WHITE-TAILED DEER DISTRIBUTION AND MOVEMENT BEHAVIOR IN SOUTH-CENTRAL TEXAS, USA

A Dissertation

by

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ABSTRACT

Providing wildlife managers with reliable population abundance estimates for white-tailed deer (*Odocoileus virginianus*; deer) is challenging and requires proper evaluation of population surveys. My objectives for this study were to compare capture techniques (drop net, single helicopter, and tandem helicopter) and evaluate deer movement in response to infrared-triggered camera (camera) and spotlight survey methods in relation to potential biases associated with each method.

Cost and labor efforts were greater for drop nets than either helicopter method. All techniques were safe and effective methods for deer capture, but results showed tandem helicopter capture was superior for balancing cost-efficiency and safety while minimizing post-capture behavioral impacts.

I used movement data to determine if the presence and absence of bait altered deer distributions. For males, the use of bait detracted from percent canopy coverage, which was significant in determining deer distributions prior to the use of bait. This indicates the use of bait evoked a stronger response from males, violating the assumption of equal detectability during camera surveys. This pro-male bait-bias can ultimately result in an underestimation of female deer.

I conducted spotlight surveys based on road surface type and disturbance level due to traffic volume. More deer per area were encountered on unimproved (trails) and maintained gravel (gravel) roads than on paved roads, suggesting that deer either shied away from paved roads or congregated near trails and gravel roads. It is more likely deer shied away from paved roads due to high traffic levels resulting in density estimates biased low.

Behavioral change attributable to capture technique must be considered when selecting a capture method, and determining the period over which data are biased is critical to wildlife research. I recommend managers either not base harvest quotas on estimates obtained via baited camera surveys or be aware of the potential biases and try to account for underestimates of females and fawns. I also recommend managers either use road types with little traffic disturbance while maximizing visibilities, or incorporate an even distribution of non-overlapping transects for all road types present.

DEDICATION

I dedicate this work to my loving wife. Kristen, thanks for being more than my wife and companion, but also a best friend. You have shown a tremendous amount of patience and provided unconditional love and unwavering support and encouragement.

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First and foremost, I would like to thank God for providing me with the opportunity and ability to work in a field that I'm passionate about and for the countless blessings he has provided in my life.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Professors Roel R. Lopez [advisor], and Nova J. Silvy of the Department of Wildlife and Fisheries Sciences, Professor Rusty A. Feagin of the Department of Ecosystem Science and Management, and Professor David G. Hewitt of the Department of Animal, Rangeland, and Wildlife Sciences of Texas A&M University-Kingsville.

The methods and results pertaining solely to the road traffic monitoring work depicted in Chapter IV were part of a pilot study at Joint Base San Antonio-Camp Bullis. This study was conducted jointly with Department of Wildlife and Fisheries Sciences student Manuel Padilla, and was published in May 2013 in his Master's Thesis titled, "The Use of Remote Cameras to Monitor Traffic Activity".

All other work for the dissertation was completed by the student, under the advisement of Roel R. Lopez [advisor], and Nova J. Silvy of the Department of Wildlife and Fisheries Sciences, Professor Rusty A. Feagin of the Department of Ecosystem Science and Management, Professor David G. Hewitt of the Department of Animal, Rangeland, and Wildlife Sciences of Texas A&M University-Kingsville, and former Natural Resource manager for Joint Base San Antonio-Camp Bullis, Lucas Cooksey. All animal procedures were approved by the Texas A&M University Institutional Animal Care and Use Committee (AUP#: 2011-154).

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CHAPTER I

INTRODUCTION AND OVERVIEW

BACKGROUND

In 1994, the Department of Defense (DoD) adopted ecosystem management guidelines for use in natural resources management on military lands. These guidelines incorporated considerations for wildlife and vegetative communities and encouraged collaboration with other federal, state, and local agencies in facilitating regional approaches to management. Under these guidelines, provisions for hunting and other outdoor recreational opportunities are managed consistent with DoD natural resources management goals.

White-tailed deer (*Odocoileus virginianus*; deer) are considered a keystone species in the United States (Miller et al. 2003). Deer densities have the potential to influence the structure and composition of vegetative communities (Tilghman 1989, Rossell et al. 2005). Most notably, elevated deer density and chronic overbrowsing can limit the availability of food and cover for many other wildlife species (Casey and Hein 1983, de Calesta 1994) and impact both faunal and floral species diversity (Anderson and Katz 1993, Rossell et al. 2005, Webster et al. 2005, Rossell et al. 2007). This not only affects other wildlife species, but also negatively affects the overall health of the deer population (Johnson et al. 1996).

Deer are the most popular game animal in the United States. Time and money spent on deer hunting exceeds that from all other game species combined (U.S. Fish and

Wildlife Service 2011). Some military installations maintain active hunting programs to provide recreational opportunities for military personnel and their families, and as a way of managing deer populations. Joint Base San Antonio (JBSA)-Camp Bullis military installation is the only military installation within Bexar County, Texas with an active deer program which includes annual deer surveys to assist in setting harvest restrictions. Thus, to maintain its hunting program, Camp Bullis Natural Resource staff needs reliable deer population estimates to meet the management goals and objectives in the JBSA-Integrated Natural Resource Management Plan and establish annual harvest quotas. Therefore, the evaluation of current survey methods and biases in estimating deer densities is a priority management concern for Camp Bullis to ensure healthy and sustainable deer populations while maximizing recreational opportunity. Additionally, survey methods whose assumptions have been evaluated and that produce estimates with low bias and high precision are most useful for managers (White et al. 1982, Diefenbach 2005, Mills 2007, Storm et al. 2011). However, providing reliable deer population estimates is a challenge for wildlife managers (Beaver et al. 2014). Budgetary, logistical, and time constraints often limit the available options.

Deer are difficult to monitor, often requiring the capturing and handling of individual animals. Capture and handling of wildlife is becoming increasingly important for natural resource management in the United States given the technological advances and amount of spatial and temporal data and that can be collected (Peterson et al. 2003, Jacques et al. 2009). This is especially true for deer given the impact they can have on vegetative communities (Anderson and Katz 1993, Rossell et al. 2005, Webster et al.

2005, Rossell et al. 2007) and the popularity of hunting (U.S. Fish and Wildlife Service 2011). Growth in both human and deer populations, coupled with rapid land change, have resulted in increased wildlife-human interactions and subsequently increased public awareness of deer welfare and safety (Peterson et al. 2003). In response to public concern, recent advancements in capture and handling methods have focused primarily on minimizing mortality and stress while increasing efficiency. These advances have made both drop net and helicopter and net gun capture techniques increasingly popular.

Use of such capture techniques can still lead to deer injury and mortality (Cattet et al. 2008, Jacques et al. 2009). Capture can alter behavior (Neumann et al. 2011, Northrup et al. 2014). Despite this operating reality, most deer studies with a capture component assume that individual animals exhibit normal behavior after capture, and that these behaviors can be extrapolated to the greater population (Northrup et al. 2014). If capture and handling alter deer behavior, then this assumption is violated and will lead to biased results (Northrup et al. 2014). As such, determining the existence of post-capture behavior modification and subsequently the period over which data are biased due to capture and handling will improve the ability to make sound management decisions (Jacques et al. 2009, Northrup et al. 2014).

OBJECTIVES

In response to these concerns and, as part of its mission to create better management practices through applied research, the Texas A&M University Natural Resources Institute (NRI) initiated a study in 2011 to investigate various aspects of deer population ecology and habitat management on Camp Bullis. As part of this investigation, my research efforts focused on comparing capture techniques used to fit deer with global positioning system (GPS) collars and evaluating basic deer movement in response to population survey methods and the associated biases of each method.

My dissertation follows Texas A&M University's Chapter method guidelines and is divided into 3 primary chapters with each designed as an individual journal publication, so some repetition between chapters is expected. The specific objectives of my dissertation were to:

1. Provide a cost-benefit analysis for techniques used to capture deer on Camp Bullis (drop net, single helicopter, and tandem helicopter) and an evaluation of their effects on deer movement behavior.
2. Determine the influence of bait on deer distributions and if changes in distribution create substantial bias in population estimates obtained by infrared-triggered camera surveys.
3. Determine the influence of road type and traffic volume disturbance on deer distributions and if differences create substantial bias in population estimates obtained by spotlight line-transect surveys.

STUDY AREA

General Description

Camp Bullis is a military installation located in Bexar County, north of San Antonio, Texas (Fig. 1). The installation covers 11,286 ha, and the area is characterized

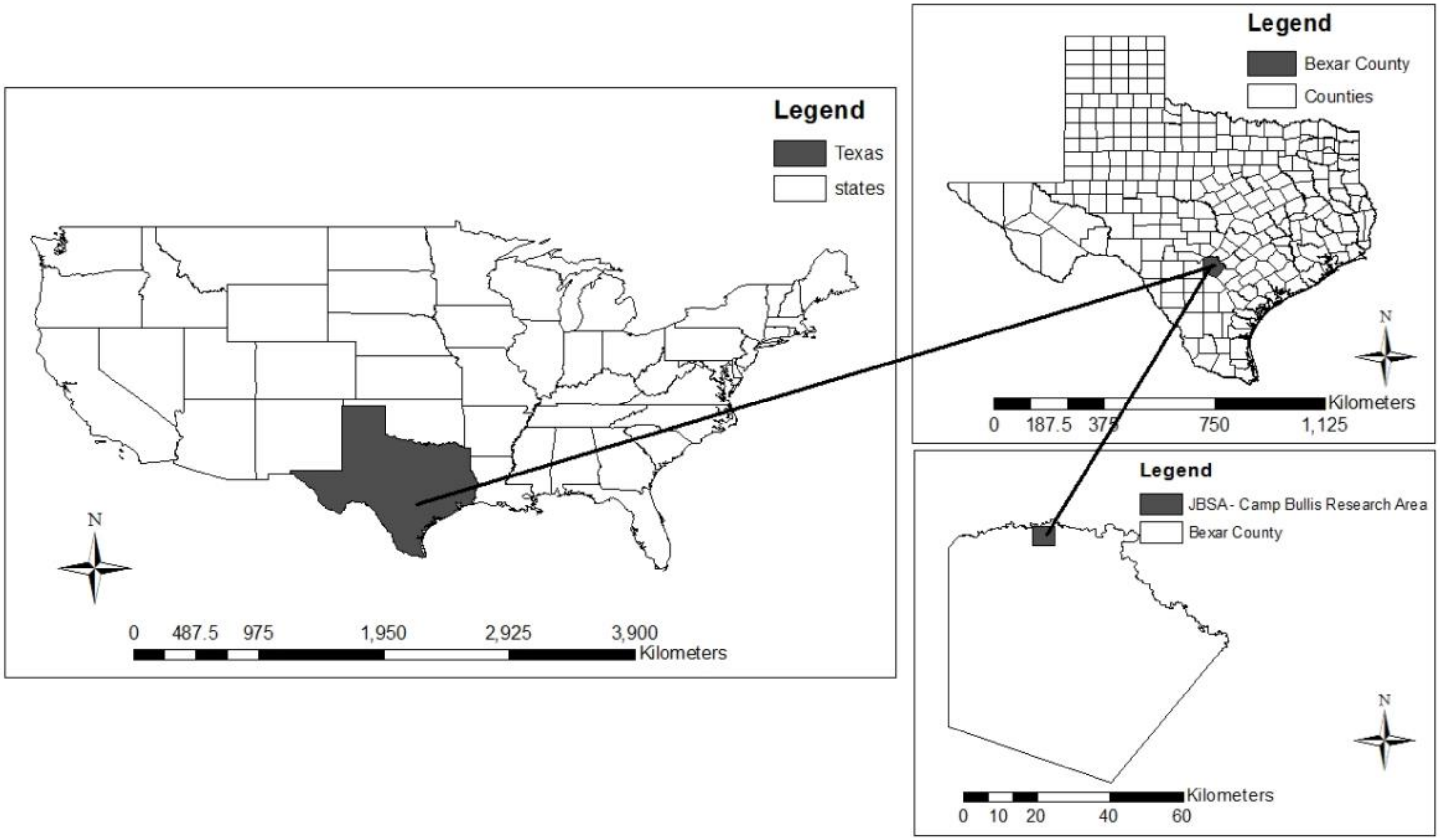


Figure 1. Location of Joint Base San Antonio-Camp Bullis white-tailed deer research study area, Bexar County, Texas, USA, 2011–2014.

as an ecotone of the Edwards Plateau, Blackland Prairies, and South Texas Plains Ecological Regions of Texas (Gould 1962). Topography is rugged with elevations ranging from 300 to 450 m above mean sea level. Limestone is the dominant parent material from which most local soils are derived, and 3 major formations underlie the study area: the Buda, Glen Rose, and Edwards Limestone formations. The central portion of the installation is classified as rolling Adobe Hills range site (8,044 ha) and is covered with shallow Tarrant-Brackett association soils. This central area is surrounded by the drainage basins of Cibolo Creek on the northern boundary, Lewis Valley Creek on the south central portion of the base, and Salado Creek along the western and southern boundaries. These drainage basins (3,238 ha) are covered with Crawford and Bexar soils, older alluvium deposits of the Krum complex, Trinity-Frio soils, Lewisville silty clay, and Patrick soils in the floodplains.

Climate

The mean annual temperature is 20° C with monthly averages ranging from 11° C in January to 30° C in July. The average date of the last spring freeze is 16 March, and the average date of the first autumn freeze is 16 November. Rainfall varies from 36 cm to 89 cm per year with more years below average rainfall than above. There are 2 distinct growing seasons, March through June and September through October, corresponding to periods with the highest average monthly rainfall (Taylor et al. 1966).

Vegetation

Dominate vegetation associated with the Buda Limestone formation and the Quaternary deposits of intermittent streambeds of the Edwards Plateau Region were

Ashe juniper (*Juniperus ashei*), plateau live oak (*Quercus viginiana*), and Texas persimmon (*Diospyros texana*). Dominant species on Quaternary deposits were Ashe juniper, cedar elm (*Ulmus crassifolia*), sycamore (*Platanus occidentalis*), and Texas persimmon (Van Auken et al. 1979).The dominant species associated with the Edwards and Glen Rose Limestone formation were Ashe juniper, plateau live oak, and Texas persimmon (Van Auken et al. 1980). In the Edwards Plateau, scrub evergreen forest communities typically occupy hilltops and the south to southwest aspects of hill slopes. Upland deciduous forests typically occupy bands on the north to northeastern aspect of hill slopes. Dominant species in the deciduous forest were Spanish oak (*Quercus texana*), Lacey oak (*Quercus glaucoides*), Ashe juniper and Texas persimmon (Van Auken et al. 1981). Dominant species in the evergreen forest were Ashe juniper, Texas persimmon, and plateau live oak (Van Auken et al. 1981).

Historically, the Edwards Plateau appears to have been a stable grassland or savannah community dominated by tall-grass species and fire tolerant woody species (Smeins et al. 1997). The climax condition of this region likely was maintained by the dynamic interaction of climatic factors, fire, vegetation, and herbivores (Fonteyn et al. 1988; Van Auken 1993). Much of this area was settled by Europeans in the early 1800s, who brought farming and ranching practices to the region. Domestic livestock and fire suppression altered the vegetative community by changing the duration and intensity of grazing and resulted in a shift of vegetative dominance away from tall-grass species and toward short grasses or woody species. The unique balance of the ecosystem, once altered, progressively favored the establishment of invasive woody species (Van Auken

1993). Historic clearing of Ashe juniper, infrastructure development, erosion, overgrazing, gravel mining, and damming of streambeds to control floodwaters have altered the native ecosystem. Various stages of secondary succession are evident throughout the installation with Ashe juniper monocultures of varying age and size occurring frequently. However, some small, but relatively diverse plant communities do occur on the installation, most of which are intermixed with the disturbed areas (Johnson et al. 1996). Active range management has slowed some of the damage, but brush control efforts have failed to maintain cleared areas in a brush-free (Ashe juniper) state. The resulting landscape is a mosaic of live oak savannahs, dense Ashe juniper dominated woodlands, and diverse semi-riparian drainages.

CHAPTER II

COST-BENEFIT ANALYSIS OF WHITE-TAILED DEER CAPTURE TECHNIQUES AND EFFECTS ON MOVEMENT BEHAVIOR

SYNOPSIS

The capture and handling of animals in wildlife research has increased with advancements in telemetry technology. However, few publications have provided a cost-benefit analysis of capture techniques while also assessing impacts post-capture on animal movement and behavior. Thus, I evaluated capture efficiency and effects of handling for drop net and both single and tandem helicopter with net gun techniques for white-tailed deer (*Odocoileus virginianus*; deer). I captured 32 (drop net), 68 (single helicopter), and 71 (tandem helicopter) deer over 6 capture periods (3 spring and 3 autumn) from August 2011 to February 2014, and recorded 3.1%, 1.5%, and 0% direct capture-related mortalities and 9.4%, 4.4%, and 4.2% post-capture mortalities, respectively. Mean personnel hours and capture cost were greater for drop nets ($655/deer) than either helicopter method ($164/deer and $231/deer, respectively). Sex-ratios and age classes for deer captured from both helicopter techniques more closely resembled historical harvest and estimated population demographics than those obtained from drop nets. Drop net results showed a skewed capture bias in favor of younger males. Spatial analysis of the effective coverage area showed the tandem helicopter technique provided the greatest coverage of the study area. Mean total post-capture deer movement and minimum convex polygons (MCP) were compared across capture method and time period (week 1 and week 5 post-capture). Total post-capture movement comparison showed a significant difference between drop net and both helicopter techniques within each time period, but single helicopter and tandem helicopter techniques did not differ overall or between time periods. There was no difference in MCP area among capture methods overall; however, MCP area coverages were larger in week 1 than week 5 for both drop net and single helicopter method but not tandem helicopter. While all 3 techniques were safe and effective methods for deer capture, the tandem helicopter capture technique is superior for balancing cost-efficiency and safety while minimizing post-capture behavioral impacts. The spatial-temporal extent of behavioral change attributable to capture technique must be considered when selecting among available capture methods.

INTRODUCTION

Wildlife research often includes capturing and handling animals because of the general difficulty in monitoring wildlife (Jacques et al. 2009). Technological advances have made animal capture for marking with global positioning system (GPS) collars very popular because of their ability to capture large quantities of spatial and temporal data with minimal effort that can then be used for determining home range use and seasonal movements, survival, cause-specific mortality, habitat use, and disease prevalence (DePerno et al. 2003, Oyer et al. 2007, Jacques et al. 2009, Northrup et al. 2014). However, animal capture can lead to injury or mortality of the animal (Cattet et al. 2008, Jacques et al. 2009).

Modern advances in capture and handling methods have reduced the risk of mortality and stress imposed on animals at the time of capture (Beringer et al. 1996, Haulton et al. 2001, Jacques et al. 2009). These advances are important because of the expense and logistics of animal capture and increased public awareness and sensitivity to the animal's welfare (Kock et al. 1987, Peterson et al. 2003, Jacques et al. 2009). This is particularly exemplified with white-tailed deer (*Odocoileus virginianus*; deer) since growth in both human and deer populations, coupled with rapid land use changes, have resulted in increased wildlife-human interactions and subsequently increased public awareness of deer welfare (Peterson et al. 2003).

Capture may also lead to altered behavior in captured animals (Neumann et al. 2011, Northrup et al. 2014). However, most studies with a capture component operate under the implicit assumption that individual animals exhibit normal behavior after capture, and that these behaviors can be extrapolated to the greater population (Northrup et al. 2014). If capture and handling alter these behaviors, then this assumption is violated, leading to the potential for biased results (Northrup et al. 2014). As such, determining the existence and extent of post-capture behavior alterations and the subsequent period during which behavior is impacted by capture and handling is beneficial to movement and spatial ecology research and will aid managers in making sound management decisions (Northrup et al. 2014).

Past research (Peterson et al. 2003, Webb et al. 2008, Jacques et al. 2009, Northrup et al. 2014) has shown that rapid capture and release of white-tailed deer with drop nets or net guns from helicopters is safe for personnel and study animals, and results in far fewer injuries or mortalities than other deer capture methods. Thus, the ability to minimize mortality and stress combined with increased efficiency, have made deer capture using both drop net and helicopter with net gun increasingly popular techniques (Peterson et al. 2003, Webb et al. 2008, and Jacques et al. 2009).

As deer captures become more common in research, assessment of its impacts are needed to ensure the validity of analyses of movement or space-use behavior (Northrup et al. 2014). Especially, since there are a limited number of publications providing a cost-benefit analysis of capture techniques across the same environment and even fewer evaluating their impacts post-capture on deer movement behavior. Most studies that use captured individuals assume deer exhibit normal behavior after capture and that these behaviors can be extrapolated to the greater population (Northrup et al. 2014). However, if behavior is altered by capture and handling, then this assumption is violated and has the potential for biased results (Northrup et al. 2014). As such, primary objectives were to provide a cost-benefit analysis for capture techniques used to capture deer on Camp Bullis (drop net, single helicopter, and tandem helicopter) and an evaluation of their effects on deer movement behavior.

METHODS

Study Area

I conducted my study on Camp Bullis, a military installation located immediately north of San Antonio, Texas, USA (Fig. 1). The installation covered 11,286 ha, and the area was characterized as an ecotone of the Edwards Plateau, Blackland Prairies, and

South Texas Plains Ecological Regions of Texas (Gould 1962). The area in which deer were captured (capture zone) was 2,500 ha on the northern part of Camp Bullis (Fig. 2).

The study area location was selected based on a variety of issues related to research objectives (e.g., troop density, varied levels of troop activity, road type, traffic levels, and distance from live ranges). However, the biggest factor was safety of military personnel and avoidance of the southern half of Camp Bullis which was mostly cantonment area consisting of buildings, barracks, and live weapon ranges.

Capture Technique and Methodology

***Drop Nets*.—** Drop nets were chosen as my original method of deer capture because they are easy to setup, safe (0–7% mortality), and less invasive than other methodologies making public perception of this technique more favorable (Peterson et al. 2003). Drop nets were constructed using a methodology similar to that outlined in Lopez et al. (1998). A 20 x 20 m^2 net of knotless nylon was used to construct the drop net. A braided nylon perimeter rope was threaded around the net perimeter and tied to an oversize ring. The net perimeter rope looped around a square frame constructed of t-posts that were driven into the ground. To suspend the net on the frame, the net was raised and the perimeter rope with oversize ring pulled forward (net strictly held up with tension) and fastened to a quick-release mechanism 20–30 m away. The quick-release mechanism, holding the net up by tension, was attached to a t-post driven into the ground next to a ground hunting blind. The net, suspended above the ground, was released using piece of baling twine which was pulled by a researcher in the hunting

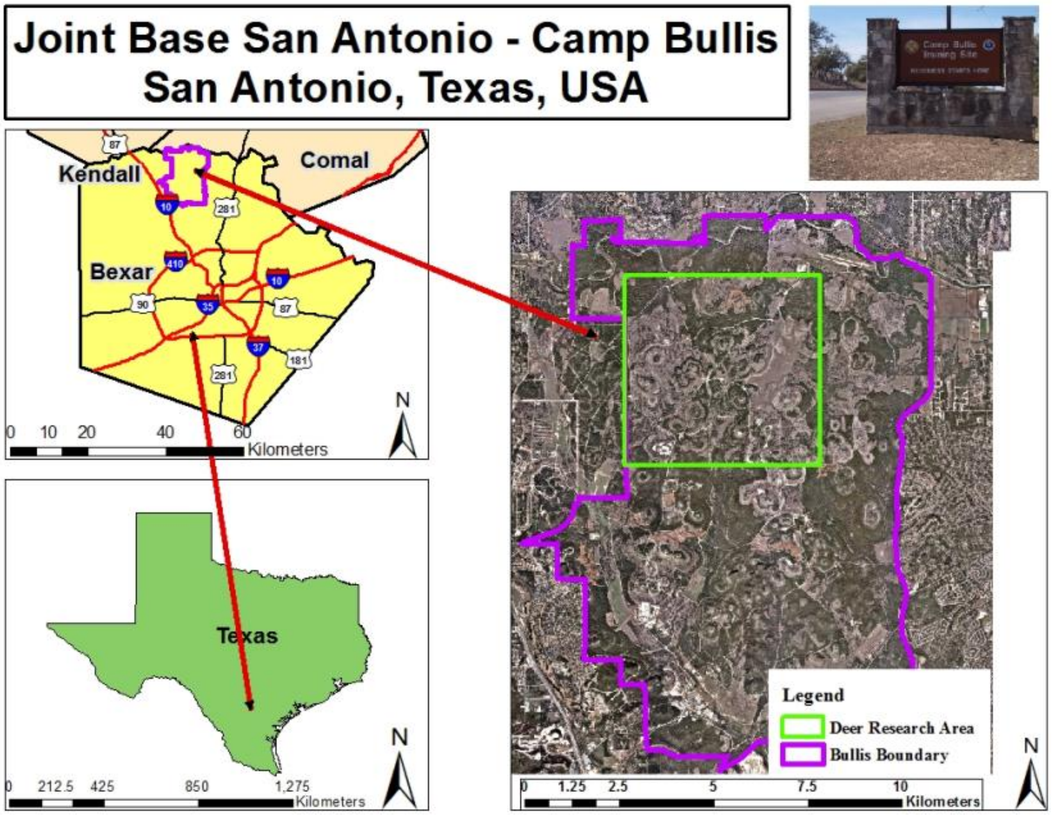


Figure 2. Joint Base San Antonio-Camp Bullis military installation, San Antonio, Texas, USA covers approximately 11,286 ha and is outlined in purple. The green border is an approximate outline of my study area (2,500 ha) and area over which deer were captured and fitted with GPS collars.

blind releasing the tension in the net and allowing the net to fall freely. Shelled corn was used as bait to attract deer and was placed at the center of the net.

Starting in August 2011, 4 drop net locations were actively used for capture 4 days a week. I was unable to meet my requirements of capturing 30–40 adult deer in this relatively short period of time (<4 weeks) in order to obtain frequency intensive locations during key times that population surveys are most commonly used (late winter–early spring; late summer–early autumn). Thus, due to this initial low trapping success, resources devoted to deer capture and collar deployment were increased and trapping occurred at a frequency of 4 days a week continuously during autumn 2011 (August–November) and spring 2012 (February–April) capture periods, not just the first 4 weeks of the capture period. Eventually, 6 drop nets were alternated across 12 drop net location sites. These sites were selected to provide an even distribution of coverage across the study area (Fig. 3). However, due to continued low trapping success with the drop net capture technique, an alternative capture method was adopted in 2012.

Helicopter and Net Gun.— Single and tandem helicopter with net-gun techniques were adopted as my alternative capture methods because studies have reported low (0–5%) mortality rates (Webb et al. 2008). This technique is safe, able to cover large areas in a relative short period of time, and more proactive making it less density dependent and allowing for selective capture (Jacques et al. 2009). However, the more invasive and aggressive chase approach has led to less favorable public perception.

The methodology used was similar to that described by DeYoung (1988). Deer were herded by a helicopter into open areas where the helicopter would pass 4–6 m

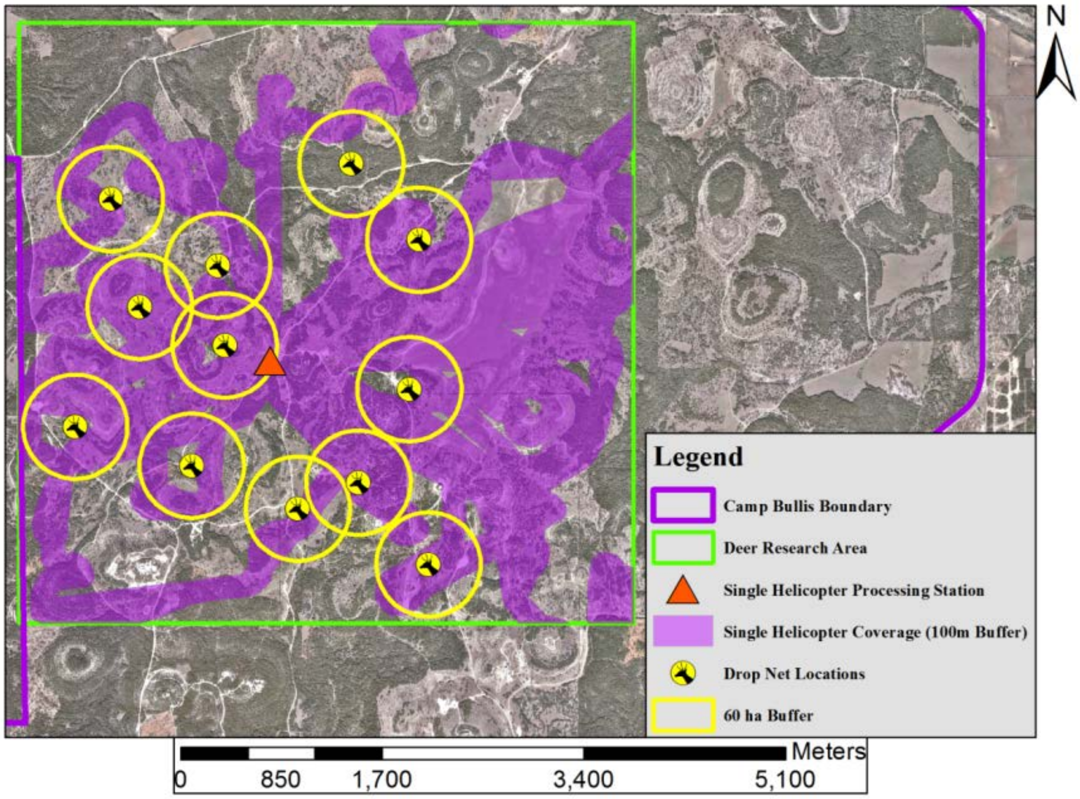


Figure 3. Spatial coverage for both the drop net and the single helicopter methods conducted on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014. Yellow circles indicate 60 ha buffer around each drop net site. The purple illustrates the helicopter flight path with a 200 meter buffer (100 m per side of helicopter).

above the deer. A 4-barreled net gun was then fired by the gunner from the right door of the helicopter. It should be noted that capture periods are referred to as spring and autumn. Capture for spring surveys occurred in February and GPS collars were released and collected at the end of May. Capture for autumn surveys occurred at the start of July and collars were released and collected at the end of October.

The single helicopter method consisted of 1 helicopter (Robinson 22) equipped with a pilot and a net gunner which actively pursued and captured deer during the autumn 2012 (4 and 5 July) capture period. All deer were captured using a net gun fired from a helicopter (Holt Helicopters Inc., Uvalde, Texas; Barrett et al. 1982, DeYoung 1988). Once a deer was captured, the gunner would hobble the deer and attach it via cable underneath the helicopter, where it was transported to a centrally located processing station where 2 experienced processing crews waited. Processing crews consisted of 4–5 Texas A&M University employees experienced with ungulate capture and handling (DeYoung, 1988, Webb et al. 2008, Jacques et al. 2009). Given its success, this capture method also was used for the spring 2013 (16 February) capture period. However, this method had to be adjusted for the autumn 2013 (4 July) and spring 2014 (15 February) capture periods due to an unforeseen change in the helicopter company.

For the autumn 2013 and spring 2014 capture periods a tandem helicopter approach was adopted (Smith Helicopters Inc., Cotulla, Texas; DeYoung 1988). This method also used a net gun fired from a helicopter, but 2 helicopters were used. One helicopter netted and hobbled deer while the other helicopter helped locate, flush, and transport captured deer. Instead of using a centrally located processing station, 2 research vehicles were equipped as mobile processing stations and followed the helicopters along main roadways in the study area.

Deer Restraint and Handling.— Regardless of capture technique (drop net or helicopter and net-gun methods) each deer was processed in the same manner. Once deer either arrived at the processing station or Texas A&M University processing crews, including myself, arrived at the captured individual, the deer were blindfolded using a cotton hood, manually restrained, and removed from the netting. Additional stress agents such as unnecessary noise and talking were minimized. Each deer was then equipped with a Sirtrack Model G2C 191 GPS neck collar (Sirtrack, Havelock North, New Zealand) set to give a frequency location every 15 minutes. Deer also were given an ear tattoo number in its right ear to mark them for identification during future captures or at hunter check stations. Each deer was aged according to tooth replacement and wear (Severinghaus 1949). Additional information recorded prior to release included sex, GPS and VHF frequency, ear tattoo number, and body condition. Each deer was then released at the processing site. Capture and release times were recorded. All capture and handling was done without use of drugs or anesthetics because of the increased risk for capture myopathy inherent with their use. Peterson et al. (2003) showed in a review of 16 journal articles the use of drugs increased handling time and had greater adverse physiological effects on the study animals than physical restraint alone. All animal procedures were approved by the Texas A&M University Institutional Animal Care and Use Committee (AUP#: 2011-154).

Cost-benefit Analysis

In order to quantitatively determine which capture technique was the most cost-effective, I examined 4 factors: time/labor, monetary cost, safety, and ability to meet the study objectives. The first 3 factors were addressed by employing a straight-forward analysis approach. Time and labor efforts were examined by dividing the number of deer captured to total number of logged labor-related hours. Labor hours included both active trapping time and preparation hours (e.g., establishing a net site, baiting, checking camera photos from each net location, etc.). The resultant ratio of time-related labor effort per deer provided a reliable standard for comparison between techniques.

I summed all expenditures per technique for a total cost in dollars per deer. Cost associated with drop nets included all equipment and material (e.g., equipment rentals for clearing vegetation from net locations, net material, wages, construction equipment, bait, etc.). Cost associated with the helicopter involved transportation of the helicopters to and from their base station and hourly rate of helicopter. Total helicopter cost was the hourly rate of the helicopter and cost for the gunner and helicopter crew. Labor cost included total number of hours for each personnel on the processing crew in addition to the maintenance and preparation hours leading up to the capture event. For consistency, minimum wage for the state of Texas from 2012–2014 ($7.25 USD) was used for the cost of labor.

For the safety analysis, I calculated and compared average restraint time for each deer by capture method. Total mortality, including both direct capture-related mortality and post-capture myopathy was evaluated for each technique. Mortalities that occurred during capture were from euthanization administered because of injuries sustained during the actual capture event. Capture myopathy was defined as any mortality event that occurred within 1 month (30 days) of the capture event. Mortality numbers were reported as a percentage of the total number of deer captured for comparative purposes.

Lastly, the ability of capture techniques to achieve project goals was evaluated using 5 different metrics. I evaluated the presence of capture bias for each technique by comparing the average age, age-structure, and sex-ratio of deer captured to expected values, obtained from harvest records and population estimates, to determine which capture method gave the most representative sample of the deer population. I also analyzed each technique's spatial coverage in my study area using ArcMap 10.3. Using GPS units attached to each helicopter I was able to upload the helicopter flight track used during capture. This allowed me to provide a 200 m buffer (100 m out each side) which is the approximate distance from the helicopter an observer can cover when searching for deer (Figs. 3 and 4). Drop net coverage was calculated using a 60.7 ha buffer around each drop net location because this is the area a baited camera site has been shown to encounter 80% of the deer in the area (Jacobson et al. 1997).

Additionally, because the collars were deployed in the field for a short period of time (3–4 months), it was imperative to evaluate the post-capture impact on animal movement and behavior to maximize the amount of usable data by determining if and how much data needed to be excluded. For this analysis I used methodology similar to Northrup et al. (2014) in ArcMap 10.3 and R statistical software. Total post-capture deer

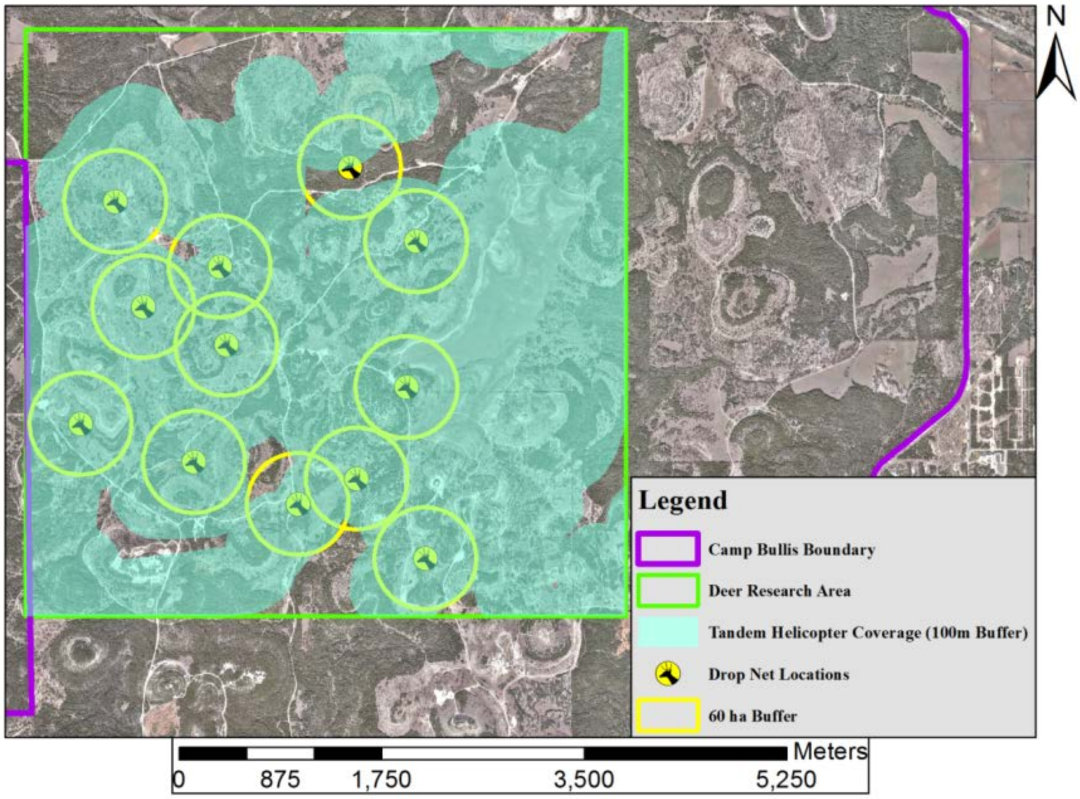


Figure 4. Spatial coverage for both the drop net and the tandem helicopter methods conducted on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014. The turquoise illustrates the combined helicopter flight paths of both helicopters with a 200 meter buffer (100 m per side of helicopter).

movement trajectories (total distance; m) and 95% minimum convex polygon coverage areas (MCP; ha) were calculated across all 3 capture methods and both time periods (week 1 and week 5 post-capture). Week 1 consisted of days 1–7 post-capture and week 5 consisted of days 29–35 post-capture. An analysis of variance was conducted to determine if differences existed across time periods within capture techniques and across capture techniques for the same time period with a significance level of 0.05. When significance was detected, a Tukey post-hoc and paired *t*-test were conducted to determine where the actual differences occurred. Gender and season (spring and autumn) served as co-variates. Note that seasonal analysis excluded drop net method because low capture success caused the method to be conducted continuously and made seasonal separation impossible.

RESULTS

Cost-benefit of Techniques

***Time and Labor*.—** Total labor-related effort per deer was 65.8, 2.7, and 2.3 (hrs/deer) for drop net, single helicopter, and tandem helicopter methods, respectively (Table 1). Thirty-two deer were captured over a period of 27 weeks (103 active trap days) using the drop net method. Single and tandem helicopters had similar capture numbers (*n* = 68 and *n* = 71) and labor-related hours (Table 1). Both helicopter methods outperformed the drop net method in terms of time and labor efficiency (Table 1).

Table 1. Time and labor efficiency of white-tailed deer capture techniques on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Deer capture	**Drop net**	**Single helicopter**	**Tandem helicopter**
Total deer captured (*n*)	32	68	71
Duration (days)	103	3	2
Active trapping (hrs)	1,550	150	110
Preparation (hrs)	750	30	55
Trap efficiency (hrs/deer)	65.8	2.7	2.3

Table 2. Monetary cost of white-tailed deer capture techniques on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Cost[1]	**Drop net**	**Single helicopter**	**Tandem helicopter**
Materials	4,500	400	400
Helicopter	N/A	8,750	13,800
Transport	N/A	1,272	1,296
Labor (wages)	16,675	1,138	830
Total cost per deer	660	170	230

[1] All cost presented are in USD ($)

Table 3. Animal safety for white-tailed deer capture techniques on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Average handling time and mortality	**Drop net**	**Single helicopter**	**Tandem helicopter**
Restraint and handle (min)	22.2 (±1.8)	6.1 (±0.4)	4.9 (±1.52)
Direct capture-related mortality (%)	3.1	1.5	0
Post-capture myopathy (%)	9.4	4.4	4.2
Total mortality (%)	12.5	5.9	4.2

Cost.— Total monetary cost per deer captured was $660, $170, and $230 (US dollars/deer) for drop net, single helicopter, and tandem helicopter methods, respectively (Table 2). For drop nets, material and equipment cost was $4,500 compared to $400 for each helicopter capture method. Labor cost calculated from personnel wage hours was $16,675 for drop nets and $1,138 and $830 for single and tandem helicopter methods, respectively (Table 2). Tandem helicopter labor cost was lower because total capture time was less.

Safety.— Percent mortality of deer captured, either directly related to capture events or capture myopathy, was 12.5, 5.9, and 4.2 (%) for drop net, single helicopter, and tandem helicopter methods, respectively (Table 3).

Capture Demographics and Behavioral Impacts.— Sex-ratio (male:female) of deer captured from both helicopter techniques were closer to 1:1 than those obtained from drop nets (>2:1; Fig. 5). Average age of deer captured was 2.4, 3.8, and 3.2 for drop nets, single helicopter, and tandem helicopter methods, respectively (Fig. 6). Age class distribution for both helicopter methods were similar with the 1.5 age class representing less than 15% of the population and the 5.5 and 6.5+ age classes present. No deer older than 4.5 years of age was captured using drop nets and the 1.5 age class represented 60% of the deer captured (Fig. 7). Spatial analysis of the effective coverage area showed that tandem helicopter capture technique provided the greatest coverage of the study area (>90%) whereas drop nets covered <30% of the study area (Figs. 3 and 4).

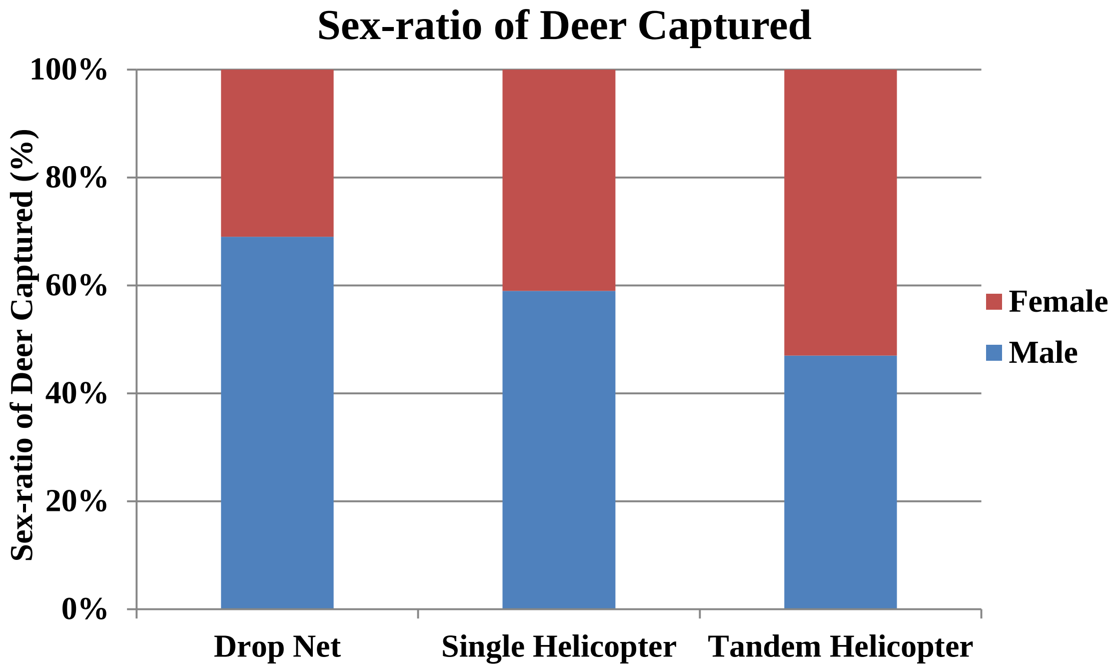


Figure 5. White-tailed deer sex-ratio for each capture method used on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014. Sex-ratio is represented as a cumulative percentage for comparative purposes across capture methods.

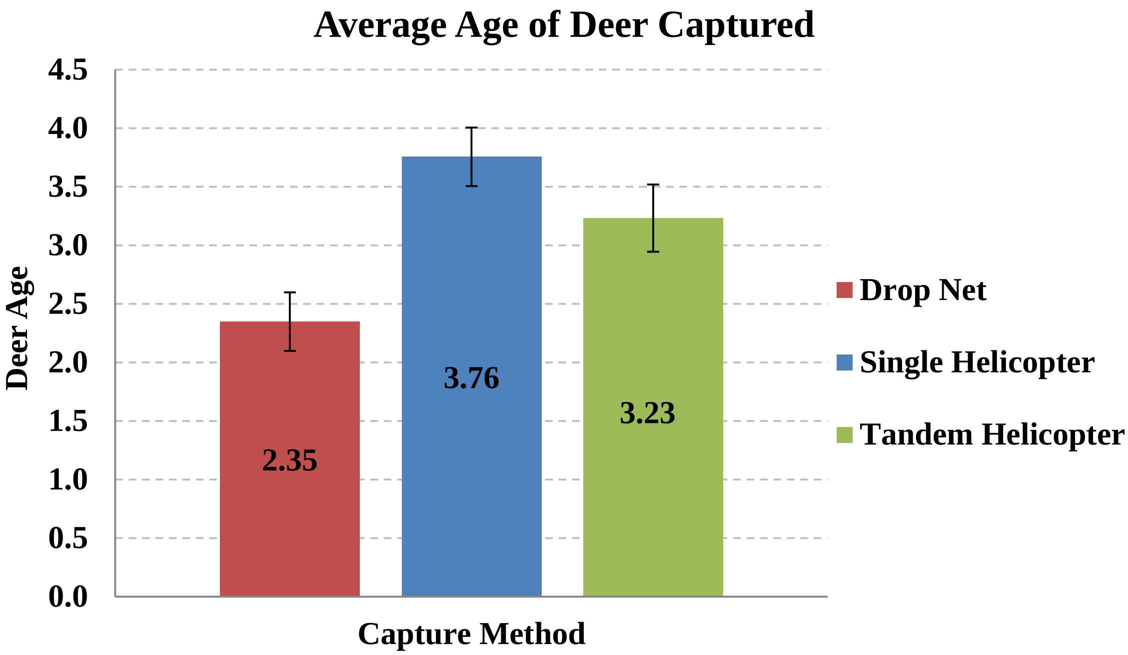


Figure 6. Average age of white-tailed deer captured for each capture method used on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

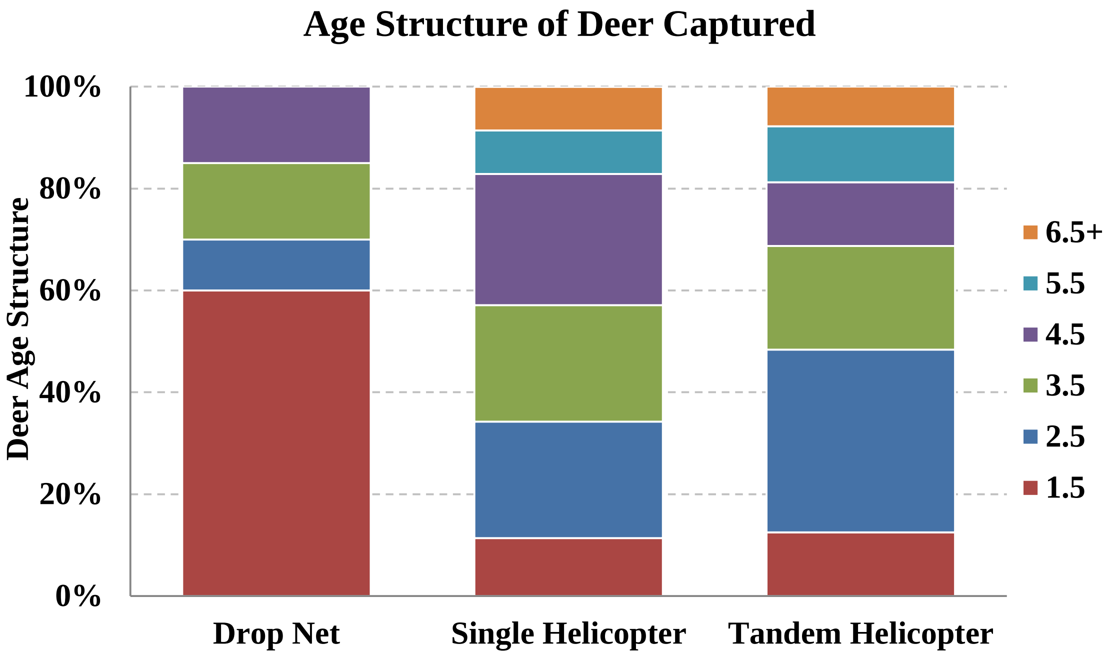


Figure 7. White-tailed deer age-structure for each capture method used on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014. Age-structure is represented as a cumulative percentage for comparative purposes across methods.

Table 4. Analysis of variance for total deer distances traveled in week 1 and week 5 post-capture factored by all 3 white-tailed deer capture methods on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Week 1	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Methods	2	2.655e+09	1.327e+09	16.18	0.000
Residuals	141	1.157e+10	8.204e+07		
Week 5					
Methods	2	6.250e+08	312516158	6.41	0.002
Residuals	139	6.775e+09	48741939		

Table 5. Tukey post hoc comparing capture methods to determine what method(s) are responsible for the significant difference in total distances traveled in weeks 1 and 5 on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Week 1	**Lower**[2]	**Upper**[2]	**Mean difference**[2]	***P* adj**
Helo2-Helo1[1]	-7,135	769	-3,183	0.140
Drop net-Helo1	3,953	14,003	8,978	0.000
Drop net-Helo2	7,084	17,239	12,161	0.000
Week 5				
Drop net[2]-Helo1	-2,068	4,074	1,002	0.720
Drop net-Helo2	1,896	9,682	5,789	0.002
Drop net[2]-Helo1	872	8,700	4,786	0.012

[1] Helo1-single helicopter method; Helo2-tandem helicopter method

[2] Numbers reported are in meters

Table 6. Analysis of variance for 95% minimum convex polygon area coverages (ha) calculated for drop net method factored by weeks 1 and 5 post-capture on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Drop nets	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Weeks	1	137,713	137,713	5.29	0.026
Residuals	48	124,7947	25,999		

Both time periods (week 1 and week 5) showed significant difference in total distance by method (Table 4). Tukey post-hoc analysis revealed that both helicopter methods had similar total distances and drop net captured deer moved farther in these weeks than helicopter captured deer (Table 5). For the MCP analysis, there was no difference between capture methods overall; however, 95% MCP area coverage did differ between time periods for individuals captured with the drop net method (Table 6, Figs. 8–10). Gender analysis revealed no difference in average MCP size during week 1 for males and females (267 ha and 285 ha, respectively); however, males had significantly larger MCP than females in week 5 (187 ha and 118 ha, respectively; Table 7). The seasonal analysis also revealed similar results with no differences in MCP size in week 1; however, MCPs were larger in the spring than the autumn for week 5 (Table 8). Note that seasonal analysis excluded drop net method because low capture success caused the method to be conducted continuously and made seasonal separation impossible.

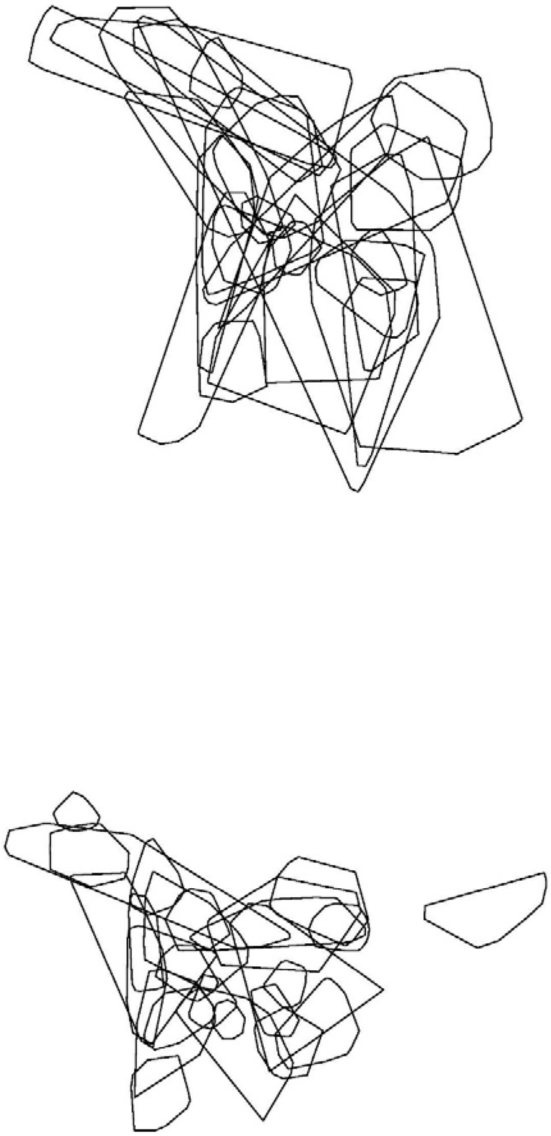


Figure 8. Illustration of 95% minimum convex polygon area coverage (ha) calculated for weeks 1 and 5, respectively, for all white-tailed deer captured using the drop net capture method on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–June 2012.

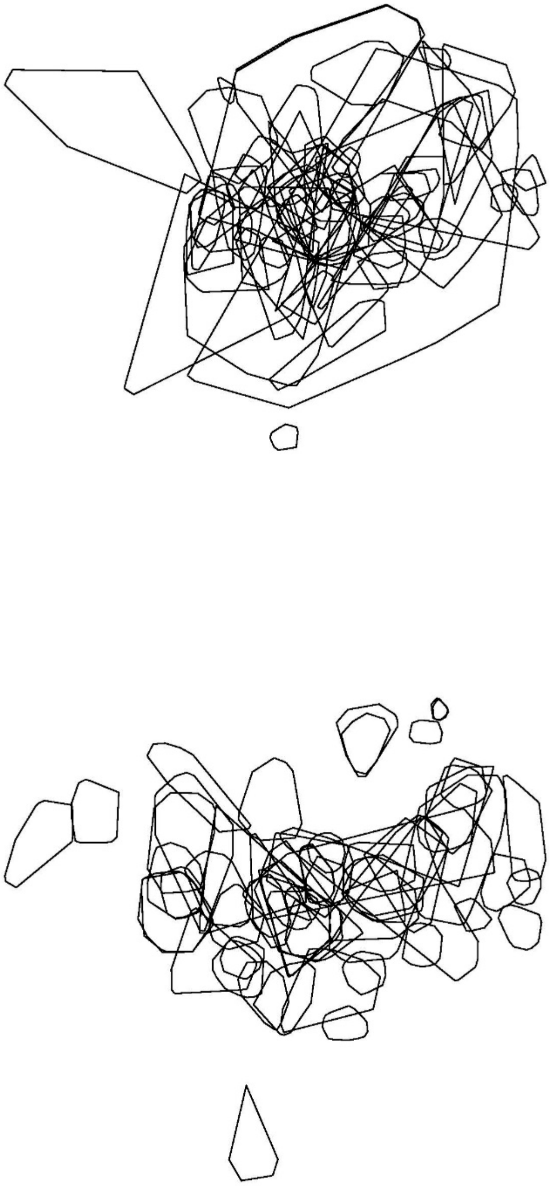


Figure 9. Illustration of 95% minimum convex polygons area coverage (ha) calculated for weeks 1 and 5, respectively, for all white-tailed deer captured using the single helicopter capture method on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA for the autumn 2012 (4 and 5 July) and spring 2013 (16 February) capture period.

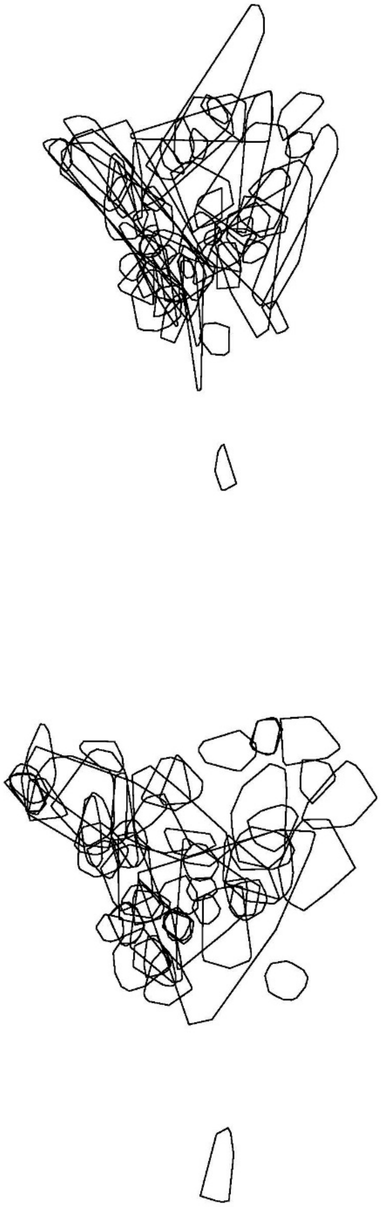


Figure 10. Illustration of 95% minimum convex polygons area coverage (ha) calculated for weeks 1 and 5, respectively, for all white-tailed deer captured using the tandem helicopter capture method on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA for the autumn 2013 (4 July) and spring 2014 (15 February) capture period.

Table 7. Analysis of variance for 95% minimum convex polygon area coverages (ha) calculated for weeks 1 and 5 post-capture factored by method and sex for white-tailed deer capture methods on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Week 1	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Methods	2	543,549	271,774	1.724	0.182
Sex	1	22,542	22,542	0.143	0.706
Method:sex	2	560,595	280,297	1.778	0.173
Residuals	139	21,907,566	157,608		
Weak 5					
Methods	2	10,418	5,209	0.242	0.785
Sex	1	33,7846	33,7846	15.710	0.000
Method:sex	2	50,639	25,319	1.177	0.311
Residuals	139	2,989,277	21,506		

Table 8. Analysis of variance for 95% minimum convex polygon coverages calculated for weeks 1 and 5 post-capture factored by method and season for white-tailed deer capture methods on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Week 1	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Methods	1	519,804	51,9804	2.951	0.089
Season	1	190,443	190,443	1.081	0.301
Method:season	1	358,561	358,561	2.036	0.156
Residuals	115	20,254,035	176,122		
Week 5					
Methods	1	9,936	9,936	0.393	0.531
Season	1	119,476	119,476	4.729	0.032
Method:season	1	23,949	23,949	0.948	0.332
Residuals	115	2,905,506	25,265		

Paired *t*-test revealed that, regardless of capture method, deer traveled further in week 5 than week 1 (Table 9); however, deer had a larger MCP area for week 1 than week 5 (Table 10). Paired *t*-test conducted by capture method provided evidence that calculated MCPs were larger in week 1 than week 5 for both drop net and single helicopter method, but not tandem helicopter (Table 11). Comparison of average MCP area (ha) coverage across week 1 and week 5 for each capture method showed similar results (Fig. 11).

DISCUSSION

Cost-benefit analysis indicated that both helicopter methods were more time efficient and cost effective, safer, and less prone to capture bias than drop nets for my study area. However, MCP analysis showed that coverages were larger in week 1 than week 5 post-capture for both drop net and single helicopter method, but not for tandem helicopter, indicating a capture effect for both drop net and single helicopter methods. Thus, the spatial coverage and movement analysis indicated that the tandem helicopter capture technique was the superior capture method on Camp Bullis for balancing cost-efficiency and safety while also minimizing post-capture behavioral impact on deer. My data provides much needed criteria for evaluating deer capture methodologies and the need for future studies to determine the period over which data are biased by other capture and handling techniques.

Changing capture methods was not something I had initially anticipated, but was required to meet the project goals given for my study area and research design.

Table 9. Paired *t*-test between week 1 and week 5 for total distance traveled for all white-tailed deer captured on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Total distance			**95% C.I.**		**Mean**	
Pair	***t***	**df**	**Lower[1]**	**Upper[1]**	**difference[1]**	***P*-value**
Week 1-Week 5	-4.146	118	-4,917	-1,738	-3,328	0.000

[1]Numbers reported are in meters

Table 10. Paired *t*-test between week 1 and week 5 for 95% minimum convex polygon area coverage (ha) for all white-tailed deer captured on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

95% MCP Area (ha)			**95% C.I.**		**Mean**	
Pair	***t***	**df**	**Lower[1]**	**Upper[1]**	**difference[1]**	***P*-value**
Week 1-Week 5	3.391	144	50	190	120	0.000

[1]Numbers reported are in meters

Table 11. Paired *t*-test between week 1 and week 5 for 95% minimum convex polygon area coverage (ha) for each capture method used on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

Week 1-Week 5 - 95% MCP Area (ha)			**95% C.I.**		**Mean**	
Method	**t**	**df**	**Lower[1]**	**Upper[1]**	**difference[1]**	**P-value**
Drop net	2.486	25	24	263	143	0.020
Single helicopter	2.588	60	42	334	188	0.012
Tandem helicopter	1.094	57	-31	107	38	0.278

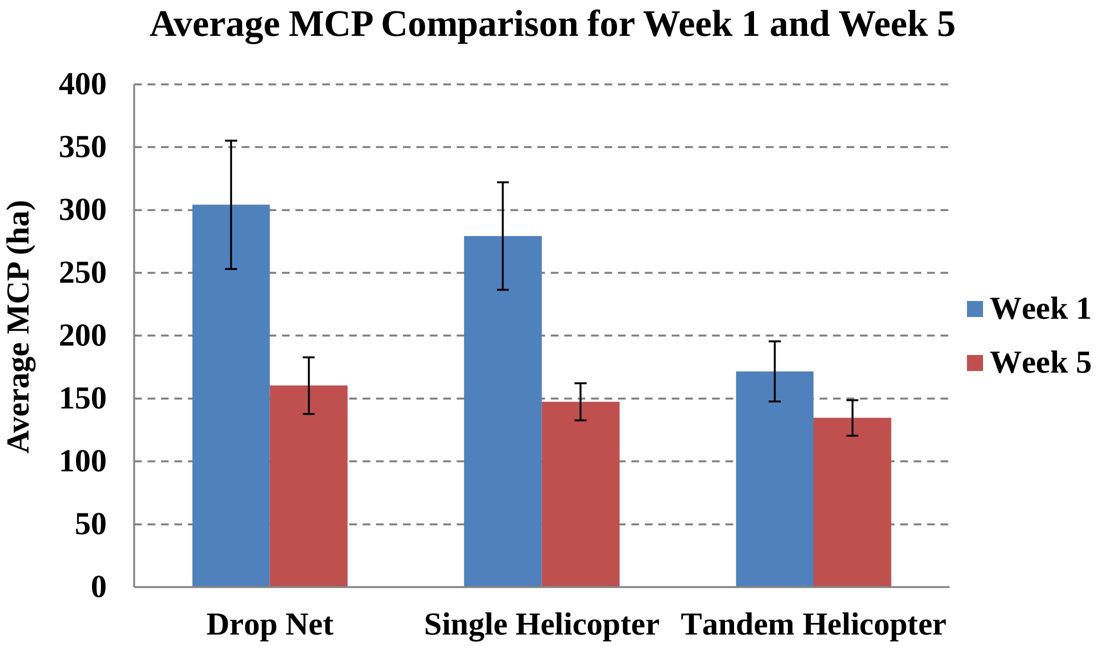


Figure 11. Comparison of 95% minimum convex polygon area coverage (ha) across week 1 and week 5 for each capture method used on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from August 2011–February 2014.

However, I took advantage of this unique opportunity to create data that addressed the need for literature providing a cost-benefit analysis of capture techniques while also assessing impact post-capture on animal movement and behavior across the same environment (White and Bartmann 1994, Peterson et al. 2003).

Previous studies had shown drops nets were simple to use, somewhat mobile, cost efficient, and safe for both the animal and the researcher (Lopez et al. 1998, Peterson et al. 2003). This technique has been shown to be both quiet and non-invasive, thus from a military perspective would pose little interference to the military mission. However, in employing this drop net method at Camp Bullis, I was unable to meet my capture research objectives in the necessary time period (<4 weeks) and needed to resort to an alternative technique that would allow me to maximize my time-efficiency while still maintaining both animal and research safety.

I selected the helicopter and net gun method as my alternative capture approach for its ability to cover vast amounts of area in a short amount of time (Jacques et al. 2009) and given the tremendous success it has had in South Texas and Northwestern United States (White and Bartmann 1994, Webb et al. 2008). However, it was not used initially because Camp Bullis is located on the southern edge of the Edwards Plateau where there is more tree coverage and elevation change than is traditionally preferred for the helicopter and net-gun method. It also is a more invasive technique that could interfere with military training, forcing capture events to occur during periods of military inactivity (i.e., holidays).

All capture methods used were a relatively safe means for capturing deer. However, both single (5.9%) and tandem (4.2%) helicopter methods outperformed the drop net technique (12.5%) in percent mortality of deer captured (direct or capture myopathy; Table 3). Mortality rates showed a positive correlation to average restraint and handling time (Table 3). Both helicopter techniques also outperformed drop nets in terms of time and labor efficiency (Table 1) and monetary cost (Table 2) with the drop net method costing nearly 3.5 times that of either helicopter technique in terms of cost per deer.

I attribute the increased cost and labor associated with drop nets to the various land uses and disturbances (e.g., military training, hunting, land management efforts, etc.) present on Camp Bullis. Historically, drop nets have shown greatest success on deer populations that encounter less disturbance and more positive human interactions making a passive capture approach feasible (Lopez et al. 1998, Peterson et al. 2003). In an environment with an actively hunted deer population exposed to a variety of human disturbances, a proactive approach proved more cost-effective and time efficient. Both single and tandem helicopter techniques were able to provide greater spatial coverage of the study area (65% and 90%, respectively) than drop nets (30%) with tandem helicopter method providing the greatest coverage (Figs. 3 and 4).

The proactive approach used by both helicopter methods and their ability to cover vast amounts of area in a short period of time also helped provide a more representative sample of the population. Sex-ratios and age classes for deer captured from both helicopter techniques more closely resembled historical harvest and estimated population demographics than those obtained from drop nets. Age class distribution for both helicopter methods were nearly identical with the 1.5-year age class representing less than 15% of the deer captured while it comprised 60% of deer captured using drop nets (Fig. 7). Additionally, the 5.5 and 6.5+ year age classes were present for both helicopter techniques while no deer older than 4.5 years of age was captured using drop nets (Fig. 7). Thus, overall drop net results showed a skewed capture bias in favor of younger males which I attribute to its passive capture approach and the use of bait as an attractant which has shown a tendency to favor male activity (Beaver et al. 2016; Figs. 5–7).

Gender analysis, revealed no difference for sex in MCP size during week 1 regardless of the capture technique. However, collectively, males had significantly larger MCP in week 5 than females (Table 7). The seasonal analysis also revealed similar results with no differences detected between capture periods in MCP size for week 1; however, collectively, week 5 MCPs showed spring had a larger area than the autumn (Table 8). Thus, regardless of capture technique, all deer behaved similarly regardless of sex or season immediately following capture. However, by week 5, movement patterns resembled that which was expected and have been documented in prior research indicating individuals were displaying ‘normal’ deer movement patterns for all 3 capture techniques. Because on average males had larger ranges (Beier and McCullough 1990, Stewart et al. 2011) and all deer had larger ranges in the spring when more desirable foraging conditions and milder temperatures were present (Taylor et al. 1966, Van Auken 1979, Beier and McCullough 1990, Stewart et al. 2011). Week 5 for the spring capture occurred around the 3rd and 4th week of March and week 5 for the autumn capture occurred around the 1st and 2nd week of August. For my study site, located in the Edwards Plateau Region, spring capture period averaged milder temperatures (16° C; 30° C) and more rainfall (59 mm; 53 mm) than autumn capture period, respectively.

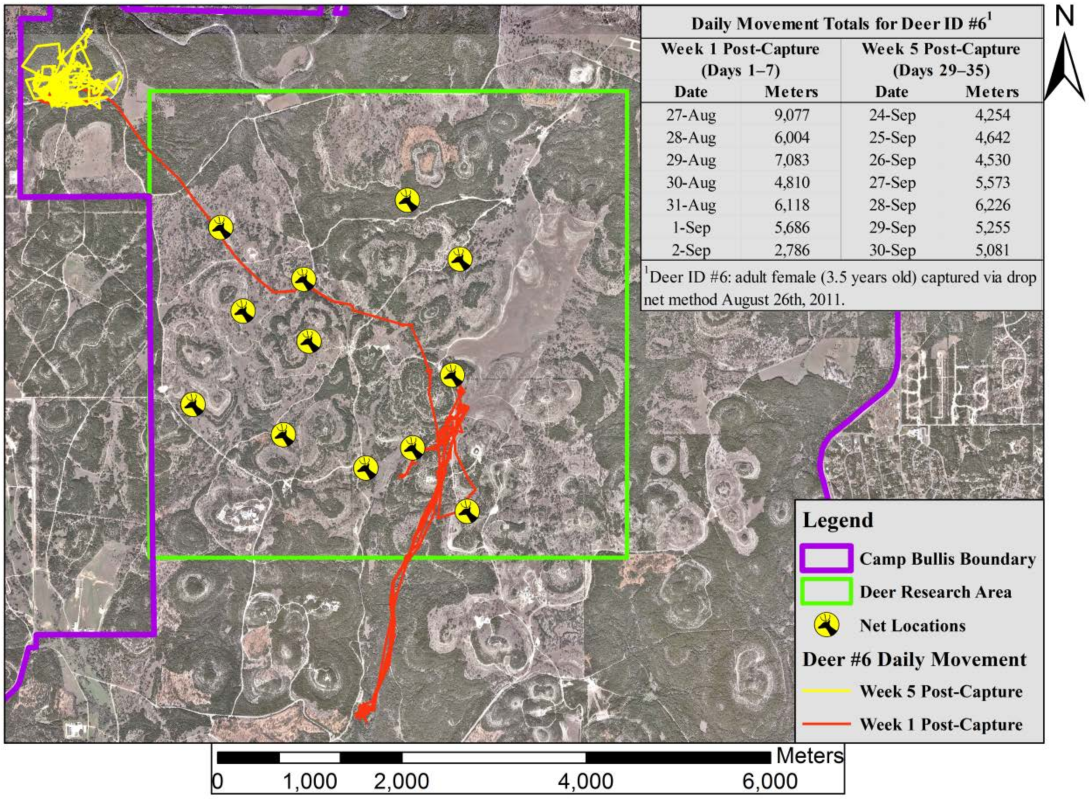
Method of capture did have a significant effect on total distance moved for both week 1 and week 5 post-capture (Table 4). Tukey post-hoc analysis showed that deer when captured by drop net method moved greater distances than that from both helicopter methods regardless of time period but that both helicopter methods had similar mean total distances (Table 5). This implied that the difference was coming from the drop net method and was thus the true cause of the difference in the total distance analysis.

For the ANOVA MCP analysis, there was no difference between either helicopter method overall or between time periods. However, MCP area coverage did differ between time periods for individuals captured using the drop net method (Table 6). This was further supported by the graphics created from the MCPs, which illustrates the biggest visible differences in MCP sizes, from week 1 to week 5, were for the drop net method while the tandem helicopter method showed the least amount of difference (Figs. 8–10). Again, indicating that the drop net method had a significant impact on deer movement post-capture.

Overall, paired *t*-test analysis between week 1 and week 5 revealed a difference for both total distance and MCP (Table 9 and 10). However, the Tukey post hoc revealed the significance difference in total distance was driven primarily by the drop net method.

Paired *t*-test comparing MCP size between week 1 and week 5 factored by capture method revealed that coverages were larger in week 1 than week 5 for both drop net and single helicopter method, but not tandem helicopter indicating a capture effect for both drop net and single helicopter methods (Table 11). This is further supported from the comparison of average MCP area (ha) coverage across week 1 and week 5 (Fig. 11) which showed that immediately following capture the average area over which deer moved was larger than normal for both drop net and single helicopter methods. However, the averaged total amount of movement between week 1 and week 5 remained the same indicating a difference in the complexity of the actual deer movement (Webb et al. 2008). Thus, deer captured by the drop net and single helicopter method moved approximately the same total distance (m) in both week 1 as in week 5 post-capture but had larger MCP area coverages (ha) in week 1. This suggest the pattern of movement differed for deer captured by the drop net and single helicopter resulting in more linear movement in week 1 as a reaction to being captured. However, once ‘normal’ behavior returned they moved the same total distances as in week 1, but covered less area indicating a more clumped and concentrated movement pattern representative of typical forage behavior (Fig. 12).

The helicopter and net gun method was the most efficient technique for Camp Bullis as measured by labor per catch success, cost, safety, and being less prone to capture bias. However, the tandem helicopter method was able to cover an even greater area than the single helicopter technique and had less impact on deer behavior post-capture. While all 3 techniques were safe and effective methods for deer capture, the



Daily Movement Totals for Deer ID #6[1]

Week 1 Post-Capture (Days 1–7)		Week 5 Post-Capture (Days 29–35)	
Date	Meters	Date	Meters
27-Aug	9,077	24-Sep	4,254
28-Aug	6,004	25-Sep	4,642
29-Aug	7,083	26-Sep	4,530
30-Aug	4,810	27-Sep	5,573
31-Aug	6,118	28-Sep	6,226
1-Sep	5,686	29-Sep	5,255
2-Sep	2,786	30-Sep	5,081

[1] Deer ID #6: adult female (3.5 years old) captured via drop net method August 26th, 2011.

Figure 12. Illustration of how the complexity of deer movement changed between weeks 1 and 5 post-capture for the drop net method used on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA. This illustration is for daily movement for an individual deer (ID #6) captured 26 August 2011. Lines were drawn connecting deer locations in sequential order. The red lines represent week 1 (days 1–7) post-capture and the yellow lines represent week 5 (days 29–25) post-capture.

results indicate that the tandem helicopter capture technique is superior for balancing cost-efficiency and safety while minimizing post-capture behavioral impact on deer.

MANAGEMENT IMPLICATIONS

The spatial coverage and movement analyses indicate the tandem helicopter capture technique is the superior method for balancing cost-efficiency and safety while also minimizing post-capture behavioral impact on deer. Thus, I recommend managers consider tandem helicopter capture technique for large study areas with similar vegetative structure and deer populations that are exposed to a variety of land uses and disturbances. Regardless, wildlife capture should be carefully balanced in regards to expense and efficiency, safety, practicality of setting, research design, and spatial-temporal extent of behavioral change attributable to capture technique. Additionally, I recommend future studies, with a capture and handling component, seek to determine the presence or extent of impacts on post-capture movement behavior and the subsequent period during which data are biased in order to help improve our ability to make sound management decisions.

CHAPTER III

DEER MOVEMENT PATTERNS IN RESPONSE TO THE PRESENCE AND ABSENCE OF BAIT AND EFFECTS ON CAMERA SURVEYS

SYNOPSIS

Infrared-triggered camera (camera) surveys for white-tailed deer (*Odocoileus virginianus*; deer) population estimation are popular among landowners. However, camera surveys often use the aid of bait in order to capture animals more frequently, which could introduce biases by failing to meet the assumption of equal detectability among animals and locations. However, few studies have tried to examine whether the use of bait during camera surveys can provide an unbiased sample of the population, and even fewer have examined to what effect it alters the spatial and temporal pattern of deer. Using movement data from 18 deer (9 male and 9 female) fitted with SirTrack satellite global positioning system (GPS) collars, I used a Mantel test to examine the sexual difference in spatial and temporal patterns of GPS-collared deer immediately before, during, and after the introduction of bait. Both males and females increased their use of locations immediately adjacent to bait sites after the application of bait, but only males adjusted their overall movements to select for areas in closer proximity to bait sites which indicated a stronger influence of baiting on males. Moving window frequency distributions indicated that males temporarily moved their activity center farther away from bait stations after bait was removed giving support for a search-like behavior. During the bait period, percent canopy was the least significant determinant of

male deer distributions. This indicates that bait not only had the greatest effect on male deer behavior, but that bait may be a more important determinant of male deer space use than canopy cover of woody vegetation. My results suggest the use of bait resulted in a higher likelihood of detection in male deer during autumn camera surveys and therefore violates the assumption of equal detectability. This violation will inflate the ratio of total male photos per uniquely identified male and ultimately result in an underestimation of female and fawn deer. Therefore, I recommend managers not base harvest quotas solely from pre-hunting season camera survey estimates obtained using bait or at a minimum be conscious of the potential bias, and adjust for the likelihood that females and fawns are being underestimated.

INTRODUCTION

Population monitoring is a critical component in wildlife ecology and management (Gibbs 2000). White-tailed deer (*Odocoileus virginianus*; deer) are not only an important big game species in North America (Miller et al. 2003), but elevated deer density can alter the structure and composition of the forest understory (Tilghman 1989, Waller and Alverson 1997, Miller et al. 2003, Rossell et al. 2005). Therefore, it is critical for managers to have reliable and cost-effective tools for making sound management and harvest decisions (Jenkins and Marchinton 1969, Jacobson et al. 1997, Heilbrun et al. 2006, McKinley et al. 2006). However, managers need survey techniques that not only estimate density (Lancia et al. 1994), but also allow for detection of changes in density over time (Gibbs 2000, Murray and Fuller 2000, Peterson et al. 2003).

Numerous techniques have been employed to estimate deer populations and parameters, but most have drawbacks. Aerial surveys, via visual count and/or use of infrared technology, are costly and not practical in some regions within the geographical range of deer (Koerth et al. 1997, Beaver et al. 2016). Line-transect counts involving pellet group and track counts are labor intensive and do not provide information regarding age structure (Mooty and Karns 1984). Other count techniques such as roadside surveys using spotlights or thermal imaging equipment are limited to road transects and are so often not representative of the entire area (Buckland et al. 2001, Beaver et al. 2014) resulting in highly variable detection probabilities (Collier et al. 2007, Collier et al. 2013).

Remote photography surveys have surged in popularity since the advent of readily available commercial infrared-triggered camera (camera) systems (Jacobson et al. 1997, Cutler and Swann 1999, Koerth and Kroll 2000, McCoy et al. 2011). Camera surveys have been used for population estimation of many wildlife species and are effective for deer population monitoring (Jacobson et al. 1997, Koerth and Kroll 2000, Heilbrun et al. 2006, Rowcliffe et al. 2008). Camera surveys can be cost-effective (Kucera and Barrett 1993, Cutler and Swann 1999, Rowcliffe et al. 2008), less invasive (Franzreb and Hanula 1995, van Schaik and Griffiths 1996, Cutler and Swann 1999, Rowcliffe et al. 2008), and less labor intensive (Seydack 1984, Cutler and Swann 1999, Rowcliffe et al. 2008) compared with other techniques, such as direct observations or live-capture studies (Cutler and Swann 1999, Larrucea et al. 2007). Cameras allow continuous detection in a variety of vegetation types and during various weather conditions with limited human attention, thus reducing human influence or observer bias (Seydack 1984, Bull et al. 1992, Larrucea et al. 2007, McCoy et al. 2011).

A technique to estimate population density of deer was created by Jacobson et al. 1997 in Mississippi using infrared-triggered cameras. His approach has become adopted as the traditional camera survey approach (McCoy et al. 2011). Jacobson used the photos obtained from cameras to identify individual males based on antler characteristics and then determined a ratio of known-antlered males to total male pictures (Jacobson et al. 1997, Karanth and Nichols 1998, Rowcliffe et al. 2008, McCoy et al. 2011). Jacobson then applied this ratio for all deer photographed to estimate deer abundance and sex-ratios. This abundance estimate can then be divided by area of the property being surveyed to obtain a deer-density estimate.

Density estimates obtained from camera surveys assume equal detectability among all individuals and locations, regardless of sex or age (Jacobson et al. 1997, McKinley et al. 2006). This approach as a population technique typically involves placing bait (usually shelled corn) in front of the camera to capture animals more frequently (Jacobson et al. 1997, Koerth et al. 1997, McCoy et al. 2011). Jacobson et al. (1997) cautioned that individual deer may not use bait equally, and, as a result, the possibility exists for biased estimates. In addition, McCoy et al. (2011) found sex-ratio and recruitment data from randomly placed cameras differed from cameras at feed stations during all time periods evaluated. Other studies indicated behavioral biases influence which animals are captured on camera (Jacobson et al. 1997, Cutler and Swann 1999, Larrucea et al. 2007). These behavioral responses to baiting may violate the assumption of equal detectability (Cutler and Swann 1999, Kilpatrick and Stober 2002, Campbell et al. 2006, Roberts et al. 2006).

McCoy et al. (20011) stated that unequal detectability (Larrucea et al. 2007) among sexes or age classes would bias parameter estimates and could ultimately lead to misinformed management decisions. However, this assumption of equal detectability has not been investigated in detail (Karanth and Nichols 1998, Kilpatrick and Stober 2002, Campbell et al. 2006, McCoy et al. 2011). A full evaluation on non-captive deer herds would require examination of spatial patterns in response to bait and very few studies have attempted to explicitly examine the spatial pattern of deer in response to the introduction and/or removal of bait sources, their interactions with biological and physical process, and the dynamics resulting from such interactions.

Therefore, my goal for this study was to examine the spatial and temporal patterns of GPS-collared deer immediately before the introduction of bait, during the baiting period, and immediately following the removal of bait. My objectives were to (1) determine if the presence and subsequent absence of bait altered deer distributions and if so, then (2) determine if those shifts in deer movement patterns would be significant enough to alter density estimates obtained from traditional infrared-camera surveys.

METHODS

Study Area

I conducted my study on Camp Bullis, a military installation located immediately north of San Antonio, Texas, USA (Fig. 2). The installation covered 11,286 ha, and the area was characterized as an ecotone of the Edwards Plateau, Blackland Prairies, and South Texas Plains Ecological Regions of Texas (Gould 1962).

The area in which deer were captured (capture zone) was 2,500 ha on the northern part of Camp Bullis (Fig. 13). Deer were throughout this area and I conducted camera surveys over approximately 1,425 ha centrally located within the capture zone (Fig. 13). The entire area where deer were captured was not covered during the camera survey due to limited camera resources.

Field Sampling

Animal Capture and Handling.— All deer were captured using a net gun fired from a helicopter (Holt Helicopters, Uvalde, Texas; Barrett et al. 1982, DeYoung 1988). One helicopter (Robinson 22) equipped with a pilot and net gunner actively pursued and captured deer. Once a deer was captured in a net, the gunner would hobble the deer and attach it via cable underneath the helicopter, where it was transported to a centrally located processing station consisting of 2 or 3 experienced, 4-person on-ground processing crews (DeYoung, 1988, Webb et al. 2008, Jacques et al. 2009).

Once deer arrived at the processing station, they were blindfolded using a cotton hood, manually restrained, and removed from the netting. Additional stress agents such as unnecessary noise and talking were minimized. I equipped each deer with Sirtrack Model G2C 191 GPS neck collars (Sirtrack, Havelock North, New Zealand). Each deer was given an ear tattoo and aged according to tooth replacement and wear (Severinghaus 1949). Additional information recorded prior to release included sex, GPS and VHF frequency, ear tattoo number, and body condition. Each deer was then released at the

Figure 13. Area within which all white-tailed deer were captured and equipped with GPS collars (green outline; 2,500 ha) and location of camera sites where bait was placed in the field (orange outline; 1,425 ha) on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA. Deer were captured 4 and 5 July 2012 via helicopter and net gun, and baited camera surveys were conducted 6–17 August 2012. Camera stations, marked by the yellow stars, were systematically placed at a camera density of 1 camera for every 57 ha.

processing site. Capture times were recorded and all deer were released within 20 minutes (5.3 min average) of capture to reduce stress.

All capture and handling was done without use of drugs or anesthetics due to the increased risks of capture myopathy inherent with their use. Peterson et al. (2003) showed in a review of 16 journal articles that drugs would increase handling time and have greater adverse physiological effects on the study animals than physical restraint alone. All animal procedures were approved by the Texas A&M University Institutional Animal Care and Use Committee (AUP#: 2011-154).

GPS Collars.— Each GPS collar had a radio VHF frequency that was designed to be compatible with the VHF R2000 receiver (Advanced Telemetry Systems, Isanti, MN), each collar could be located 1–2 times/week. Collars were programmed to record a mortality signal when there was no movement for 4 hrs. This signal was then transmitted to the GPS's satellite and VHF signal frequency increased from 60 beats per second to 90, which could then be tracked from the ground. Each collar was equipped with a timed collar release mechanism that was programmed to drop off on 31 October 2012 at which time the collars were retrieved from the field.

The GPS collars were programmed to record GPS locations every 15 minutes. These locations were stored on the collar and downloaded after the collars were retrieved from the field.

Camera Design.—I established 25 camera sites based on guidelines provided by Jacobson et al. (1997), using Cuddeback Attack IR digital cameras (Non Typical, Inc., Green Bay, WI). I overlaid a 5 x 5 grid with a cell size of 57 ha in GIS and place cameras near the center of each grid creating a camera density of 1 camera for every 57 ha. Exact placement varied slightly based on topography, likelihood of visitation by deer, and ease of access (Jacobson et al. 1997). The GPS location for each camera site was recorded and a numbered tag was placed in view of the camera for site identification. Debris and vegetation were removed and cameras were oriented in a northerly direction to eliminate backlighting caused by sunrise or sunset.

I performed the baited camera survey from 6 August 2012 through 17 August 2012 in order to coincide with times when deer are typically surveyed and while I had GPS-collared deer in the field. I baited and activated all 25 cameras on 6 August 2012 using approximately 12.5 kg of shelled corn per camera site placed 3–5 m from each camera. Each camera was set on a 24-hr motion capture setting with a 1-minute delay between pictures.

Selection Criteria

I selected among the 35 adult (>18 months of age) deer (18 female, 17 male) captured and GPS-collared on 4 and 5 July 2012 (Fig. 14) for those with access to baited camera locations to eliminate bias from deer that were never exposed to bait. I narrowed my deer selection by 2 methods using ArcGIS (ArcMap GIS, Version 10.0, Redlands, CA). First, I calculated minimum convex polygons (MCP) for each individual to determine the complete range of each animal for the 12 days that bait was present. From this, I was able to determine that 20 deer had a range that overlapped at least 1 bait source location. I then performed a search by location for these 20 individuals to

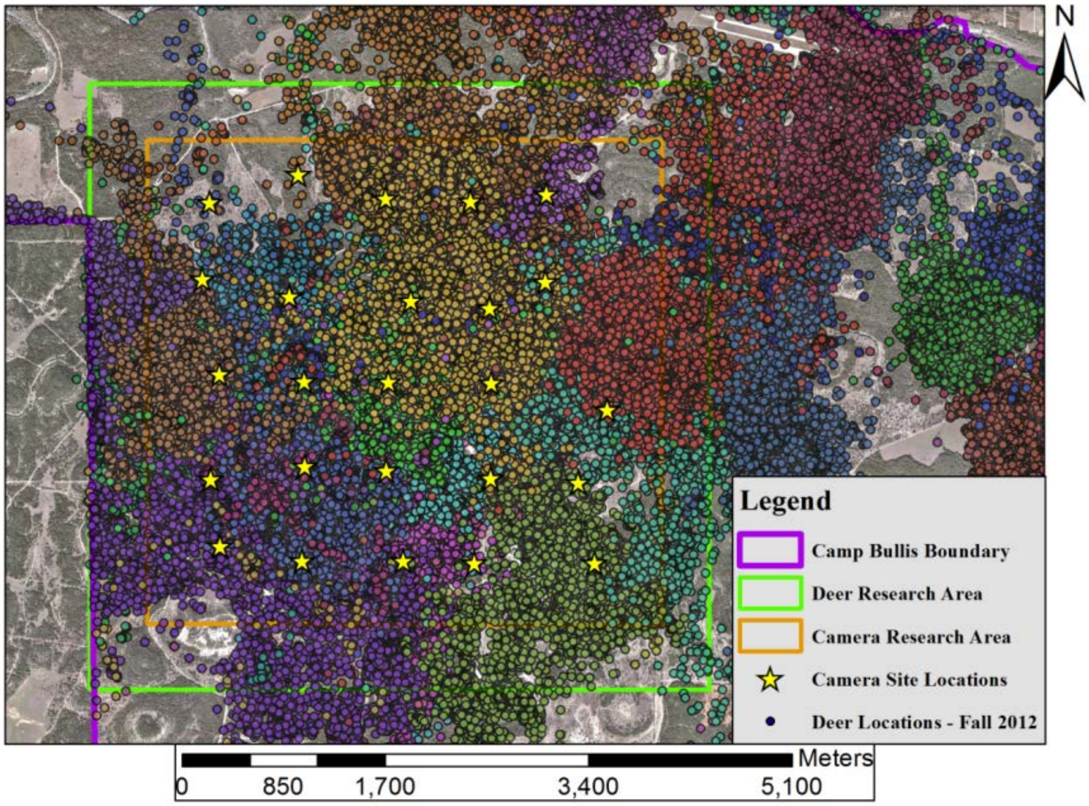


Figure 14. Distribution of all 35 white-tailed deer captured 4 and 5 July 2012 in relation to camera bait site locations on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA. Deer were captured using the helicopter and net gun method within the neon green box covering approximately 2,500 ha.

determine if they came within 10 m (maximum observed error range in complete canopy closure) of a bait source location. I determined 18 (9 males and 9 females) deer came within 10 m of at least 1 bait source location and thus believed them to have been exposed to bait and included them in the analysis.

For these 18 deer, I selected points within 3 distinct 10-day time periods: before bait was placed in to the field (pre-bait), during the time bait was placed in the field (bait), and after bait was removed from the field (post-bait). The 3 time periods extended from 27 July–5 August 2012, 8–17 August 2012, and 20–29 August 2012 for pre-bait, bait, and post-bait time periods, respectively. The pre-bait period examined dates immediately before the introduction of bait into the field and therefore was treated as my control time period to mark ‘normal’ deer behavior. The bait period examined the time period in which deer were actively exposed to bait in order to capture any change in behavior due to the introduction of bait. The post-bait period examined the time period immediately following the removal of all bait from the field and allowed me to examine whether deer displayed a ‘search-like’ behavior following the removal of bait they were previously exposed to (Kilpatrick and Stober 2002).

The first 2 days that bait was introduced into the field were excluded from analysis in order to minimize variance due to bait discovery by allowing deer time to locate the bait sources. Preliminary analysis showed all 18 deer appeared within 10 m of a bait location by 8 August 2012. Because I baited every 2 days, I repeated this exclusion of the first 2 days for the post-bait period because I expected the opposite effect to occur. Deer would be returning to their normal sites in hopes of finding the bait source replenished.

Data Analysis

Deer do not use their environment uniformly and therefore will not be randomly distributed across the landscape and thus, deer locations closer together will be more similar than those farther apart (Hobbs 1996, Kie et al. 2002, Stewart et al. 2006). This will result in a degree of spatial autocorrelation which violates the assumption of independence among observations required by more traditional statistical methods such as an analysis of variance (Legendre 1993). Therefore, I analyzed my deer point locations using a Mantel test because of its ability to account for spatial autocorrelation in the data. The effect of the temporal presence or absence of bait sources across the landscape on deer point locations, fractured by sex, was tested against the spatial distance to the nearest bait source and percent canopy coverage using a simple Mantel test, partial Mantel test, and cross Mantel test using the software PASSaGE (Rosenberg and Anderson 2011). For each test, I used the normalized Mantel correlation statistic (r) and 2-tailed P -value with a level of significance 0.05 to assess the relationship between 2 matrices. I also performed a modified t-test between the variables used in the Mantel tests.

A grid was used to help create the matrices used for the Mantel test analyses. I used the Grid Index Features within ArcGIS to create a 100 x 100 m grid coverage of all the deer locations and baited camera sites (Fig. 15). The center location (X, Y) of each grid cell served as my spatial distance matrix (B). I then calculated total count of deer

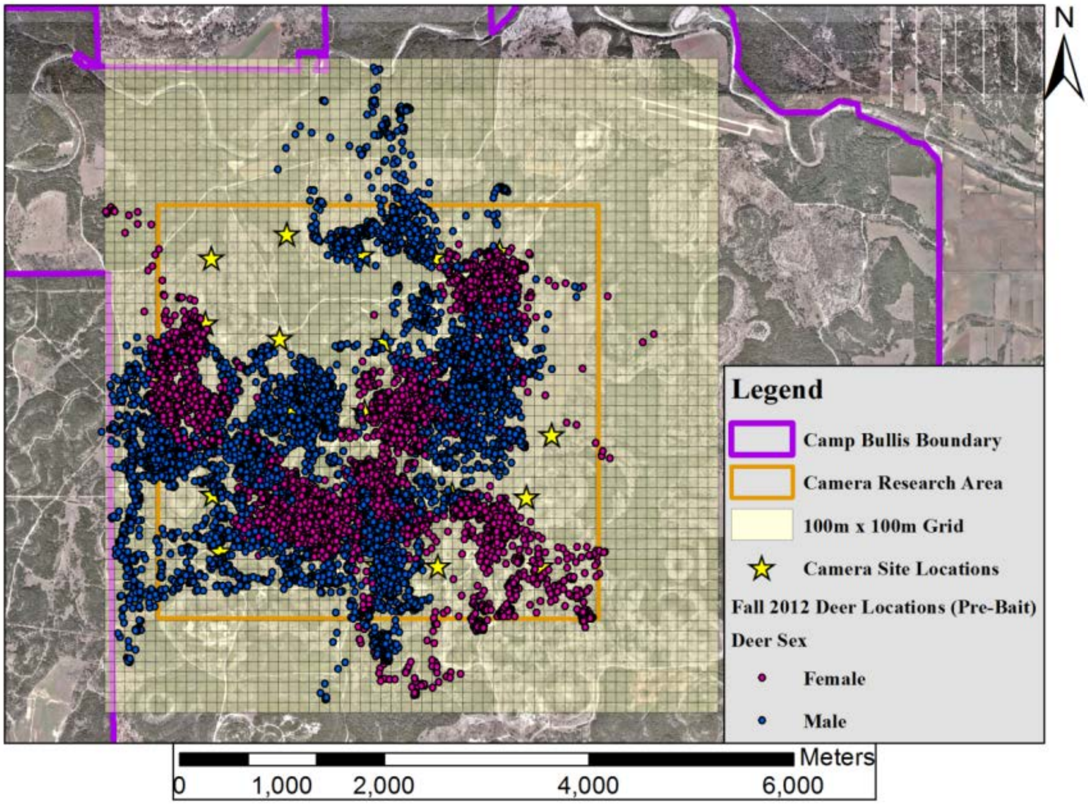


Figure 15. Distribution of all white-tailed deer locations, fractured by sex, for the 10-day pre-bait time period (27 July–5 August) in relation to bait site locations at a grid scale of 100 x 100 m on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA. The 100 x 100 m grid which was used for variable calculations is marked by the light yellow transparent grid that encompasses all deer locations.

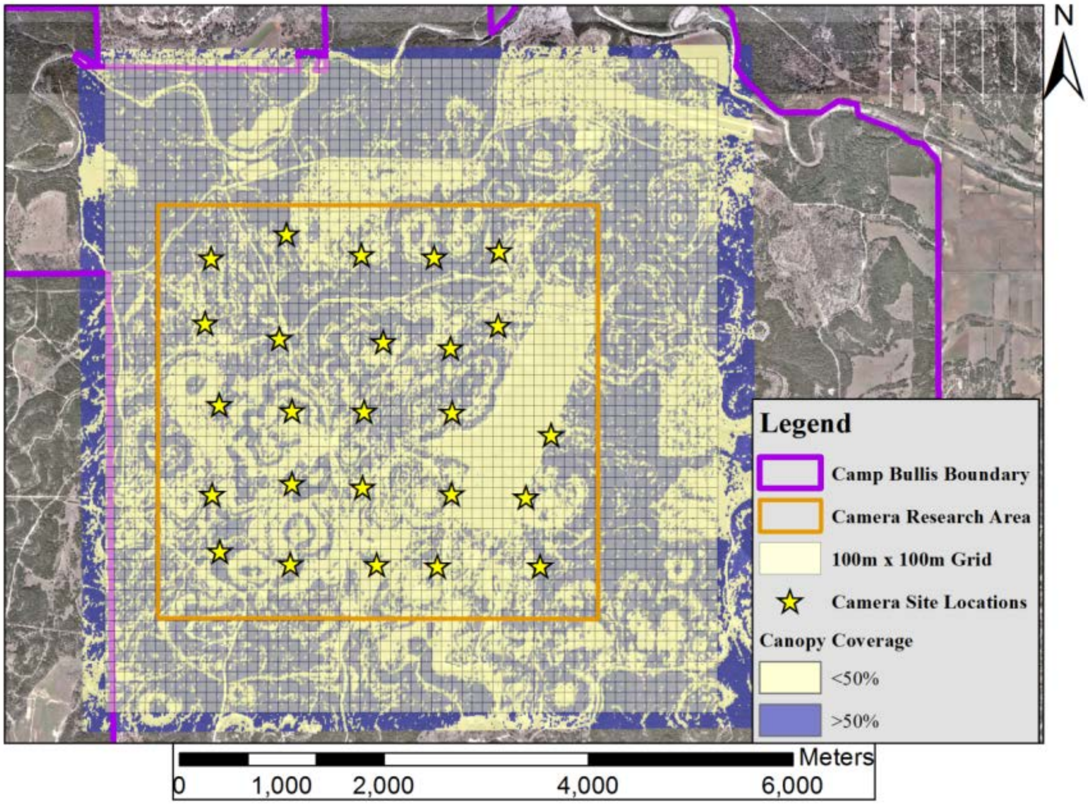


Figure 16. Percent canopy cover overlaid by 100 x 100 m grid system for my study area on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA. Percent canopy coverage within each grid cell of the 100 x 100 m grid system served as a distance matrix (C1) classified using a supervised classification of 10 m resolution satellite aerial image. The blue highlights canopy coverage greater than or equal to 50% and the yellow highlights canopy coverage less than 50%.

point locations, fractured by sex, for each of the 3 distinct time periods, within each grid as my variable distance matrix (A1, A2, and A3). I then had an additional variable distance matrix: percent canopy coverage within each grid cell (C1). Percent canopy cover was classified using a supervised classification of 10 m resolution satellite aerial image (Fig. 16).

In addition to the Mantel test, I wanted to provide a measure of difference across the 3 time periods for deer distributions in relation to bait location. Therefore, I used ArcGIS to calculate the distance from each deer location to the nearest bait site, fractured by sex, for each of the 3 time periods. I then used these distances to create and compare frequency distributions at 100 m intervals.

RESULTS

All simple, partial, and cross Mantel tests showed significance regardless of sex (Tables 12 and 13). Although statistically significant, the correlation between male locations and percent canopy cover during the bait period was the weakest relationship tested. All 3 time periods were significantly correlated for both males and females. Additionally, tests between the sexes showed that male and female pre-baiting and post-baiting were significantly correlated, but the baiting period was slightly insignificant. None of the tests with percent canopy cover were significant. All significant modified *t*-test indicated positive correlations (Table 14).

The relative frequency distribution, for the 3 full 10-day time periods, of males and females revealed that males used bait stations at a higher frequency while bait was

Table 12. Simple, cross, and partial Mantel test results for male and female white-tailed locations and distance matrices created from data collected on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from 27 July–29 August 2012. Variables include time period (pre-bait (A1), bait (A2), post-bait (A3)), center location (X, Y) of each 100 x 100 m grid cell (B), and percent canopy cover (C) distance matrices.

Distance matrices	**Results (males)**	**Results (females)**
A1B	t = -9.859; P = 0.000	t = -15.618; P = 0.000
A2B	t = -9.385; P = 0.000	t = -14.739; P = 0.000
A3B	t = -11.834; P = 0.000	t = -16.445; P = 0.000
A1C	t = -2.782; P = 0.005	t = -2.022; P = 0.043
A2C	t = -2.537; P = 0.011	t = -2.728; P = 0.006
A3C	t = -2.553; P = 0.011	t = -2.686; P = 0.007
A1B.C	t = -9.801; P = 0.000	t = -15.569; P = 0.000
A2B.C	t = -9.331; P = 0.000	t = -14.680; P = 0.000
A3B.C	t = -11.779; P = 0.000	t = -16.386; P = 0.000
A1A2	t = 19.265; P = 0.000	t = 42.689; P = 0.000
A2A3	t = 29.156; P = 0.000	t = 34.476; P = 0.000
A1A3	t = 32.673; P = 0.000	t = 35.655; P = 0.000

Table 13. Intersex Mantel test results for white-tailed deer located on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA for data collected from 27 July–29 August 2012. Variables included male pre-bait (A1M), female deer pre-bait (A1F), male deer bait (A2M), female deer bait (A2F), male post-bait (A3M), and female post-bait (A3F) distance matrices.

Distance matrices	**Results**
$A1_MA1_F$	t = 5.903; P = 0.000
$A2_MA2_F$	t = 4.936; P = 0.000
$A3_MA3_F$	t = 9.090; P = 0.000

Table 14. Modified t-tests for direct correlation analysis between males and female white-tailed deer located on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA for data collected from 27 July–29 August 2012. Variables included in analysis were pre-bait (A1), bait (A2), post-bait (A3), and percent canopy cover (C) distance matrices.

Variable 1	**Variable 2**	**Results**
Male A1	Male A2	$\rho = 0.336$; $P = 0.000$
Male A1	Male A3	$\rho = 0.524$; $P = 0.000$
Male A1	Female A1	$\rho = 0.109$; $P = 0.000$
Male A1	Female A2	$\rho = 0.101$; $P = 0.000$
Male A1	Female A3	$\rho = 0.222$; $P = 0.000$
Male A1	C	$\rho = -0.046$; $P = 0.391$
Male A2	Male A3	$\rho = 0.474$; $P = 0.000$
Male A2	Female A1	$\rho = 0.080$; $P = 0.112$
Male A2	Female A2	$\rho = 0.093$; $P = 0.054$
Male A2	Female A3	$\rho = 0.109$; $P = 0.040$
Male A2	C	$\rho = -0.048$; $P = 0.341$
Male A3	Female A1	$\rho = 0.063$; $P = 0.271$
Male A3	Female A2	$\rho = 0.069$; $P = 0.209$
Male A3	Female A3	$\rho = 0.161$; $P = 0.007$
Male A3	C	$\rho = -0.069$; $P = 0.220$
Female A1	Female A2	$\rho = 0.679$; $P = 0.000$
Female A1	Female A3	$\rho = 0.573$; $P = 0.000$
Female A1	C	$\rho = -0.044$; $P = 0.471$
Female A2	Female A3	$\rho = 0.559$; $P = 0.000$
Female A2	C	$\rho = -0.046$; $P = 0.429$
Female A3	C	$\rho = -0.059$; $P = 0.362$

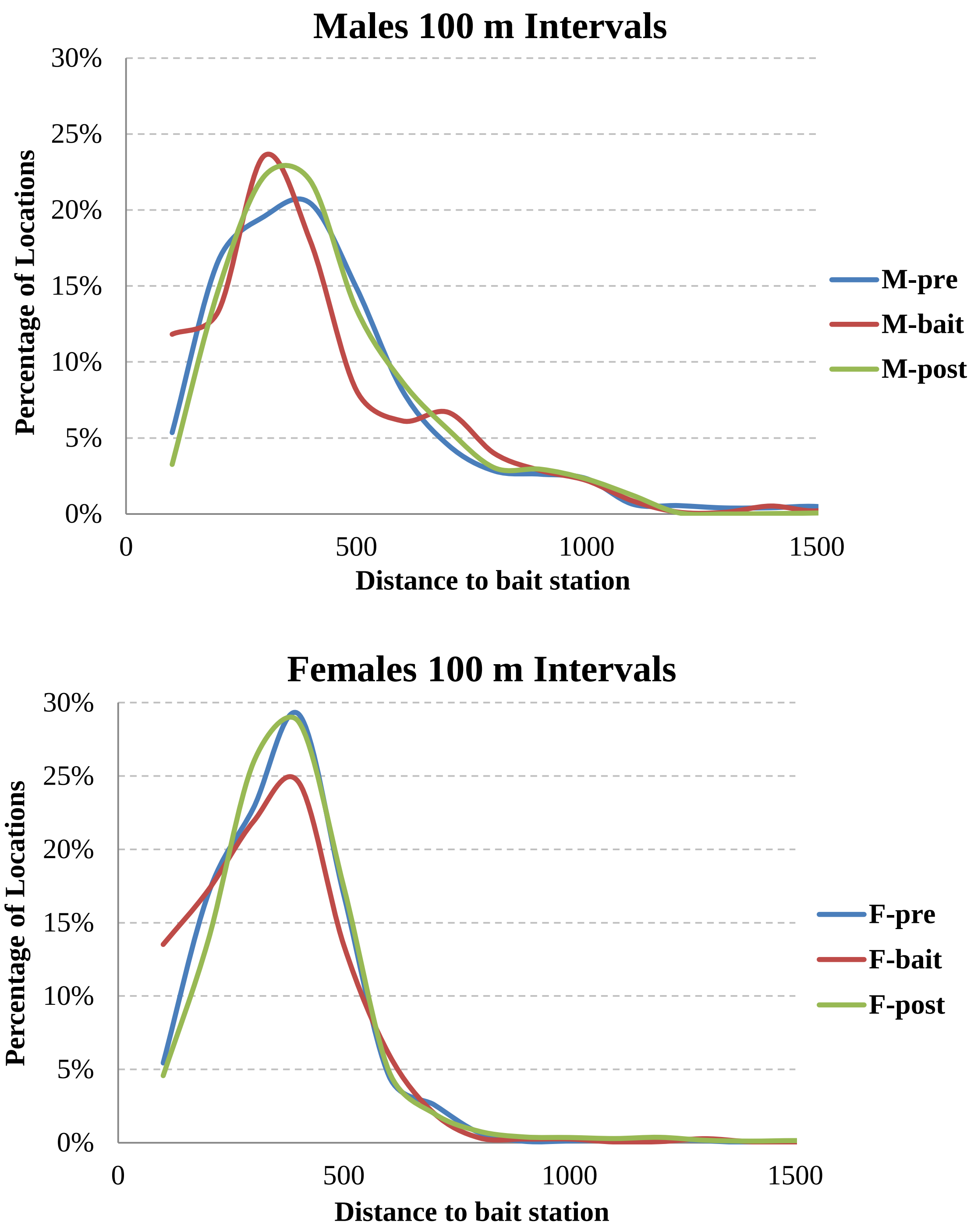


Figure 17. Relative frequency distribution curves for male and female white-tailed deer distances to bait station at 100 m bins during pre-bait (27 July–5 August 2012), bait (8–17 August 2012), and post-bait (20–29 August 2012) time periods for Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA.

present (Fig. 17). The center of activity for male frequency distributions shifted approximately 100 m (25%) closer to bait locations and showed a 7% increase in percentage of locations in grid-squares adjacent to the bait stations when bait was present in relation to pre-bait period (Fig. 17). Females also showed a 7–8% increase in frequency of locations in grid-squares adjacent to bait stations when bait was present in relation to pre-bait period. However, center of activity for female frequency distribution curves remained consistent over all 3 time periods regards to distance from bait sites (Fig. 17). Frequency distributions for the 3 full 10-day time periods revealed no difference between the pre- and post-bait time periods for either sex (Fig. 17). However, the 3-day frequency distribution for the post-bait time period, with a 1-day moving window, revealed that male deer shifted their peak distances away from bait sites for the 2–4, 3–5, and 4–6 day frequency curves (Fig.18).

DISCUSSION

Deer distributions were non-random for both sexes, during all 3 bait periods, and for percent canopy cover. However, for the males, the Mantel test comparing time period against percent canopy cover for the bait period (A2C) and post-bait period (A3C) were less significant (Table 12). Both males and females increased their use of locations immediately adjacent to bait sites after the application of bait; however, only males appeared to adjust their overall movements to select for those areas in closer proximity to bait sites indicating that bait had a stronger influence on males. Moving window frequency distributions indicated that males temporarily moved their peak deer distances

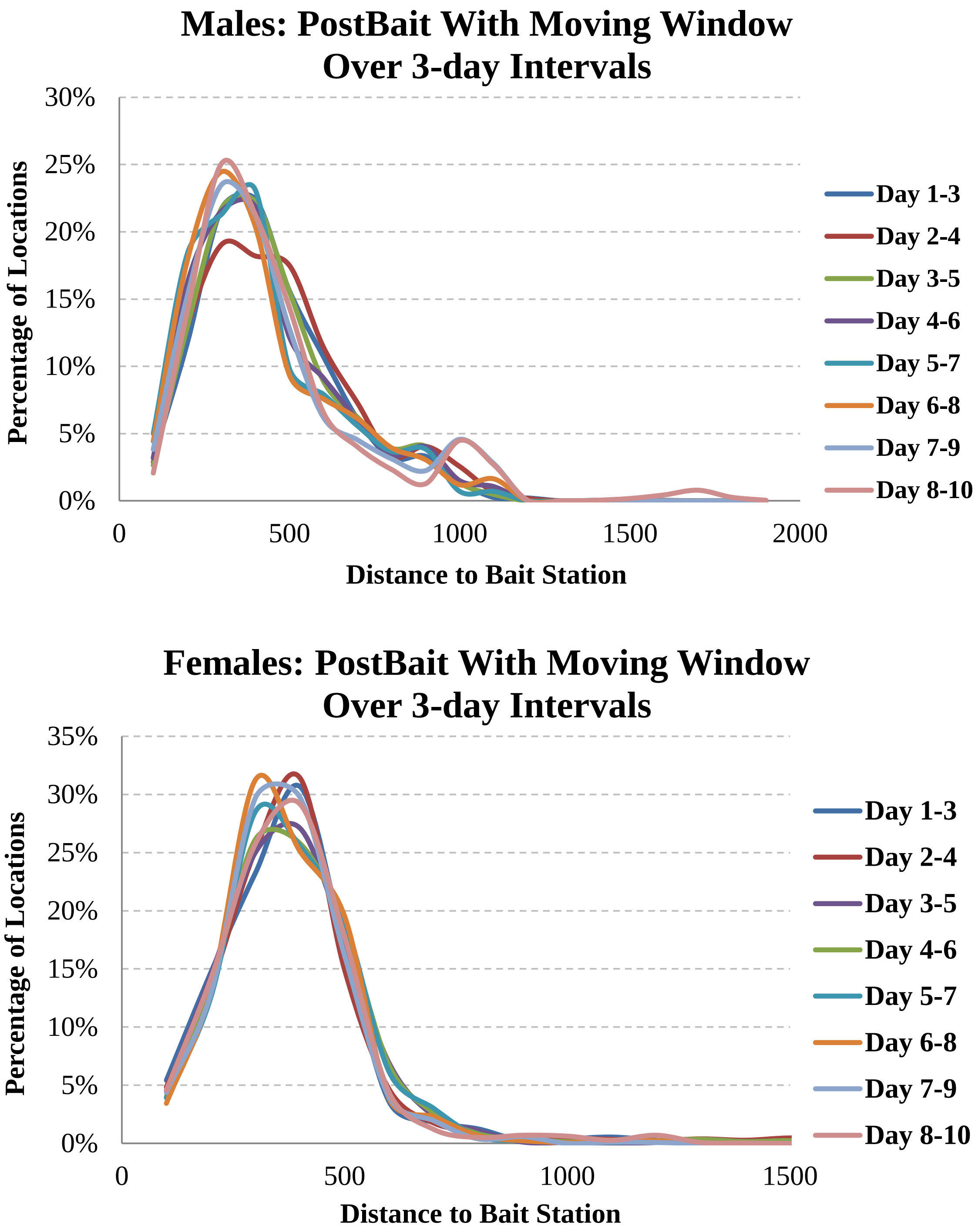


Figure 18. Relative frequency distribution curves for male and female white-tailed deer distances to bait station, grouped by 3 day intervals using 100 m bins, during the post-bait time (20–29 August 2012) with a 1-day moving window for Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA.

farther away from bait stations after bait was removed giving support for a search-like behavior. During the bait period, percent canopy was the least significant determinant of deer distributions. My data provide evidence supporting the potential of bait to evoke a stronger response from males and ultimately violate the assumption of equal detectability during camera surveys and result in underestimation of density estimates. However, overall results indicate that there may be greater individual variation in response to the presence of bait than previously expected.

Deer distributions across the landscape were non-random irrelevant of sex, bait period, or percent canopy cover (Table 12). Modified *t*-test revealed that these non-random deer distributions all had a positive correlation with males and females responding similarly to the presence and absence of bait. During the bait period, percent canopy was the least significant determinant of deer distributions. This indicates that bait not only had the greatest effect on male deer behavior, but that bait may be a more important determinant of male deer space use than canopy cover of woody vegetation. Therefore, it appears that the presence of bait is especially significant for male deer because it has the potential to diminish their selection of other environmental factors (e.g., canopy cover) that are biologically relevant for controlling deer distributions in the absence of bait. This could potentially result in decreased male survivability because unlike other naturally occurring food sources the availability of bait locations is strictly dependent upon human choice.

As with studies from other regions of the United States, deer displayed variable behaviors in response to baiting throughout my study; however, I believe temporary bait sites may increase sightability of local deer, but will not affect deer with home ranges that do not contain bait sites (Kilpatrick and Stober 2002, Campbell et al. 2006). For example, examination of camera photos in conjunction with my GIS data revealed 2 of the 35 deer originally captured had bait sites within their non-baiting range did not use bait sites, 1 deer that did not have bait sites within their non-baiting range used bait sites, and 2 of the 18 deer included in the bait analysis used as many as 4 different bait sites within a 10-day period.

Females showed an increase in frequency of locations in grid-squares adjacent to bait stations when bait was present in relation to pre-bait period; however, the overall center of activity for female frequency distribution curves remained consistent over all 3 time periods in regards to distance from bait sites (Fig. 17). Campbell et al. (2006) saw similar behavior with radio-collared female deer showing high variability in response to baiting, with an overall pattern of increased activity closer to bait sites during baiting periods but no real change in overall range. Although, the relative frequency distribution curves showed that male deer not only increased their time spent near bait stations, but also shifted their center of activity nearer to bait sources by approximately 25% (Fig. 17) providing further support for a pro-male bait bias.

Moving window calculations indicate that male deer, from days 2–5 of the post bait period, had shifted their center of activity >100 m farther away from bait sites than during the pre-bait period (Fig. 18). The females also appeared to indicate a similar searching behavior, but not as distinctly as the males (Fig. 18). Furthermore, visual inspection of the actual male and female point distributions across the landscape during the post-bait time period also supports the moving window’s conclusions (Fig.19). In comparison to the pre-bait time period, the point locations during the baiting period are more heavily concentrated around the bait sites (Fig. 19). After the removal of bait, deer locations are again dispersed, and in some instances, are dispersed even farther away from bait sites than observed in the pre-bait period (Fig. 19) supporting the notion that deer, at least temporarily (2–5 days), may display a hyperdispersed or ‘search-like’ behavior following the removal of bait. Deer distances appeared to transition back to those during the pre-bait period around the 5–7 day window for both males and females with the last 3, 3-day moving windows (6–8, 7–9, and 8–10 days) exhibiting similar distances to the pre-bait time period. Kilpatrick and Stober (2002) observed similar behavior where temporary bait sites caused an increase in movement activity when bait sources were removed.

Jacobson et al. (1997) recognized gender bias could be problematic for estimates of deer populations. The results of my study support this idea, and showed that male deer increased time spent near bait site locations and thus have a greater likelihood of detection during baited camera surveys conducted in the autumn (Cutler and Swann 1999, Kilpatrick and Stober 2002, Campbell et al. 2006, Roberts et al. 2006). This pro-male bait-bias is a violation of the assumption of equal detectability and will lead to skewed sex-ratios and more importantly, inflated ratios of male pictures to uniquely identifiable males, which will result in density estimates which are biased low because the number of females and fawns will be underestimated.

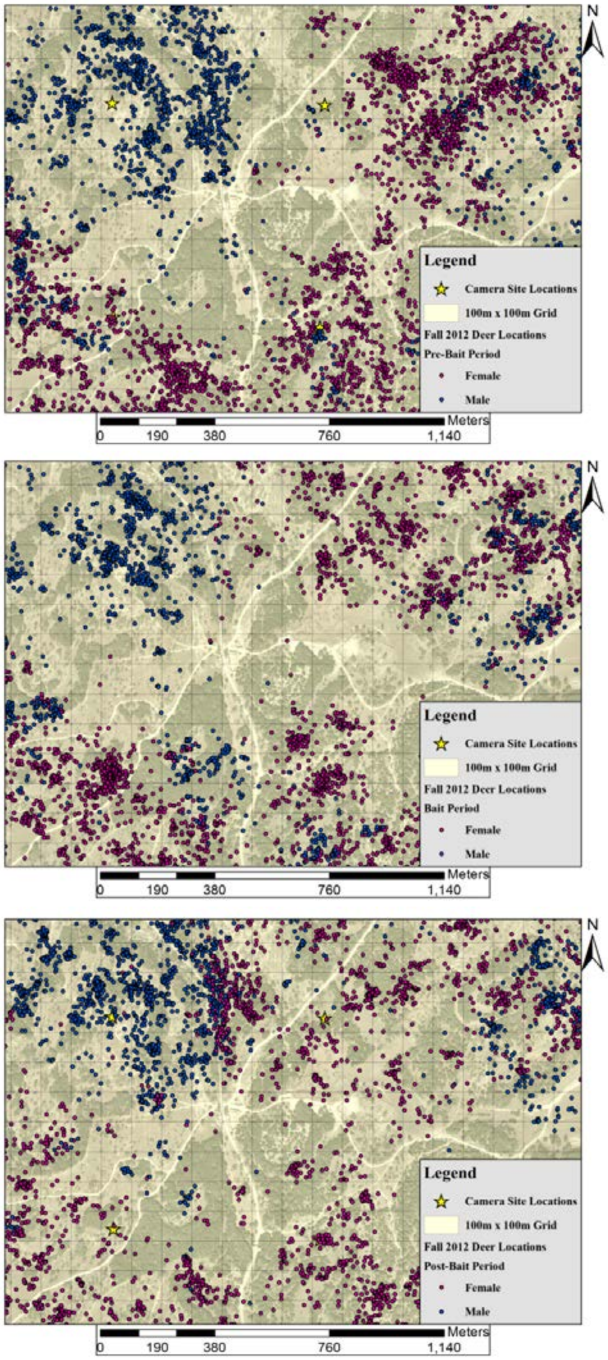


Figure 19. White-tailed deer locations, by sex, in relation to camera bait sites 12 (northwest), 13 (north-central), 17 (southwest), and 18 (south-central) for pre-bait (27 July–5 August 2012), bait (8–17 August 2012), and post-bait (20–29 August 2012) time periods, respectively, at a grid scale of 100 x 100 m on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA.

My data revealed that percent canopy was the least significant determinant of male deer distributions in the presence of bait. Therefore, it appears that the presence of bait is especially significant for male deer because it has the potential to diminish their selection of other environmental factors (e.g., canopy cover) that are biologically relevant for controlling deer distributions in the absence of bait. Therefore, I believe that further examination of additional biologically relevant environmental variables (e.g., edge density, nearest neighbor distance to patch, core patch size, and overall landscape diversity and richness) that determine deer movements and distributions across the landscape, are needed to get a better understanding of the influence bait has on determining deer distributions at the patch and landscape levels.

MANAGEMENT IMPLICATIONS

My results showed a pro-male bait-bias and thus a higher likelihood of detection in male deer during baited autumn camera surveys, violating the assumption of equal detectability. Therefore, I recommend managers not base harvest quotas solely from estimates obtained via pre-hunting season camera surveys that use bait or at least, be aware of the potential biases and adjust for the likelihood that females and fawns are underestimated. My data also suggests that control (e.g., sport hunting) or eradication (e.g., localized management) strategies that use temporary bait sites will have limited effect on deer with ranges outside of the bait sites, but may concentrate those already naturally occurring in areas near bait sites.

CHAPTER IV

EVALUATION OF ROAD-BASED SURVEY BIAS AND EFFECTS ON SPOTLIGHT SURVEYS[*]

SYNOPSIS

Spotlight line-transect (spotlight) surveys are a popular means of surveying white-tailed deer populations (*Odocoileus virginianus*; deer). Spotlight surveys have been employed at Joint Base San Antonio-Camp Bullis (Camp Bullis) since 1997 for estimating deer population estimates. Established roads are often used as survey transects for convenience and safety, but can bias research due to their nonrandom infrastructure and the effect traffic may have on wildlife distributions. Few publications have examined the influence road type and traffic volume (traffic disturbance) have on deer observations and how it could bias population estimates. Using methodology similar to Pierce (2000), I conducted spotlight surveys along 11 roadway segments based on road surface type (paved, maintained gravel (gravel), and unimproved (trail)) in both the spring and autumn 2012 and 2013 across my research area on Camp Bullis. Distance sampling analysis was conducted using R statistical computing software in order to obtain density estimates. Road traffic also was monitored for each spotlight transect using infrared-triggered cameras to provide a categorical disturbance level for traffic volume per road type. Deer-density estimates suggest a possible difference between

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[*] Part of the data reported in this chapter is reprinted with permission from “The use of remote cameras to monitor traffic activity” by M. A. Padilla, 2013. Thesis, Texas A&M University, College Station, USA.

gravel and trail road types compared to paved roads, but differences were not distinct as all confidence intervals overlap. Analysis of variance comparing observed deer distance measurements by road type, traffic disturbance level, and average visibility (distance from observer to vegetation edge) showed a clear distinction between gravel roads with medium traffic disturbance (34.3 m visibility) and paved roads with high traffic disturbance (90.5 m visibility) and trails with low disturbance (72.6 m visibility). Ultimately, more deer per area are encountered on trails and gravel roads than on paved roads, supporting the idea that deer either shy away from paved roads or congregate near trails and gravel road types. Because more deer were seen per unit of distance on trail and gravel roads than paved roads it is more likely deer shied away from paved roads due to traffic level and thus have density estimates that are biased low. However, deer density could be biased high for gravel roads where distance from observer to vegetation edge (i.e., visibility distance) was lowest because deer preferentially use edges for foraging which could be inflating observation data. I recommend that managers either try to use road types that minimize traffic disturbance while maximizing visibilities, or incorporate an even distribution of non-overlapping transects for all road types present.

INTRODUCTION

A variety of survey techniques have been developed for estimation of white-tailed deer (*Odocoileus virginianus*; deer) population densities (Lancia et al. 1994, Gill et al. 1997, Drake et al. 2005, Collier et al. 2013). Spotlight line-transect surveys are a specialized transect method (Anderson et al. 1979) used to generate population estimates, and has been employed at Joint Base San Antonio-Camp Bullis (Camp Bullis) since 1997 (e.g., Pierce and Baccus 1999, Pierce 2000). Spotlight surveys are a popular means of surveying deer populations (McCollough 1982, Synatzke 1984, Fafarman and DeYoung 1986) and commonly used for distance sampling of deer because of low cost and simplicity (Whipple et al. 1994, Collier et al. 2007).

Distance sampling estimates density by fitting a function through observed perpendicular distances and evaluating that function at distance zero (Anderson et al. 1979, Buckland et al. 1993, Langdon et al. 2001, Roberts 2005). By avoiding the need to ensure that all animals within a predetermined area are detected, distance methods are usually more efficient than conventional deer survey methods such as strip-transect sampling using spotlighting and pellet surveys (Burnham et al. 1985, Gill et al. 1997, Buckland et al. 2001, Ward et al. 2004, Roberts 2005). Distance sampling techniques are potentially well-suited to monitor deer in areas where detection or visibility varies as a continuous function of distance from the observer (Gill et al. 1997, Buckland et al. 2001, Focardi et al. 2002).

Distance sampling also requires randomly or systematically placed transects (Buckland et al. 2001, Marques et al. 2010, Collier et al. 2013), but for logistical and safety reasons, established roads are often used as survey transects for distance sampling methods (e.g., spotlight surveys, ground imaging; Gill et al. 1997, Heydon et al. 2000, Ward et al. 2004, McShea et al. 2011). However, road systems bias population estimates due to their nonrandom placement and the effect traffic may have on wildlife (Buckland et al. 2001, Roberts et al. 2006). Sampling designs that, either by choice or necessity, use roads are subject to potential systematic differences in deer distribution with respect to the sampling location, because deer preferentially use openings along roadsides for foraging (Case 1978, Findera et al. 1999, Stewart et al. 2011) or avoid roads because of the disturbance from vehicles, resulting in nonrandom sampling.

Furthermore, roads are engineering constructs designed to allow for efficient conveyance between locations. Consequently, the engineering and sociological specifications determining the location of roadways seldom include a proportional linear intersection of all available vegetation types within the area traversed by the road. Worse, deer distribution may be correlated with abiotic factors associated with road locations due to engineering constraints such as topography, soil type, and/or geology. Whether the difference in deer distribution is caused by the road type, or merely correlated with the location of the road, makes no difference. If the distribution of deer near roads is different from the distribution of deer throughout the remaining area of inference, bias will occur. As such, the challenge with sampling from roads is to demonstrate that the samples obtained are a valid representation of the area of inference. Problems associated with road-based sampling have been previously documented (Anderson et al. 1979, Burnham et al. 1980, Pollock et al. 2002, Collier et al. 2013) and reported to bias density estimates by ≥100% (2× greater; Marques et al. 2010, Beaver et al. 2014).

Traffic data are important factors in wildlife research and are already collected by governmental agencies for use in infrastructure planning (Padilla 2013). Various sensors and pressure plates are used for larger freeway traffic, but more inexpensive, practical means can be used for rural or 2-lane roads (Padilla 2013). Manual observations are relatively simple, but are often limited by labor, time, and availability of personnel (Skszek 2001). Road-based population surveys are assumed to be influenced by traffic volume; however, are few data to validate this assumption (Progulske and Duerre 1964, Beier and McCullough 1990). Knowledge of traffic density on road systems can help eliminate bias when using these techniques (Butler et al. 2005, Erxleben et al. 2011).

Recent observations by Camp Bullis natural resource personnel have lead them to question whether the movement of white-tailed deer due to road type and/or disturbance related to traffic volume violate some of the assumptions required when using distance sampling methodology for analyzing spotlight deer survey data: (1) deer located on the transect are detected with certainty, (2) deer do not move in response to the observer's presence, and (3) accurate measurements are taken (Buckland et al. 1993, Langdon et al. 2001, Tomas et al. 2001, Focardi et al. 2002, Koenen et al. 2002). Thus, a major objective of my study was to determine the influence of road type (paved, maintained gravel (gravel), and unimproved (trail)) and traffic volume on deer distributions and if differences create substantial bias in population estimates obtained by distance sampling during spotlight line-transect surveys.

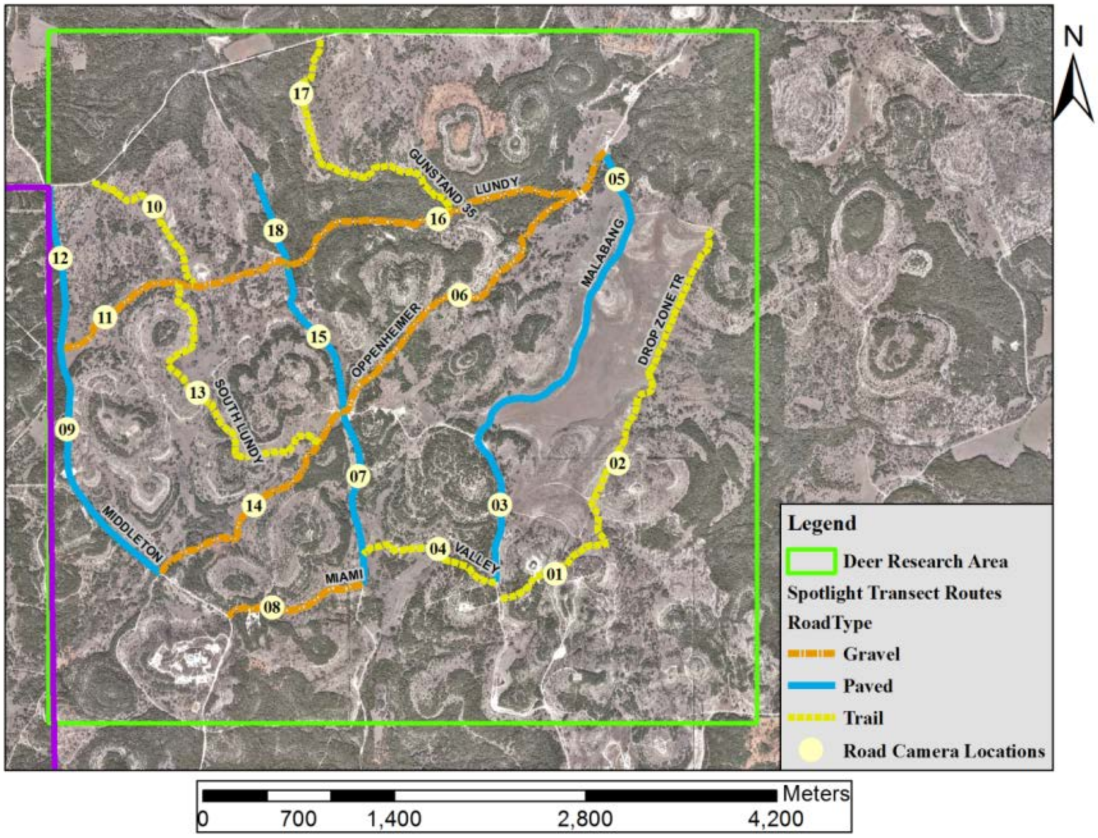

Figure 20. White-tailed deer research study area overlaid with spotlight line transects and traffic monitoring camera stations for Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA, 2012–2013. Traffic monitoring camera locations are numbered and the 3 different road types are color coded (blue = paved, orange = maintained gravel, yellow = unimproved (trail)).

METHODS

Study Area

I conducted my study on Camp Bullis, a military installation located immediately north of San Antonio, Texas, USA (Fig. 2). The installation covered 11,286 ha, and the area was characterized as an ecotone of the Edwards Plateau, Blackland Prairies, and South Texas Plains Ecological Regions of Texas (Gould 1962). The area in which spotlight surveys were conducted expanded over 2,500 ha on the northern part of Camp Bullis (Fig. 20).

The study area location was selected based on a variety of issues related to research objectives (e.g., troop density, varied levels of troop activity, road type, traffic levels, and distance from live ranges). However, the biggest factor was safety of military personnel and avoidance of the southern half of Camp Bullis which was mostly cantonment area consisting of buildings, barracks, and live weapon ranges.

Spotlight Surveys

Spotlight surveys were conducted using a standardized protocol (Pierce 2000) to collect data for distance sampling estimates of local population density. This method is a modification of the standard spotlight strip transect (Progulske and Duerre 1964, Harwell et al. 1979, Mitchell 1986) and line transect sampling techniques (Burnham and Anderson 1984, Burnham et al. 1985, Buckland et al. 1993), which allows for the calculation of perpendicular distances from non-linear transects. Surveys were conducted during spring and autumn to coincide with each capture period in order to obtain density and herd composition estimates when GPS-collared deer were in the field

(Downing et al. 1977, McCullough 1982, Beier and McCullough 1990, McCullough et al. 1994). Spring spotlight surveys were conducted late March – early April and autumn surveys mid-August for both 2012 and 2013. Spotlight surveys were conducted around sunset which was typically 1800–2000 hours during these survey periods.

Spotlight surveys were conducted along 11 roadway segments based on road surface type (paved, gravel, and trail; Fig. 20). Each road surface type was represented by approximately 10.2 km of road. Surveys were initiated within 30 minutes of official sundown with research crews consisting of a driver, recorder, and 2 spotters. Data collected for each survey transect included time and climatic conditions at the start and end of the transect, time and location of vehicle at each sighting, number of animals in each group, distance and bearing to the center of each group or individual, mark status (i.e., whether individual is GPS-collared or not), and sex and age (fawn vs. adult). Groups were defined as any localized gathering of deer that move as a unit, whether feeding or fleeing. Spotlight routes were selected to include at least 1 segment per road type, each evening (randomized block design with 1 treatment factor and 3 covariables). Spotlight surveys were replicated so that all 11 road segments were covered weekly over a period of 3 nights and replicated for 4 weeks for each season. So each roadway segment was covered 4 times for a total of 44 surveys for the entire study area during each season.

Distance sampling analysis was conducted using R statistical computing software (version 3.4.1; Program R) which allowed me to calculate probability of detection by integrating the hazard detection function across all perpendicular distances (Mills 2007), and obtain a density estimate (D; deer/km^2) per road type (Table 15). I did not attempt to account for affects by vegetation types (e.g., open, forested, scrub, and developed areas) because of insufficient data (i.e., detections per vegetation type; Gill et al. 1997). Because a few detections were on or near the transect line I left-truncated lower distances of the distribution by 20 m, which was the minimum distance that provided a shoulder for all comparisons as suggested by Ward et al. (2004), and I rescaled the data to 0 to offset the detection line (Buckland et al. 2001). I right-truncated ground-imaging and spotlight data at 5–10% of the observations, as recommended by Buckland et al. (2001).

Visibility

I completed visibility readings for each spotlight transect prior to conducting the surveys. Visibility readings were determined by estimating how far a deer could be seen at right angles to the vehicle. Visibility readings were recorded every tenth of a kilometer (100 m). This was done for both sides of the vehicle and averaged per road type (Table 16). I also calculated maximum and minimum visibility readings for each road type to compare to actual distance readings of deer observations.

Road Traffic Monitoring

The following section reviews the methodologies that were part of a pilot experiment using cameras and pneumatic axel counters conducted to evaluate the effectiveness of using cameras to monitor traffic density on Camp Bullis and published in Manuel Padilla’s thesis (May 2013).

Table 15. Distance sampling white-tailed deer density calculations by road type for spotlight surveys conducted on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA, 2012–2013.

Road type	**D**$^{(1)}$	$n^{(2)}$	**df**	**Effective strip width (m)**	**Area (km^2)**$^{(3)}$	**95% Confidence interval**	**Detection probability**
Gravel	69.1	124	5.99	164.54	1.66	0.487 - 0.980	0.26
Paved	47.4	154	2.47	311.26	3.24	0.186 - 1.208	0.48
Trail	67.2	258	5.00	322.84	3.32	0.373 - 1.212	0.50

[1] D is deer/km^2

[2] Total number of deer observed during spotlight surveys per road type

[3] Transect length x effective strip width

Table 16. Visibility estimates for each road type used during white-tailed deer spotlight surveys on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA, 2012–2013.

Road type	**Avg. distance / vehicle side (m)**[1]	***SD***	**Max**[3]	**Min**[3]
Visibility Numbers[2]				
Gravel	34.3	36.8	313	1
Paved	90.5	167.7	649	2
Trail	72.6	185.5	647	1
Actual Deer Observations				
Gravel	113.7	66.6	335	1
Paved	187.8	115.7	587	2
Trail	208.3	134.1	643	1

[1] Average distance (m) out one side of the vehicle

[2] Perpendicular distance to nearest obstruction

[3] Max-maximum observed distance; Min-minimum observed distance

Road monitoring to determine level of disturbance related to traffic activity was conducted within my deer research area on Camp Bullis from March 2012 to March 2013 using Cuddeback Attack© digital infrared-triggered cameras. Eighteen cameras were placed along 3 different road types: paved, improved, and trail (Padilla 2013; Fig. 20). These cameras were set to the specifications determined in the pilot study: 1 picture followed by a 30-second video on a 15-second delay (Padilla 2013). All cameras were placed in a Cuddesafe© (Cuddeback; Non-typical Inc., Park Falls, WI) to protect from theft and weather. The Cuddesafes were all welded onto steel fence posts that were driven into the ground approximately 2 meters from a road (Padilla 2013). Cameras were placed inside the Cuddesafes which were 1 meter from the ground and pointed 30 degrees off parallel from the road. Data were downloaded weekly using 2-GB SD cards (Padilla 2013).

Vehicle observation data were summarized by hour and month and analyzed using Program R. Pearson's Chi-square analysis of vehicle observations by road type were conducted to test for independence (Padilla 2013). I used these data to help determine the level of vehicular traffic per road type and applied a categorical traffic disturbance level (low, medium, and high) per road type used during spotlight surveys. This allowed me to include traffic disturbance as a variable along with road type and visibility into my analysis of observed deer distances.

Table 17. Analysis of variance for white-tailed deer spotlight survey distance observations factored by year (2012 and 2013) on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA.

Groups	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Between	1	79.19	79.19	0.005	0.942
Within	534	7,977,346.72	14,938.85		

Table 18. Analysis of variance for white-tailed deer spotlight survey distance observations factored by observation season (spring and autumn) on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA.

Groups	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Between	1	11,060.66	11,060.66	0.741	0.389
Within	534	7,966,365.24	14,918.29		

Table 19. Analysis of variance for white-tailed deer spotlight survey distance observations factored by road type (paved, gravel, trail) on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA.

Groups	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Between	2	760,434.67	380,217.30	28.08	0.000
Within	533	7,216,991.24	13,540.32		

Table 20. Analysis of variance and Tukey pairwise comparison for white-tailed deer spotlight survey distance observations factored by categorical level of traffic disturbance (low, medium, and high) on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA.

Groups	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Between	2	760,434.67	380,217.3	28.08	0.000
Within	533	7,216,991.239	13,540.32		

Categorical disturbance	***n*[1]**	**Mean**	**Grouping[2]**
Low (trail)	258	208.25	A
High (paved)	154	187.84	A
Medium (gravel)	124	113.69	B

[1] Total number of deer observed during spotlight surveys per road type.

[2] Means that do not share a letter are significantly different.

Table 21. Analysis of variance and Tukey pairwise comparison for white-tailed deer spotlight survey distance observations factored by average visibility per road type on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA.

Groups	***df***	**Sum Sq.**	**Mean Sq.**	***F* value**	***P*-value**
Between	2	760,434.67	380,217.3	28.08	0.000
Within	533	7,216,991.239	13,540.32		

Average visibility by road type	***n*[1]**	**Mean**	**Grouping[2]**
72.6 (trail)	258	208.25	A
90.5 (paved)	154	187.84	A
34.3 (gravel)	124	113.69	B

[1] Total number of deer observed during spotlight surveys per road type.

[2] Means that do not share a letter are significantly different.

Impacts on Deer Distribution

Analysis of variance (ANOVA) comparing observed perpendicular deer distances from road to year (2012 and 2013), season (spring and autumn), road type (paved, gravel, trail), traffic disturbance (low, medium, high), and visibility (average per road type; Tables 17–21). Program R and Minitab was used for this analysis. I used a significance level of 0.05. When significance was detected a Tukey pairwise comparison along with interval plot figures, comparing distance to the factor of concern, were used to determine where the actual differences occurred.

RESULTS

Spotlight Surveys

I observed deer 0–587 m and 0–335 m and 0–643 m from the vehicle during spotlight surveys, for paved, gravel, and trail road types, respectively. Average cluster size was 2.1 deer (*SE* = 0.2). Probability of detection varied by road type, but gravel roads had a lower detection probability than paved and trails roads (Table 15). I observed 154, 124, and 258 individual deer observations (*n*) for paved, gravel, and trail roads across all survey replications, respectively (Table 15).

Distance sampling analysis results were averaged across all 4 replicates per season (spring and autumn) and year (2012 and 2013) and estimated density of deer (deer/km^2) was 47, 69, and 67 per paved, gravel, and trail roads, respectively (Table 15).

Visibility

Visibility readings ranged from 0–649 m and 0–313 m and 0–647 m from the vehicle for paved, gravel, and trail road types, respectively (Table 16), and were similar to observed deer ranges. Average visibility was 90.5 m, 34.3 m, and 72.6 m for paved, gravel, and trails, respectively (Table 16).

Road Traffic Monitoring

The following results pertaining to road traffic monitoring were part of a pilot experiment using cameras and pneumatic axel counters conducted to evaluate the effectiveness of using cameras to monitor traffic density on Camp Bullis (Padilla 2013).

Over the course of 12 months 58,658 vehicles were observed at all 18 camera stations and paved roads had the highest vehicle occurrence at 49,812 (84.9%; Padilla 2013). Gravel and trail roads had vehicle counts of 7,689 (13.1%) and 1,157 (2.0%), respectively (Padilla 2013; Fig. 21). Vehicle observations by month were dependent on road types ($P < 0.001$; Padilla 2013). March had the highest vehicle observations with 8,377 (14.3%), and July had the fewest with 3,023 (5.2%; Padilla 2013; Fig. 22). Daily vehicle observations also differed by road type ($P < 0.0001$; Padilla 2013). Hourly traffic activity was highest during the hours 0900, 1000, and 1100 (military time scale) with observations of 5,671 (9.7%), 6,498 (11.1%), and 5,580 (9.5%), respectively. Traffic activity was lowest between 0200–0400 hours with observations of 182 (0.3%), 127 (0.2%), and 167 (0.3%), respectively (Padilla 2013; Fig. 23).

Paved roads were still being used at the time that spotlight surveys were being conducted, and this could potentially affect deer movement patterns if deer prefer less

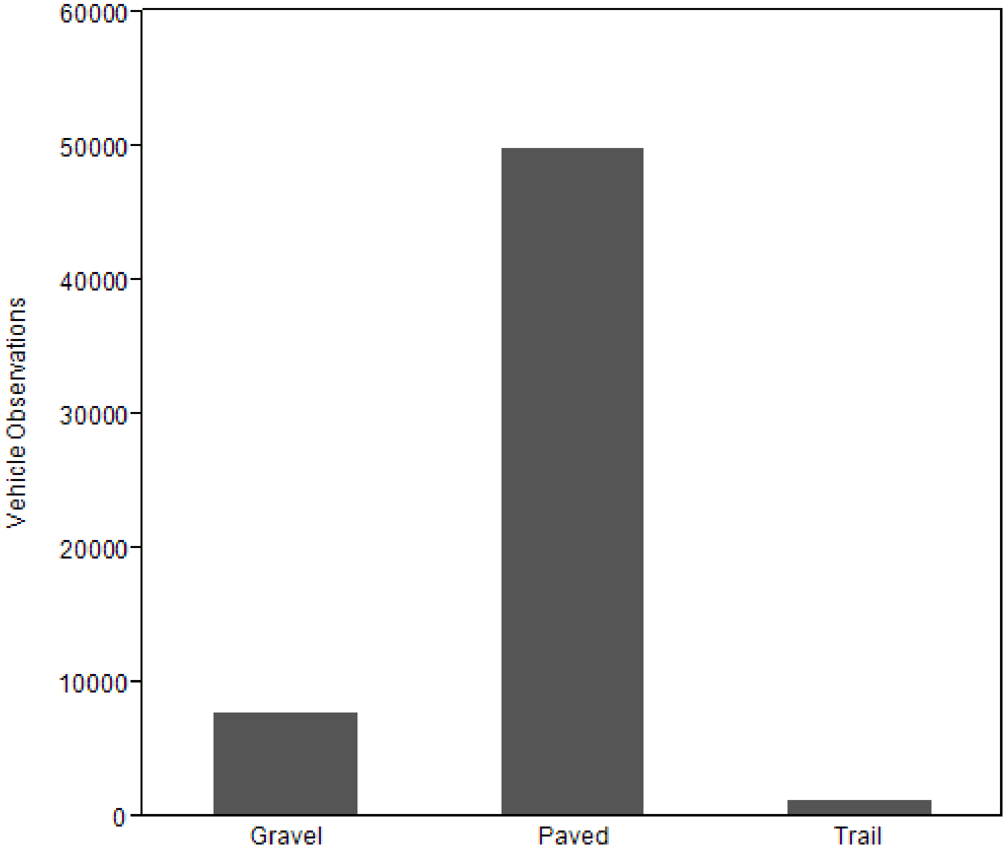

Figure 21. Total vehicle counts by road type for spotlight survey transects on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from March 2012–March 2013 (Padilla 2013).

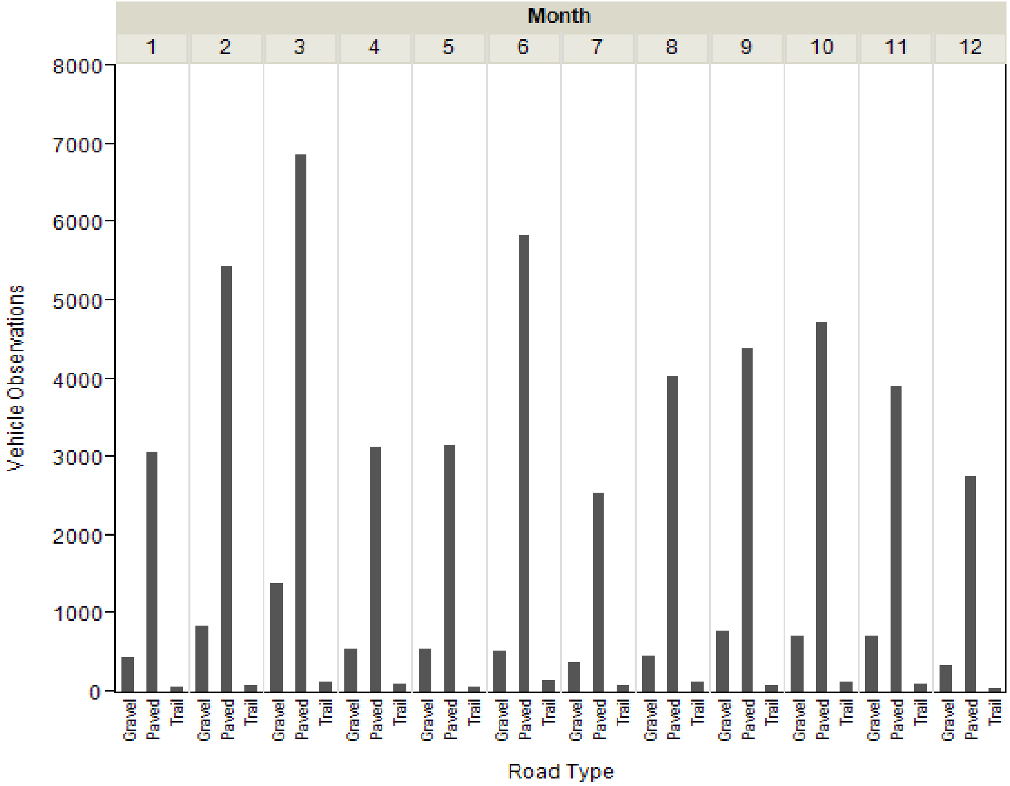

Figure 22. Total vehicle counts by month and road type for spotlight survey transects on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from March 2012–March 2013 (Padilla 2013).

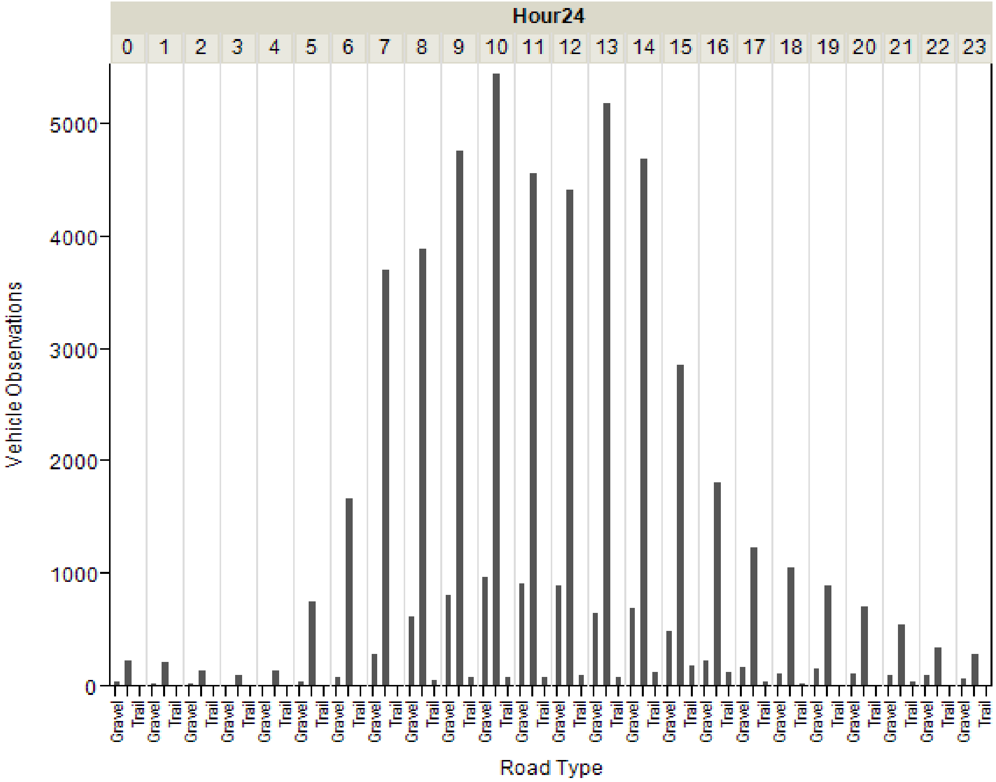

Figure 23. Total vehicle counts by 24-hour period and road type for spotlight survey transects on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA from March 2012–March 2013 (Padilla 2013).

trafficked road systems so I incorporated this factor into my analysis by calculating daily average number of vehicles that used paved roads (83 spring; 126 autumn), gravel roads (14.6 spring, 15.7 autumn), and trails (2.7 spring, 4.4 autumn), respectively. These numbers were used to apply categorical labels (paved-high, gravel-medium, trail-low) to describe relative levels of traffic disturbance.

Impacts on Deer Distribution

Annual and seasonal analysis revealed no difference in relation to deer observation distances (Tables 17 and 18). However, road type, disturbance, and visibility all differed in regards to deer observation distances from road (Tables 19–21). Gravel road type differed from both trail and paved road types. However, trail and paved roads showed no difference (Tables 20 and 21). Interval plots for deer distances comparing both traffic disturbance and average visibility by road type supported the Tukey pairwise comparisons (Figs. 24 and 25).

DISCUSSION

The number of vehicles observed was dependent on the road type. Most traffic occurred on paved roads, as the military uses these routes to access their training forward operating bases (FOB; Padilla 2013; Fig. 21). The military traveled in convoys consisting of high mobility multipurpose wheeled vehicles, troop transports, and pickup trucks (Padilla 2013). The majority of these convoys occurred on paved roads to drop off troops and/or supplies for training. Gravel and trail roads were used sparingly as they can cause damage to vehicles and rarely lead to FOBs. Throughout the year, traffic

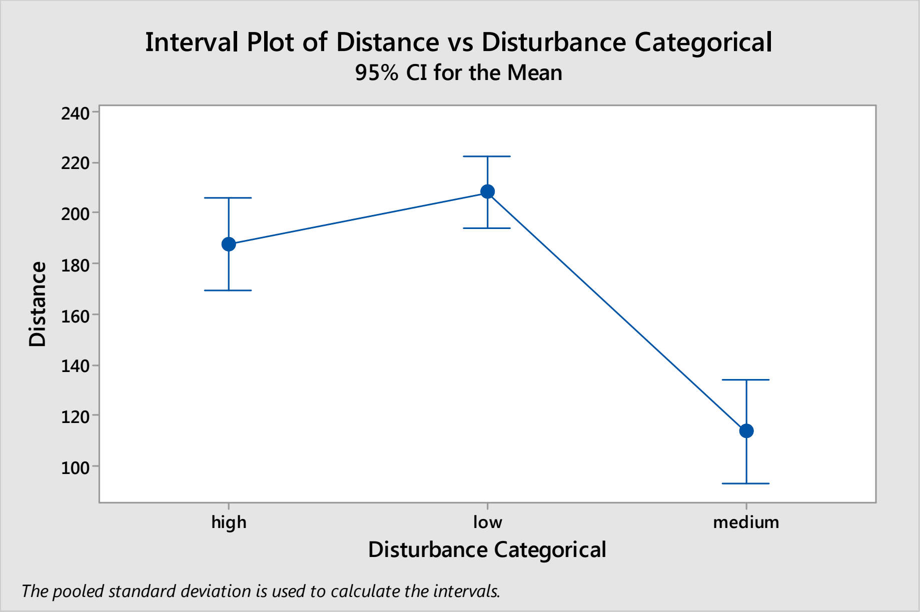

Figure 24. Interval plot of perpendicular deer distances (m) from road compared to categorical level of traffic disturbance for paved (high), gravel (medium), and trail (low) roads used during spotlight surveys conducted on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA, 2012–2013.

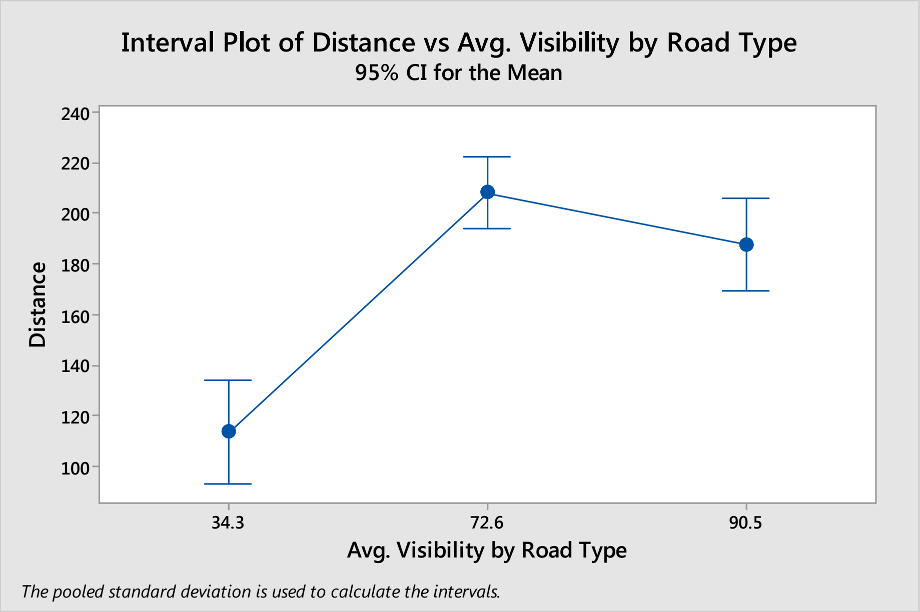

Figure 25. Interval plot of perpendicular deer distances (m) from road compared to average visibility for paved (90.5 m), gravel (34.3 m), and trail (72.6 m) roads used during spotlight surveys conducted on Joint Base San Antonio-Camp Bullis, San Antonio, Texas, USA, 2012–2013.

activity was highest during the temperate months (Padilla 2013; Fig. 22). Traffic varied by hour, but was highest at midday (Padilla 2013; Fig. 23).

Deer density was lowest for paved roads suggesting deer could be avoiding roads with high traffic use (Tables 15 and 16). Observed deer distance measurements to road type, traffic disturbance level, and average visibility showed a clear distinction between gravel roads with medium traffic disturbance (34.3 m visibility) and paved roads with high traffic disturbance (90.5 m visibility) and trails with low disturbance (72.6 m visibility; Tables 16, 19–21; Figs. 24 and 25). Fewer deer in total (*n*) were observed (Table 15) for gravel roads as a result of decreased visibilities, distance from observer to vegetation edge (Table 16). However, this difference in visibility for gravel roads resulted in an effective strip width nearly half that of paved roads and trails and subsequently a higher number of deer actually seen per area surveyed (Table 15).

Ultimately, deer-density estimates indicate more deer per area are encountered on unimproved trails and maintained gravel than on paved roads (Table 15 and 16), lending evidence to the idea that deer either shy away from paved roads or congregate near unimproved trails and maintained gravel. Because more deer were seen per unit of distance on trail and gravel roads than paved roads it is more likely deer shied away from paved roads due to traffic level and thus have density estimates that are biased low. However, deer density also could be biased high for gravel roads where overall visibility (i.e., distance from observer to vegetation edge) was lowest because deer preferentially use edge for foraging (Case 1978, Finder et al. 1999, Steward et al. 2011) and could be inflating observation data. Thus, for my study density estimates obtained via trails most likely reflect reality because they minimized traffic disturbance and maximized visibilities. It should be noted, I am not proposing trails as the preferred or superior road type for use during spotlight surveys, but rather road systems that minimize traffic disturbance related to traffic volume while maximizing visibilities.

Observed deer distance measurements to road type, traffic disturbance level, and average visibility showed a clear distinction between gravel roads with medium traffic disturbance (34.3 m visibility) and paved roads with high traffic disturbance (90.5 m visibility) and trails with low disturbance (72.6 m visibility; Table 16, 19–21). Results were nearly identical between traffic disturbance and visibility suggesting an inherent association among the 2 variables (Table 20 and 21). Because traffic disturbance and visibility were classified by road type it is reasonable to expect these variables to be associated. There also is a possible difference between high (paved) and low (trail) traffic disturbance levels, with low traffic disturbance roads having the highest average for deer observations from road. Because year and season had no effect on observable distance under these data, I believe the significant difference detected for gravel road types (medium disturbance; 34.3 m visibility) was due strictly to the fact that distance from observer to vegetation edge (visibility) for trails (72.6 m) and paved roads (90.5 m) were over 2 and 2.5 times greater, respectively.

However, while density estimates were greater for gravel roads and trails compared to paved roads, it is not distinct, because all confidence intervals overlap (Table15). Thus, I was unable to truly distinguish differences within the ability of my techniques and thus density estimates should be classified as similar. Problems associated with road-based sampling have been previously documented (Anderson et al. 1979, Burnham et al. 1980, Pollock et al. 2002, Collier et al. 2013) and reported to bias density estimates by ≥100% (2× greater; Marques et al. 2010, Beaver et al. 2014). Therefore, to fully understand the driving factor, future studies should include GPS data in order to calculate perpendicular distances from GPS-collared deer to road type interpoint distances. This will allow for direct comparisons of deer to road type interpoint distance means and variances between survey and non-survey periods and provide a measure for both the magnitude and direction of aggregate changes in white-tailed deer distribution in relation to factors believed to alter deer behavior and subsequently bias road-based density estimates.

MANAGEMENT IMPLICATIONS

Road systems are a reality in every environment and understanding them and their impact on wildlife movement can benefit wildlife management. More deer per area were encountered on trails and gravel roads than on paved roads. So deer either shied away from paved roads due to high traffic disturbance levels resulting in density estimates that were underestimated and/or deer observations were biased high for gravel roads where visibility (i.e., distance from observer to vegetation edge) was lowest because deer preferentially use edge for foraging (Case 1978, Finder et al. 1999, Stewart et al. 2011) and could be inflating observation data. Thus, when conducting spotlight surveys to obtain population estimates for management purposes, managers should either try to utilize road types that minimize traffic disturbance while maximizing visibilities, or incorporate an even distribution of non-overlapping transects for all road types present. Regardless, managers should preferentially utilize road systems that minimize traffic disturbance.

CHAPTER V

CONCLUSIONS

Providing wildlife managers with reliable techniques for estimating white-tailed deer (*Odocoileus virginianus*; deer) populations is challenging and requires proper evaluation of population surveys. Budgetary, logistical, and time constraints often limit the available options for estimating deer numbers. Additionally, deer are difficult to monitor, often requiring capturing and handling individual animals, which is growing increasingly important in the United States as the amount of spatial and temporal data that can be collected increases.

In response to these concerns and management issues, I initiated a study in 2011 on Joint Base San Antonio-Camp Bullis to investigate various aspects of deer population ecology and movement behavior. My research efforts focused on comparing capture techniques (drop net, single helicopter, and tandem helicopter) used to fit deer with global positioning system (GPS) collars and evaluating basic deer movement in response to commonly used deer survey methods (infrared-triggered camera and spotlight) in relation to potential biases (bait, road type, traffic volume).

While all 3 capture techniques were safe and effective for deer capture, spatial coverage and movement analysis indicate that the tandem helicopter capture technique was superior for balancing cost-efficiency and safety while also minimizing post-capture behavioral impact on deer. The tandem helicopter method should be considered for large study areas with similar vegetative structure and deer populations that are exposed to a variety of land uses and disturbances. Wildlife capture should be carefully balanced in regards to expense and efficiency, safety, impacts post-capture, practicality of setting and research design. I recommend future studies with a capture component try to assess impacts post-capture on animal movement and behavior.

The use of bait resulted in a higher likelihood of detection in male deer during autumn camera surveys violating the assumption of equal detectability. This ultimately resulted in an underestimation of female and fawn deer. Therefore, I recommend managers not base harvest quotas solely from estimates obtained via pre-hunting season camera surveys using bait, or at least be aware of the potential biases and adjust for the likelihood that females and fawns are underestimated. Use of bait detracted from percent canopy coverage, which was shown to be significant in determining deer distributions prior to the use of bait. Therefore, further examination of environmental variables (e.g., edge density, nearest neighbor distance to patch, patch size, and overall landscape diversity and richness) that are biologically relevant in determining deer movements and distributions across the landscape are needed to get a better understanding of the influence bait has on determining deer distributions at the patch and landscape levels.

During spotlight surveys more deer per area were encountered on unimproved trails and maintained gravel than on paved roads, supporting the idea that deer either shy away from paved roads or congregate near trails and maintained gravel roads. Assuming that greater quantity represents normality, it is more likely deer shy away from paved roads due to high traffic level and thus results in density estimates that are biased low. However, deer density could be biased high for gravel roads where distance from observer to vegetation edge (i.e., visibility distance) was lowest because deer preferentially use edges for foraging which could be inflating observation data. Thus, when conducting spotlight surveys to obtain population estimates for management purposes, managers should either try to use road types that minimize traffic disturbance while maximizing visibilities, or incorporate an even distribution of non-overlapping transects for all road types present. Regardless, managers should preferentially use road systems that minimize traffic disturbance. Future studies should include GPS data in order to calculate perpendicular distances from GPS-collared deer to road type interpoint distances. This will allow for direct comparisons of deer to road type interpoint distance means and variances between survey and non-survey periodsa nd provide a measure for both the magnitude and direction of aggregate changes in white-tailed deer distribution in relation to factors believed to alter deer behavior and subsequently bias road-based density estimates. Road systems are a reality in every environment and understanding them and their impact on wildlife movement can only benefit the field of wildlife management.

The combined results from my research provide natural resource managers with vital information pertaining to capture effects and biases related to deer population survey techniques that will help better manage the species. A complete cost-comparison and evaluation of the spatial-temporal extent of behavioral change attributable to capture technique must be considered when selecting among commonly used deer capture methods. Determining the existence of such alterations and subsequently the period over which data are biased by capture and handling will improve our ability to make sound management decisions. Additionally, data collected via camera and spotlight surveys showed that knowledge of the factors that contribute to bias in population/density estimates caused by changes in deer distribution and/or behavior will help improve harvest expectations and herd management, both of importance to natural resource managers and landowners.

LITERATURE CITED

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