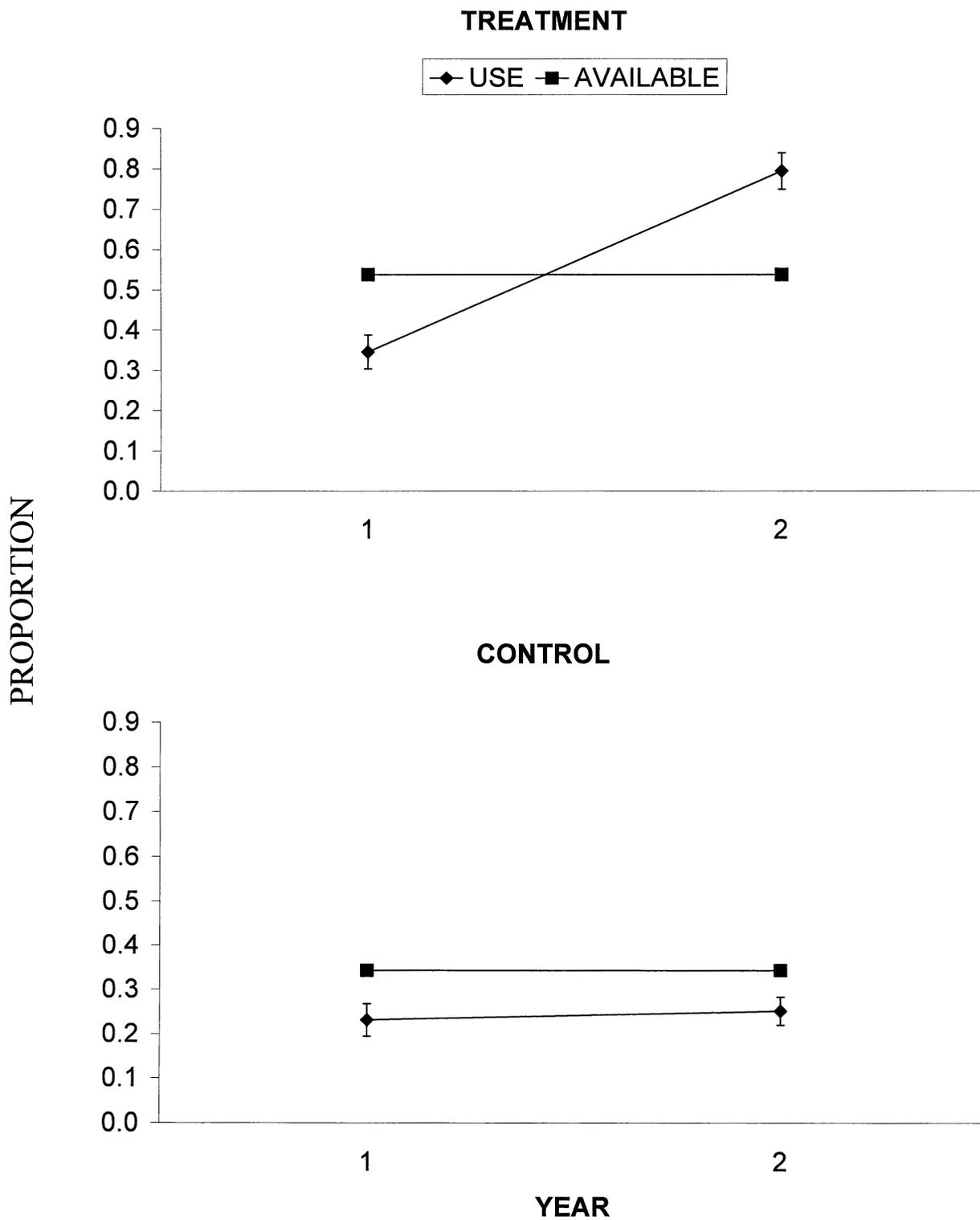


Figure 2. Proportion of wooded habitat used in survey seasons one and two by white-tailed deer in the treatment and control areas compared to the amount of wooded habitat available. Error bars represent 95 % confidence intervals.

and incomplete displacements of axis deer by white-tailed deer were observed 2 times (mean rate of displacement = 0.002, $s = 0.002$). When both types of displacements were pooled, the mean rate of displacement for axis deer displacing white-tailed deer was 0.226 ($s = 0.119$) and white-tailed deer displacing axis deer was 0.002 ($s = 0.002$). Axis deer displaced white-tailed deer to a greater degree than white-tailed deer displaced axis deer for all displacement types (complete: $t_s = 1.123$, $P < 0.001$; incomplete: $t_s = 0.666$, $P = 0.005$; combined: $t_s = 1.789$, $P = 0.0002$).

During all occasions when at least one animal of either species was present, white-tailed deer were observed at feeders alone 300 minutes ($\bar{x} = 15.79$, $s = 3.74$), axis deer were observed alone 213 minutes ($\bar{x} = 11.21$, $s = 3.85$), and both species were observed together 100 minutes ($\bar{x} = 5.26$, $s = 1.85$). Variance of each species composition in each diel period differed ($X_5^2 = 29.89$, $P < 0.0001$), therefore I conducted the maximum likelihood ANOVA. There was no interaction between diel period and species composition ($t_{51} = -0.209$, $P = 0.8353$). The amount of time that axis and white-tailed deer spent at feeders alone was longer than when both axis and white-tailed deer were present together ($t_{51} = -1.89$, $P = 0.0644$). When at least one animal of either species was present at a feeder, 1542 deer minutes were recorded for white-tailed ($\bar{x} = 81.16$, $s = 22.71$), and 1194 for axis deer ($\bar{x} = 62.84$, $s = 22.24$). There were significant differences between variances in each diel period and species ($X_3^2 = 6.178$, $P = 0.051$) so the maximum likelihood ANOVA was used again. No interaction was present between diel period and species ($t_{34} = -1.47$, $P = 0.151$), and the number of deer-minutes white-tailed deer spent at feeders was not significantly different from the number of deer minutes axis deer spent at feeders ($t_{34} = 1.58$, $P = 0.124$).

CHAPTER V

DISCUSSION

The goal of my research was to explore the possibility of coexistence between exotic axis deer and native white-tailed deer by determining if the presence of axis deer affected habitat use by white-tailed deer. This was done to provide wildlife managers a better understanding of how axis deer in Texas can affect native white-tailed deer. Because axis deer have fundamental niches that overlap with white-tailed deer this will be a persistent issue (McGhee and Baccus 2006). By comparing habitat use by white-tailed deer in the presence and absence of axis deer to a control area with similar habitat types but no axis deer, an accurate conclusion about effects of axis deer on habitat selection by white-tailed deer should be possible. The effects of axis deer on white-tailed deer were examined within a framework of competitive coexistence. Interference competition is a pervasive form of competition in interspecific interactions; consequently, if white-tailed deer are to coexist with the larger axis deer that exploit a greater variety of food types, white-tailed deer should be superior at exploitative competition (Carothers and Jaksić 1984, Ziv et al. 1993).

My study suggested that axis deer were superior at interference competition. First, I found that white-tailed deer shifted habitat use 45% in the absence of axis deer whereas white-tailed deer habitat use in the control area was virtually constant over the same time span. Second, the data from behavioral interactions clearly indicated that axis deer were socially dominant over white-tailed deer. I observed both male and female axis deer displacing male and female white-tailed deer. When both complete and incomplete

displacements were pooled, at least one displacement of white-tailed deer by axis deer took place during every observation. In the two recorded observations of axis deer displacement by white-tailed deer, two male white-tailed deer made an aggressive advance towards two female axis deer moving them to a different location to feed. The rate of displacement of axis deer by white-tailed deer was never greater than the displacement of white-tailed deer by axis deer. Third, at stations with highly desired food, each species occurred singly more frequently than both species together. This supports interference competition by axis deer toward white-tailed deer because the subordinate species should avoid areas that are used by the dominant species or change the time that they use the resource to avoid interactions with the dominant species. Case and Gilpin (1974) and Carothers and Jaksić (1984) suggest that temporal partitioning between species may be one of the most recognizable symptoms of interspecific competition.

My study also suggests that the two species will not coexist because white-tailed deer are not superior at exploitative competition. Of the three conditions that should be met for white-tailed deer to be superior at exploitative competition, the two critical conditions were falsified. Habitat use by white-tailed deer should not change in the presence or absence of axis deer and white-tailed deer should have occurred more frequently at stations with a highly desired food source. If white-tailed deer had spent a greater amount of time at feeders than axis deer, I would have expected white-tailed deer to be able to consume corn before axis deer or in a more efficient way. Extending this finding to habitat use, white-tailed deer habitat use should be similar in the presence and absence of axis deer because foraging time in habitat is unaltered.

To further refute the hypothesis that white-tailed deer are superior at exploitative competition, axis deer have a slight advantage over white-tailed deer in that they are capable of utilizing three forage classes, grasses, forbs, and browse (Ables 1977, Geist 1998, Henke

et al. 1988, Mungall and Sheffield 1994, Putman 1988, Traweek and Welch 1992) while white-tailed deer are capable only of exploiting two forage types (forbs and browse). Food habit studies of axis deer have varied according to the location in which the study was conducted. While some have suggested the primary food choice of the axis deer is grass, others have suggested that as much as half of their diet may consist of forbs and browse (Ables 1977, Geist 1998, Henke et al. 1988, Mungall and Sheffield 1994, Putman 1988). The important conclusion is that axis deer are capable of using the same resources as white-tailed deer.

Because white-tailed deer were not superior at exploitative competition, coexistence is unlikely to occur between white-tailed deer and axis deer (Amarasekare 2002, Stewart et al. 2002). Axis deer can interfere with resource selection of white-tailed deer and potentially exploit resources before white-tailed deer.

Although, I have suggested that co-existence is unlikely, exploitative competition may not be as influential if densities of axis and deer white-tailed deer are kept low and habitat quality is high. The use of common resources manifests itself most when densities of animals are high and resources are limited (Stewart et al. 2002). When densities are low, there is greater potential for habitat partitioning, less interspecific competition, and fewer aggressive interactions which should promote coexistence or niche partitioning to occur. When designing this study, I thought that densities of white-tailed deer and axis deer were approximately equal. However, I found that there were approximately twice as many axis deer as there were white-tailed deer within the treatment area. This difference in abundance between the species possibly allowed axis deer to both interfere with and exploit resources before white-tailed deer (Amarasekare 2002, Stewart et al. 2002). If the densities of white-tailed deer and axis deer had been similar (25 animals of each species) or white-tailed deer were twice as abundant as axis deer (50 white-tailed deer, 25 axis deer) in the treatment area,

I think that axis deer would still be superior at interference competition, but white-tailed deer would be able to compete more strongly for available resources. Niche partitioning may have taken place to a greater degree, but over time, owing to interference from axis deer, white-tailed deer population sizes would decrease and axis deer would become more abundant.

This study is one of the first to show habitat displacement of a native large mammal by an exotic large mammal using both spatial and temporal controls (Bartos et al. 2002, Berger 1985, Stewart et al. 2002). Previous studies have had one type of control (usually spatial), but not both. Having both spatial and temporal controls was important because it allowed me to assess whether factors such as climatic changes or slight differences in habitats in the treatment and control areas affected results. For instance the first survey season was a slightly below average year for precipitation with only 61 cm recorded (NOAA 2006), however the second survey season received over 2.5 times that amount (NOAA 2007). If the dramatic difference in habitat use by white-tailed deer in the treatment area could have been attributed to this difference in precipitation, a change in the habitat use by white-tailed deer in the control area should have occurred.

Although it was apparent that white-tailed deer shifted their habitat use because of axis deer, the underlying cause is unknown. The most likely conclusion was that axis deer displaced white-tailed deer from their preferred habitat either by direct aggressive behavior resulting in interference competition, or by increasing the total deer density in wooded habitats to the point that white-tailed deer sought food in less preferred habitats. My results suggest that interference competition took place; therefore displacement by aggressive behaviors is most likely. Furthermore, given that axis deer are capable of consuming forbs and browse, their removal would decrease the foraging pressure in wooded areas allowing white-tailed deer to use this habitat to a greater degree. Both of these ideas are based on the

assumption that white-tailed deer prefer and select wooded habitat. However, this was not apparent in the control area where white-tailed deer used wooded habitat less than its availability.

The difference in habitat selection of white-tailed deer between treatment and control areas may have been due to two possibilities. One, there could have been subtle differences in characteristics of habitat in the two areas (Fig. 1). For example, in the control area open habitat was characterized by more trees and shrubs scattered in the grassland and more broken terrain. More screening cover could have resulted in the deer spending greater amounts of foraging time away from the escape cover of the wooded habitat. Two, the densities of white-tailed deer probably differed by at least a factor of two between treatment ($21 \text{ deer}/130 \text{ ha} = 0.16$) and control ($25/360 = 0.07$) areas. Most likely, habitat selection by deer is density dependent (Morris 1987). The differing densities probably influenced habitat selection differently in the treatment and control areas.

The primary concern in the state of Texas is free-ranging axis deer. Currently, there are fewer free-ranging axis deer than white-tailed deer so negative affects likely are minimal. However, due to their superiority at interference competition and a lack of large scale population control, it is likely that axis deer densities will continue to increase. As their densities increase, local populations of white-tailed deer will be displaced from higher quality to lesser quality habitats. If this displacement occurs, white-tailed deer densities are likely to decrease, thus compounding the effects of the interspecific competition. Although these displacements may begin at relatively small, local scales, the combined effect may result in large scale displacements of white-tailed deer across the range of axis deer in Texas. In an effort to manage these free-ranging axis populations, an attempt should be made to obtain more accurate population estimates. Due to their current numbers, it is unlikely that they will ever be extirpated from the state. However, steps need to be taken to control population sizes

before they reach levels that result in negative, possibly irreversible, effects on native white-tailed deer populations.

LITERATURE CITED

- Ables, E. 1977. The Axis Deer in Texas. The Caesar Kleberg Research Program in Wildlife Ecology. Texas A&M Press. College Station, Texas, USA.
- Amarasekare, P. 2002. Interference competition and species coexistence. *Proceedings of the Royal Society* 269:2541-2550.
- Bartos, L., D. Vankova, K. V. Miller, and K. V. Miller. 2002. Interspecific competition between white-tailed, fallow, red, and roe deer. *Journal of Wildlife Management* 66:522-527.
- Berger, J. 1985. Interspecific interactions and dominance among wild great basin ungulates. *Journal of Mammalogy* 66:571-573.
- Brian, M. V. 1956. Exploitation and interference competition. *The Journal of Animal Ecology* 25:339-347.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second Edition. Springer Verlag, New York, New York, USA.
- Butts, G. L. 1979. The status of exotic big game in Texas. *Rangelands* 1:152-153.
- Carothers, J. H., and F. M. Jaksić. 1984. Time as a niche difference: the role of interference competition. *Oikos* 42:403-406.
- Case, T. J., and M. E. Gilpin. 1974. Interference competition and niche theory. *Proceedings of the National Academy of Sciences of the United States of America* 71:3073-3077.
- Demarais, S., J. T. Baccus, and M. S. Traweek Jr. 1998. Non-indigenous ungulates in Texas: long-term population trends and possible competitive mechanisms. *Transaction of the North American Wildlife Natural Resource Conference* 63: 49-55.
- Demarais, S., K. V. Miller, and H. A. Jacobson. 2000. White-tailed deer. Pages 601-628 in Demarais, S. and P. R. Krausman, editor. *Ecology and management of large mammals in North America*. Prentice Hall. Upper Saddle River, New Jersey, USA.

- Draper, N. R., and H. Smith. 1998. Applied regression analysis. Third edition. Wiley – Interscience. New York, New York, USA.
- Flying A Ranch. 2008. Harvest data records: 2003-2007.
- Fulbright, T. E., and J. A. Ortega Sr. 2006. White-tailed deer habitat: Ecology and management on rangelands. Texas A&M University Press, College Station, Texas, USA.
- Gabor, T. M., and E. C. Hellgren. 2000. Variation in peccary populations: landscape composition or competition by an invader? *Ecology*. 81:2509-2524.
- Geist, V. 1998. Deer of the world. Stackpole books. Mechanicsburg, Pennsylvania, USA.
- Halls, L. K. 1984. White-tailed deer: Ecology and Management. Stackpole Books. Harrisburg, PA.
- Hedeker, D. R., and R. D. Gibbons. 2006. Longitudinal data analysis. Wiley-Interscience. Hoboken, New Jersey, USA.
- Henke, S. E., S. Demarais, and J. A. Pfister. 1988. Digestive capacity and diets of white-tailed deer and exotic ruminants. *Journal of Wildlife Management* 52:595-598.
- Kendall, W. L. 1999. Robustness of closed capture-recapture methods to violations of the closure assumption. *Ecology* 80:2517-2525.
- Lancia, R. A., C. S. Rosenberry, and M. C. Conner. 2000. Population parameters and their estimation. Pages 64-83 in Demarais, S. and P. R. Krausman, editor. Ecology and management of large mammals in North America. Prentice Hall. Upper Saddle River, New Jersey, USA.
- Longoria, M. P., and F. W. Weckerly. 2007. Estimating detection probabilities of collared peccary from sign. *Journal of Wildlife Management* 71:652-655
- Manly, B. F. J. 1997. Randomization, bootstrap and monte carlo methods in biology, Second Edition. Chapman and Hall, London.
- MacKenzie, D. I. 2005. What are the issues with presence-absence data for wildlife managers? *Journal of Wildlife Management* 69:849-860.
- MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83:2248-2255.
- MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling: Inferring patterns and dynamics of species occurrence. Elsevier. Burlington, Massachusetts, USA.

- McCullough, D. R. 1985. Variables influencing white-tailed deer on the George Reserve. *Journal of Mammalogy* 66:682-692.
- McGhee, J. D., and J. T. Baccus. 2006. Behavioral interactions between axis and fallow deer at high-value food patches. *The Southwestern Naturalist* 51: 358-367.
- Morris, D. W. 1987. Tests of density-dependent habitat selection in a patchy environment. *Ecological Monographs* 57:270-281.
- Morse, D. H. 1974. Niche breadth as a function of social dominance. *The American Naturalist* 108:818-830.
- Mungall, E. C., and W. J. Sheffield. 1994. *Exotics on the range: The Texas example*. Texas A&M University Press. College Station, Texas, USA.
- National Oceanic and Atmospheric Administration (NOAA). 2006. Climatological data annual summary, Texas. U.S. Department of Commerce, Report No. ISSN 0364-6041. 111:13.
- National Oceanic and Atmospheric Administration (NOAA). 2007. Climatological data annual summary, Texas. U.S. Department of Commerce, Report No. ISSN 0364-6041. 112:13.
- Pinheiro, J. C., and D. M. Bates. 2000. *Mixed – effects models in S and S-Plus*. Springer – Verlag. New York, New York, USA.
- Putman, R. 1988. *The natural history of deer*. Cornell University Press. Ithaca, New York, USA.
- Rongstad, O. J., and R. A. McCabe. 1984. Capture techniques. Pages 655-676 in L. K. Halls, editor. *White-tailed deer ecology and management*. Stackpole Books, Harrisburg, Pennsylvania, USA.
- Sanders, C. L. 1963. Habitat preferences of white-tailed deer and several exotic ungulates in South Texas. *Ecology* 44:803-806.
- Sokal, R. R., and F. J. Rohlf. 1995. *Biometry – Third Edition*. W. H. Freeman and Company. New York, USA.
- Stewart, K. M., R. T. Bowyer, J. G. Kie, N. J. Cimon, and B. K. Johnson. 2002. Temporospatial distributions of elk, mule deer, and cattle: Resource partitioning and competitive displacement. *Journal of Mammalogy* 83:229-244.
- Texas Parks and Wildlife Department. 2007. *2007-2008 Outdoor annual hunting and fishing regulations*. Austin, Texas, USA.

- Texas Parks and Wildlife Department. 2008. The rut in white-tailed deer. <http://www.tpwd.state.tx.us/huntwild/hunt/planning/rut_whitetailed_deer/>. Accessed 29 May 2008.
- Thomas, J. W., J. G. Teer, and E. A. Walker. 1964. Mobility and home range of white-tailed deer on the Edwards Plateau in Texas. *The Journal of Wildlife Management* 22:463-472.
- Traweek, M., and Roy Welch. 1992. Exotics in Texas. Texas Parks and Wildlife Department. Reproduced from PWD-BK-W7000-206.
- Webb, S. L., J. S. Lewis, D. G. Hewitt, M. W. Hellickson, and F. C. Bryant. 2008. Assessing the helicopter and net gun as a capture technique for white-tailed deer. *Journal of Wildlife Management* 72:310-314.
- Weckerly, F. W. 1999. Social bonding and aggression in female Roosevelt elk. *Canadian Journal of Zoology* 77:1379-1384.
- Weckerly, F. W., and M. L. Kennedy. 1992. Estimating hypotheses about feeding strategies of white-tailed deer. *Canadian Journal of Zoology* 70:432-439.
- Wheaton, C., and R. D. Brown. 1983. Feed intake and digestive efficiency of South Texas white-tailed deer. *Journal of Wildlife Management* 47:442-450.
- White, G.C., and R. A. Garrot. 1990. *Analysis of Wildlife Radio-tracking Data*. Academic Press. San Diego, CA, USA.
- Ziv, Y., Z. Abramsky, B. P. Kotler, and A. Subach. 1993. Interference competition and temporal and habitat partitioning in two gerbil species. *Oikos* 66:237-246.

VITA

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