A SIGHTABILITY MODEL FOR AERIAL SURVEYS OF MULE DEER IN WESTERN TEXAS

A Research Thesis

By

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ABSTRACT

A Sightability Model for Aerial Surveys of Mule Deer in Western Texas

(May 2011)

Cody James Zabransky, B.S., Texas A&M University-Kingsville

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Aerial surveys are used to assess mule deer (*Odocoileus hemionus*) populations, but are biased because not all deer are counted. My objectives were to quantify factors affecting visibility of mule deer during helicopter surveys, and develop a sightability model to reduce bias in deer population estimates. I collared 215 deer with GPS collars on 6 sites covering distinct habitats of mule deer range in Texas. I obtained data on group size, vegetation, activity, light, terrain, and distance from transect for deer seen during surveys and deer not seen. I used logistic regression to derive two sightability models, one in which all measured variables were included and one which excluded group size because of difficulty measuring group size of unseen groups. Population size estimated using sightability models averaged 93.1% of the estimates derived using mark-resight techniques. Implementing sightability models will improve data available for mule deer management in Texas.

DEDICATION

To my parents, Mike and Ruth Zabransky

For your amazing love and support to allow me to follow my dreams

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CHAPTER I. LITERATURE REVIEW

INTRODUCTION

Helicopter surveys are commonly used to estimate population size and composition of large wildlife species. Helicopters allow biologists to count animals in areas where roads are sparse and to survey large areas quickly. However, sightability bias is a problem because not all animals are counted (Caughley 1977, 1974, Beasom et al. 1981, DeYoung 1985, Pollock and Kendall 1987, Samuel et al. 1987, Bodie et al. 1995). Sightability bias impairs the ability of biologists to accurately manage wildlife species.

The primary goal in improving aerial survey estimates is to determine the number of animals not seen during surveys (Samuel et al. 1987). Uncorrected survey data provide population estimates where the true population size may not lie within the confidence intervals of the estimate (Steinhorst and Samuel 1989, Bleich et al. 2001). Texas Parks and Wildlife Department (TPWD) uses helicopter surveys and uncorrected data to monitor and set regulations on mule deer (*Odocoileus hemionus*) in Texas. There are several accepted methods to estimate populations from survey data. My focus was on sightability models which estimate total population size based on the number of deer counted and the likelihood of observation for each group.

HELICOPTER NET-GUN CAPTURE TECHNIQUE

Webb et al. (2007) evaluated helicopter net-gun capture of white-tailed deer (*Odocoileus virginianus*) in South Texas. Incidence of bodily injury, excluding broken antlers, or death was low (2.2%). Only 1% of collared white-tailed deer died of capture

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This thesis follows the style of The Journal of Wildlife Management myopathy. Helicopter net-gun technique for capturing desert mule deer was effective and of comparable cost to remote drug delivery with a helicopter (Krausman et al. 1985).

DeYoung (1988) showed that large numbers of deer could be captured quickly and inexpensively using the helicopter net-gun technique relative to other methods. Webb et al. (2007) were able to capture and process 75-100 deer/day with experienced ground and helicopter crews. Helicopter capture allows researchers to selectively capture deer, an essential element for most research projects in which animals are to be collared. The stress of capture can influence animal health. DeYoung (1988) reported average pursuit times of 7-8 min. Webb et al. (2007) reported average pursuit times of < 3 min, further reducing the amount of stress and incidence of capture myopathy.

AERIAL SURVEY DESIGN

Survey design is extremely important because surveys must be representative of the area where populations are being estimated. Borders and transects, if used, of the survey sites should be set prior to flight and loaded to the aircraft's GPS navigation systems to provide additional reference for the survey crew (Unsworth et al. 1999). Timing of surveys during the day is important as Bartmann et al. (1986) showed that higher and more consistent numbers of deer were counted between 0800-1000 and 3 hrs before sunset. Seasonal timing of surveys is also important because visibility increases when deciduous plants are defoliated or there is snow on the ground.

In previous studies, surveys have been flown covering quadrats at 100% coverage allowing each animal in the survey area the opportunity to be seen (Cogan and Diefenbach 1998). Though TPWD flies single transect surveys, the model developed using quadrats is applicable for annual mule deer population assessment. Helicopter ground speed averaged 97-113 km/hr (Cogan and Diefenbach 1998). Observation statistics for sightability models are often based on the initial animal seen in a group (Cogan and Diefenbach 1998). Many survey protocols require the pilot and 2 observers to search for deer, but only the 2 observers count and classify deer (Samuel et al. 1987, Cogan and Diefenbach 1998). In four-seat helicopters, the pilot is usually seated at the right front position, primary observer at the left front, and secondary observer at the right rear position (Cogan and Diefenbach 1998).

CURRENT WESTERN STATE SURVEY METHODS

Annual surveys of mule deer are completed by western states to assess population parameters and monitor population trends. Helicopters are effective in obtaining population data and are used by Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Washington, and Texas (deVos et al. 2003). Six states use the computer modeling program POP II (Fossil Creek Software, Fort Collins, CO) to summarize survey results, estimate population characteristics, and make harvest decisions (deVos et al. 2003). Sightability models are currently used in New Mexico and Idaho (deVos et al. 2003). All states utilizing helicopter survey techniques collect data on age class (fawn vs. adult), group size, and sex (deVos et al. 2003). Additionally, Idaho, New Mexico, and Washington record habitat type for use in their estimation models (deVos et al. 2003).

TPWD uses annual helicopter survey data to monitor mule deer population trends and to help establish and assess management decisions. Approximately 3,950 km of surveys are flown during January and February with transect location and direction selected randomly. Observers record information on group size and on age and sex of each animal in each group electronically and manually on data sheets (Texas Park and Wildlife Department 2007). Surveys are flown between sunrise and 1100 hrs and the last 3 hours of daylight. TPWD law enforcement pilots are instructed to fly at 15 to 19 m above ground level and maintain speeds of 56 to 89 km/hr depending on woody vegetation cover and terrain ruggedness (Texas Park and Wildlife Department 2007). Transect length varies from 24 to 56 km and varies based on historic density of the herd monitoring unit. Areas are divided into herd monitoring units of high density (>5 deer/km^2), medium density (>2.5-5 deer/km^2), low density (>.85-2.5 deer/km^2), and very low density (<.85 deer/km^2) (Figs. 1 and 2; Texas Park and Wildlife Department 2007). Transects are all maintained at a width of 183 m for the entire survey length, with no variation. Areas are excluded from the annual survey if mule deer densities are very low, terrain is 85% grade or rougher, or canopy cover inhibits visibility (Texas Park and Wildlife Department 2007). Estimating true size of the mule deer population in Texas is important to TPWD and private landowners for proper management.

In addition to helicopter surveys, Texas also currently uses browse surveys to substantiate its local population estimates relative to carrying capacity. While this method provides evidence of browse pressure and a measure of relative animal densities, it cannot effectively estimate population size. Population size is extremely important for management of a species that has suffered historical, extensive range losses in Texas (Cantu and Richardson 1997).

Figure 1. Trans-Pecos region TPWD survey monitoring units and mule deer survey transects for survey year 2009. Map courtesy TPWD Wildlife Division.

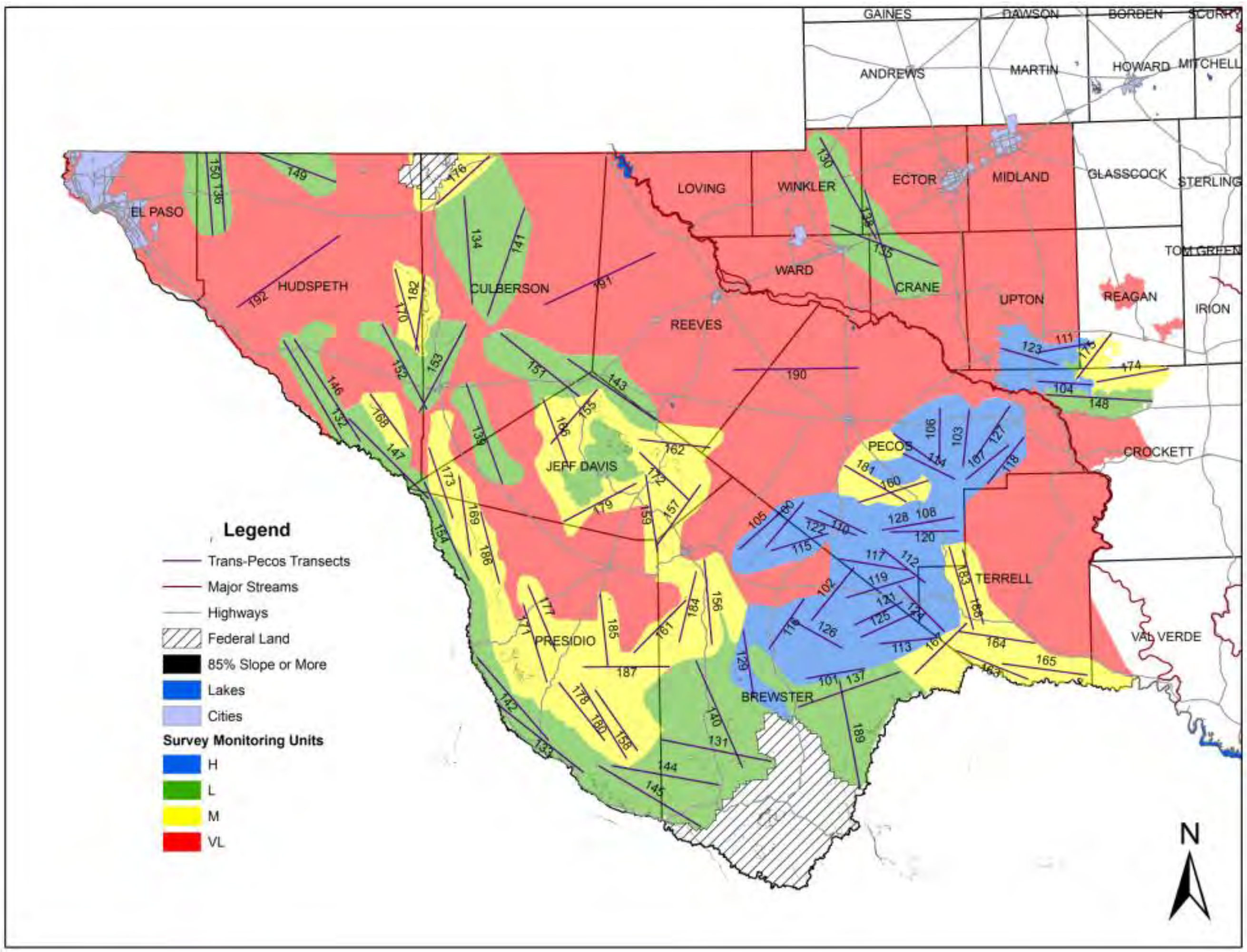
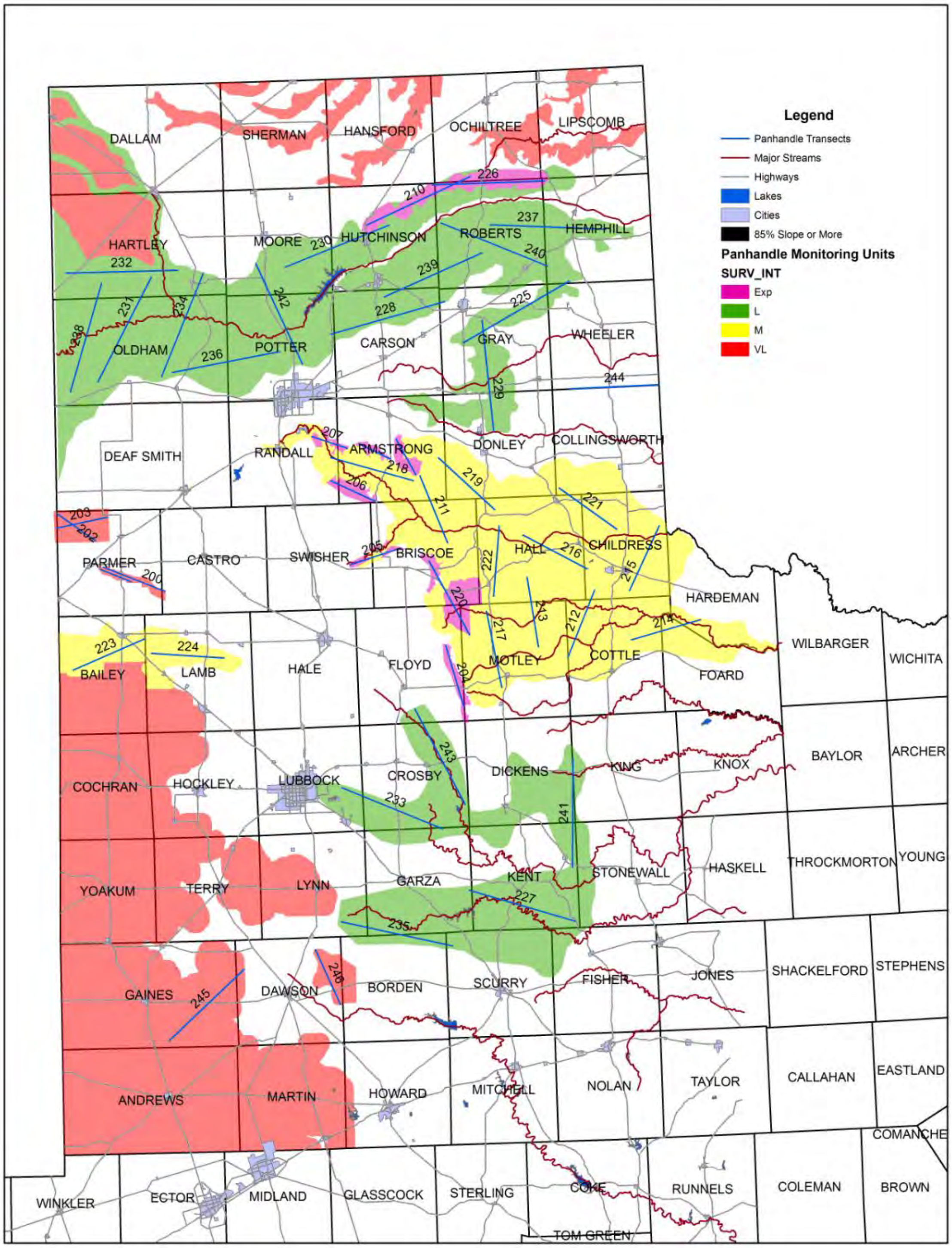


Figure 2. Panhandle region TPWD survey monitoring units and mule deer survey transects for survey year 2009. Map courtesy TPWD Wildlife Division.



POPULATION ESTIMATION

Numerous techniques are used to account for undetected animals on aerial surveys. The three most commonly used are mark-resight, distance sampling, and sightability models. In many cases, the number of groups sighted on a survey is inadequate to compute population estimates using mark-resight or distance sampling techniques (White 2005).

Mark-Resight

Mark-resight is based on marking a known number of animals, flying surveys over those animals, and estimating the total population based on the proportion of marked individuals observed during the survey. This method requires capture and marking of a large number of animals on the area to be surveyed, and the number of marked individuals must be known. Deer may not be available for resight because they have died or have moved off the area surveyed. Recent development of mark-resight models using data from multiple surveys, as available in Program MARK, has improved mark-resight estimates (McClintock et al. 2009). Mark-resight estimates derived from Program MARK, are accepted as an unbiased estimate of population size and thus serve as an acceptable standard on which to compare population estimates from my sightability models.

Unintended consequences arise from the process of marking animals using helicopter capture. Captured animals may develop a learned fear of the helicopter, making them less likely to be seen during surveys (Bartmann et al. 1986). Mark-resight models also require large numbers of marked animals on the survey area every time a survey is conducted, while sightability models only require marked animals during model development and high densities are not required (Anderson and Lindzey 1996).

Distance Sampling

Distance sampling estimates animal density based on detectability at different distances from the survey transect. When applied correctly and the assumptions of distance sampling are met, the method is effective. Two assumptions for distance sampling are regularly violated in aerial surveys of large mammals. First, all animals on the transect line must be seen (Burnham et al. 1980), but several studies indicate this assumption is violated in aerial surveys of big game (Caughley 1974, 1977, Beasom et al. 1981, DeYoung 1985, Pollock and Kendall 1987, Samuel et al. 1987) causing estimates using distance sampling to be biased low. A second assumption is that animals are fixed at their initial sighting position (Burnham et al. 1980). This assumption is almost always violated because most deer seen on surveys are running, a behavior that makes deer more visible to observers. Deer that remain fixed at their position are often not observed.

Sightability Models

Sightability models account for deer that are missed by observers by applying a correction factor to each observed group (Samuel et al. 1987). The correction factor for each group is determined by conditions (e.g. group size, activity) in which the deer was seen and the extent those specific conditions influence sightability. There are fewer assumptions and no need for a known number of marked animals to be maintained on the area to be surveyed. Models are more specific in correcting for visibility bias than blanket corrections from mark-resight methods.

Sightability models have been developed using VHF collars to locate and gather information on animals not seen during surveys (White et al. 1989, Cogan and Diefenbach 1998, Unsworth et al. 1999, Bleich et al. 2001). Gathering information was either costly due to use of multiple aircraft during surveys (Cogan and Diefenbach 1998), or missed deer were located after the survey, allowing animals to move long distances and possibly producing inaccurate results (Bleich et al. 2001). Additionally, returning to locate missed deer after the survey does not provide information on deer movements as the survey helicopter passed. Deer behavior in response to the helicopter is important to understand because activity is a significant factor in other sightability models (Gasaway et al. 1985, Ackerman 1988, Anderson et al. 1998, Allen et al. 2005).

GPS technology allows accurate location and activity data to be collected as surveys are flown. Using GPS collars can eliminate the bias associated with returning hours later to obtain data for missed groups or costs of extra flight hours if two aircraft are used simultaneously during surveys.

Bleich et al. (2001) flew elk surveys in fixed-wing aircraft $\geq$ 75 m above ground level (AGL) with 600 m wide transects. At 600 m spacing, observers have large areas to search for animals and transect spacing was inconsistent and ranged from 360 m to 870 m, so observers had variable and often unknown distances to scan. At this altitude, deer size animals are more difficult to see compared to lower flight altitudes (Shupe and Beasom 1987).

Cogan and Diefenbach (1998) flew helicopter surveys of elk (*Cervis elaphus*) at higher altitudes (50-60 m) and at higher rates of speed (97-113 km/hr) than TPWD helicopter survey protocols for mule deer (Texas Park and Wildlife Department 2007).

Flying surveys at lower altitudes and slower speeds increases the likelihood of observing animals (Shupe and Beasom 1987). Additionally, slower flight speeds allow observers more time to properly identify observed groups without disrupting survey progress.

Previous studies have recorded data on many variables thought to influence sightability of animals (Table 1). Many influences, such as aircraft speed, observer, observer condition, and terrain have not been significant in most logistic regression analyses (Table 1). All studies measured more factors than were included in the final model (Table 1). Most models found animal sightability influenced by percent woody vegetation cover while some models also included group size and activity as significant variables (Table 1).

Most published sightability models are for elk surveys. The model developed for mule deer by Ackerman (1988) and Unsworth et al. (1999) is probably not applicable to mule deer in Texas because of differences in habitats and snow cover. Unsworth et al.'s (1999) models are an excellent example of model development (Tables 2 and 3, pgs. 13-14). Models developed for other animals required snow cover (Ackerman 1988, Cogan and Diefenbach 1998, Unsworth et al. 1999), and methods are not consistent with Texas Parks and Wildlife Department mule deer aerial survey protocol.

Table 1. Variables investigated by wildlife studies which could potentially influence sightability of specific species using various survey methods.

Variable	Species	Studies[1]
Group size	**General**	**Cook and Martin 1974**
	General	**Cook and Jacobson 1979**
	Moose	**Thompson 1979**
	Moose	**Novak 1981**
	River Otter	**Samuel and Pollock 1981**
	Moose	**Gasaway et al. 1985**
	Elk	**Samuel et al. 1987**
	Mule Deer	**Ackerman 1988**
	Bighorn Sheep	Bodie et al. 1995
	Moose	**Anderson and Lindzey 1996**
	Elk	**Anderson et al. 1998**
	Elk	**Cogan and Diefenbach 1998**
	Elk	**Allen et al. 2005**
Vegetation cover type	Moose	LeResche and Rauch 1974
	Mule Deer	Biggins and Jackson 1984
	Moose	**Gasaway et al. 1985**
	Bighorn Sheep	**Bodie et al. 1995**
	Moose	Anderson and Lindzey 1996
	Elk	Cogan and Diefenbach 1998
	Elk	Allen et al. 2005
Percent Woody Vegetation Cover	Elk	Samuel et al. 1987
	Elk	Otten et al. 1993
	Moose	Anderson and Lindzey 1996
	Elk	Anderson et al. 1998
	Elk	Cogan and Diefenbach 1998
	Elk	**Allen et al. 2005**
Terrain	**Bighorn Sheep**	**Bodie et al. 1995**
	Moose	Anderson and Lindzey 1996
	Elk	Allen et al. 2005
Distance	General	Burnham and Anderson 1984

Table 1 (Continued)

Variable	Species	Studies[1]
	Bighorn Sheep	**Bodie et al. 1995**
	Moose	Anderson and Lindzey 1996
Light Intensity	Moose	LeResche and Rauch 1974
	Bighorn Sheep	**Bodie et al. 1995**
	Moose	Anderson and Lindzey 1996
	Elk	**Allen et al. 2005**
Observer Experience	Caribou	Caughley 1974
	Moose	**LeResche and Rauch 1974**
	Elk	Samuel et al. 1987
	Elk	Allen et al. 2005
Aircraft Speed	**Caribou**	**Caughley 1974**
	Elk	Samuel et al. 1987
Percent Snow Cover	**Moose**	**LeResche and Rauch 1974**
	Moose	Crete et al. 1986
	Elk	Samuel et al. 1987
	Moose	Anderson and Lindzey 1996
	Elk	**Allen et al. 2005**
Animal Behavior	**Moose**	**Gasaway et al. 1985**
	Elk	Samuel et al. 1987
	Mule Deer	**Ackerman 1988**
	Bighorn Sheep	**Bodie et al. 1995**
	Moose	Anderson and Lindzey 1996
	Elk	**Anderson et al. 1998**
	Elk	Cogan and Diefenbach 1998
	Elk	**Allen et al. 2005**

[1] Studies in bold concluded the variable was a significant factor influencing sightability of the investigated species.

Table 2. Mule deer sightability survey results by independent variable in southern Idaho (Unsworth et al. 1999).

Variable	States	Number of Groups Missed	Number of Groups Seen	Proportion Seen
Activity	Bedded	66	12	0.15
	Standing	57	92	0.62
	Moving	11	177	0.94
Vegetation Class	Grass/Open/Agriculture	8	88	0.92
	Sagebrush	27	100	0.79
	Juniper/ mtn. Mahogany	78	60	0.43
	Mtn. Brush/ Aspen	18	29	0.62
	Conifer	1	5	0.83
Observer Experience	1-Low	8	12	0.6
	2	10	5	0.33
	3	48	57	0.54
	4-High	69	208	0.75
% Vegetation Cover	0-15	76	212	0.74
	16-30	21	31	0.6
	31-45	8	7	0.47
	46-60	14	12	0.46
	61+	16	19	0.54
% Snow Cover	0-20	49	192	0.8
	21-79	29	24	0.45
	80+	57	66	0.54
Group Size	1	35	13	0.27
	2	16	5	0.23
	3	15	13	0.47
	4	8	20	0.71
	5	18	16	0.47
	6	6	15	0.71
	7-15	25	91	0.78
	16-30	10	55	0.85
	30+	2	54	0.96

Table 3. Logistic regression results (N = 413) from evaluation of factors influencing sightability of radio-collared mule deer in southern Idaho (Unsworth et al. 1999).

Variable	States	P-Value	Coefficient	t-ratio
Constant		0.643	-0.254	-0.463
Activity	Bedded		0	
	Standing	<.001	1.562	3.738
	Moving	<.001	4.43	8.45
Vegetation Class	Grass/Open/Agriculture		0	
	Sagebrush	0.081	-0.888	-1.742
	Juniper/ Mtn. Mahogany	<.001	-2.383	-4.399
	Mtn. Brush/ Aspen	0.318	-0.602	-0.998
	Conifer	0.579	-0.634	-0.555
Snow Cover Class	0-20		0.000	
	21-79	0.003	-1.368	-3.008
	80+	0.116	-0.598	-1.57
Group Size		0.005	0.047	2.812
Observer Experience		0.091		
Vegetation Cover		0.495		

CHAPTER II. RESEARCH

INTRODUCTION

Aerial surveys provide an efficient means to count animal populations in areas where roads are sparse, and enable rapid coverage of large geographic areas (Bodie et al. 1995). The use of Helicopters allows greater flexibility in survey speed and altitude in comparison to fixed-wing aircraft, allowing observers to verify sightings (Bodie et al. 1995). Despite these advantages, all survey methods face the problem of sightability bias, where all individuals are not seen (Caughley 1977, 1974, Beasom et al. 1981, DeYoung 1985, Pollock and Kendall 1987, Samuel et al. 1987). For instance, aerial surveys of white-tailed deer count 34-65% of marked individuals (Beasom et al. 1981, DeYoung 1985, Beasom et al. 1986). Furthermore, counts may be highly variable, with extremes of 20 to 80% of marked deer sighted.

Uncorrected surveys rarely provide precise estimates of population size (Steinhorst and Samuel 1989, Bleich et al. 2001). Sightability bias occurs due to animal behavior, dispersion, observer experience, weather, vegetation cover, aircraft model, group size, terrain, distance from the aircraft, and many other factors. Uncorrected counts are useful for assessing temporal trends in abundance, but may not be comparable across different geographic regions or temporal periods. Uncorrected counts may be appropriate for setting season length and bag limits, but inappropriate for a species which has suffered population declines across its range (Gill 2001). Finally, reliance on uncorrected count data may not be adequate to address public challenges, reducing agency credibility (Freddy et al. 2004).

One way to improve the precision of aerial counts is to determine the number of animals not seen during surveys (Samuel et al. 1987). Sightability models may reduce bias in population estimates by adjusting counts based on the most important sources of bias. Sightability models are widely used in the western United States for elk, bighorn sheep (*Ovis canadensis*), moose (*Alces alces*), and mule deer (Samuel et al. 1987, Bodie et al. 1995, Anderson and Lindzey 1996, Anderson et al. 1998, Cogan and Diefenbach 1998, Unsworth et al. 1999, Bleich et al. 2001). However, mule deer in Texas occur in a wide array of habitat types not addressed by previous models. Development of a sightability model for mule deer in Texas will enable wildlife biologists to correct for sightability bias with a minimal increase in cost and the amount of data recorded for each observation.

Sightability models account for deer not seen by using the detection probability of each group of deer seen during the survey. For example, if a group has a 50% chance of being seen, then 1 group was missed for every group seen. The probability of detecting a group is established by flying surveys over areas with animals fitted with collars transmitting very high frequency (VHF) signals or a GPS unit to record the animal's location. For each deer group observed, characteristics of the group and its surroundings (group size, vegetation, activity, etc.) are recorded for deer seen during surveys and those not seen. The effects of the factors are then assessed using logistic regression and a final model is developed with those variables that influence sightability.

OBJECTIVES

The objective of the research is to create a sightability model that is robust to variable habitat types and is simple enough for users to understand and apply to survey results. Variability in sightings of mule deer from a helicopter can be attributed to group size, percent woody cover, vegetation type, animal behavior, terrain, light conditions, and perpendicular distance of the group from the transect line. An equation enabling observers to estimate the number of animals not detected on a survey can be developed by quantifying the effect of each variable.

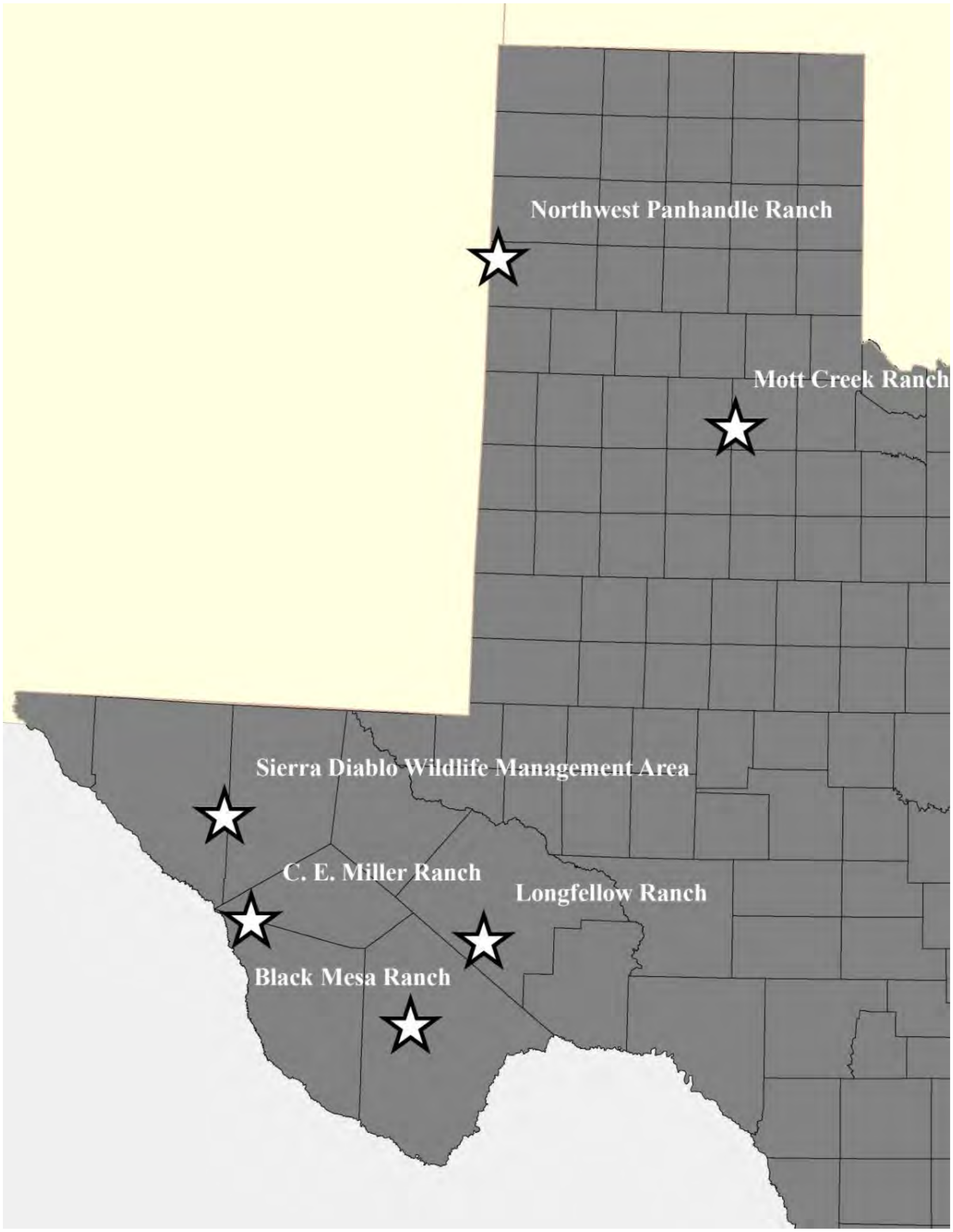
STUDY AREA

The TPWD conducts mule deer surveys on transects totaling approximately 3,950 km annually. This study was conducted on 6 sites representative of the major habitat types encountered during surveys. Locations of study areas were determined with the help of TPWD biologists. Study areas averaged 30 km^2 and were located in the Trans-Pecos region (4 sites) and in the Panhandle region (2 sites). The study areas in the Trans-Pecos region were Black Mesa Ranch, Longfellow Ranch, C. E. Miller Ranch, and the Sierra Diablo Wildlife Management Area (Fig. 3). The Panhandle study locations were the Mott Creek Ranch, and Northwest Panhandle Ranch (NWPH; Fig. 3).

The Trans-Pecos region of Texas provides the most diverse habitats in Texas ranging from deserts to mountains and their respective vegetative communities. The Trans-Pecos has hot summers, mild winters, and average annual precipitation varying by location from 17.8-45.7 cm (Cantu and Richardson 1997). Peak rainfall occurs during July and August in the form of thunderstorms while drought conditions are common (Cantu and Richardson 1997).

Predominant woody species in the Trans-Pecos region include whitebrush (*Aloysia gratissima*), redberry juniper (*Juniperus pinchotii*), piñon pine (*Pinus remota*), skeleton leaf goldeneye (*Viguiera stenoloba*), purple sagebrush (*Leucophyllum*

Figure 3. Study locations used for development of mule deer aerial sightability model for western Texas January-February, 2008-2010.



frutescens), and honey mesquite (*Prosopis glandulosa*; Cantu and Richardson 1997). Grasses include little bluestem (*Schizachyrium scoparium*), sideoats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), black grama (*Bouteloua eriopoda*), and Arizona cottontop (*Digitaria californica*). Forbs include mariola (*Parthenium incanum*), bush sunflower (*Simsia calva*), and showy menodora (*Menodora longiflora*). Yucca (*Yucca* spp.), sotol (*Dasylirion wheeleri*), lechuguilla (*Agave lechuguilla*), prickly pear (*Opuntia lindheimeri*), cholla (*Opuntia imbricata*), and various cactus species are common throughout the region.

The Black Mesa Ranch is geographically diverse. The west side of the ranch is flat to gently rolling with low and mixed brush as well as bare ground. On the east side of the ranch are the rugged Santiago Mountains and piñon-juniper vegetation. The Longfellow Ranch is more homogeneous with expansive flat to gently rolling terrain and piñon-juniper vegetation. Localized areas of low and mixed brush and rugged terrain occur on the northeastern edge. Farther west, the Miller Ranch in the Sierra Viejas is predominantly low brush in rolling to rough terrain with small pockets of juniper. Open vegetation is common on the eastern edge of the survey area. The Sierra Diablo Wildlife Management Area has the roughest terrain of all the study areas, including large cliffs and deep canyons in the northern portion of the area. Other portions of the area are flat with open habitats. Most of the Sierra Diablo study area is characterized by rolling to rough terrain with most mule deer in piñon-juniper vegetation.

Mule deer in the Panhandle region are more common in rolling plains habitats than creek bottoms and sandhills. The Panhandle climate is characterized by warm summers, cold winters, and precipitation averaging 45 cm annually (Cantu and

Richardson 1997). The Panhandle region is also comprised of extensive agricultural fields which deer frequent during winter when native forage is sparse and winter wheat is present.

Dominant woody species of the Panhandle include purple sagebrush, skunkbrush sumac (*Rhus trilobata*), sand shinnery oak (*Quercus havardii*), yucca, redberry juniper, honey mesquite, catclaw acacia (*Acacia greggii*), mountain mahogany (*Cercocarpus montanus*), hackberry (*Celtis occidentalis*), four-wing saltbrush (*Atriplex canescens*), and feather dalea (*Dalea formosa*; Cantu and Richardson 1997). Grasses include Indiangrass, sand bluestem (*Andropogon hallii*), switchgrass (*Panicum virgatum*), sideoats grama, little bluestem, hairy grama (*Bouteloua hirsuta*), blue grama, silver bluestem, hooded windmillgrass (*Chloris cucullata*), and perennial threeawn (*Aristida purpurea*). Forbs of the Panhandle include trailing ratany (*Krameria lanceolata*), sagewort (*Artemisia spp.*), silverleaf nightshade (*Solanum elaeagnifolium*), spectacle-pod (*Dimorphocarpa wislizenii*), bladderpod (*Lesquerella argyraea*), western ragweed (*Ambrosia psilostachya*), and gaura (*Gaura lindheimeri*).

The Mott Creek Ranch is representative of the caprock region of the Texas Panhandle. Juniper dominates the area on flat to rolling terrain. Extensive areas of brush control to remove juniper provide open habitat characterized by native grasses. The Northwest Panhandle Ranch is also characteristic of the caprock region. However, below the breaks of the caprock are extensive grasslands and mixed brush prairie on flat to gently rolling terrain. Both Texas Panhandle locations had winter wheat planted, though deer were observed using the agriculture fields only on the Mott Creek Ranch study location. Deer were known to use the agriculture fields on the Northwest Panhandle Ranch occasionally.

METHODS

Collar Preparation

I used 72 Lotek GPS 3300L (Lotek, Inc., Newmarket, Ontario, Canada) collars in this study and set them to identical schedules for timing of GPS locations and the telemetry beacon using the Lotek GPS 3000 host software. I set the GPS collars to take locations every 5 min from 0700 to 1100 hrs, and from 1500 to1900 hrs to correspond with times when aerial surveys were conducted. While surveys were not being conducted, the collars took coordinates once each hour. The collars were equipped with timed drop-off units, which allowed collars to be retrieved after completion of the surveys without recapturing the animal.

Capture

I captured 36 mule deer ≥ 1 year of age annually between 15 December and 10 January on each of two study sites (Appendix 2) during 2007-2010. Mule deer were captured using the helicopter net-gun technique and I attempted to capture male and female deer in proportions representative of the local population. Once captured, deer were restrained, tied, and blindfolded by capture personnel and moved to a processing crew by vehicle or helicopter. Sex and age of each deer were determined by TPWD personnel using morphological characteristics for sex and tooth wear and replacement for age.

Each collar had a unique color combination of duct tape and ear tags on the right and left sides so that animals could be quickly identified without having to resort to slower and less precise methods, such as telemetry. I affixed collars to captured deer as per specifications of Lotek Wireless, Inc. Captured deer were then released at the processing site.

Surveys

I conducted surveys between 1 January and 1 March each year. Survey areas averaged 28.6 km^2 and were designed to contain most of the collared deer based on the telemetry locations of deer <48 hrs prior to surveys. I conducted 8 to 9 surveys on each study site. I surveyed study sites in the morning between sunrise and 1100 hrs and in the afternoon between 1500 hrs and sunset, following the TPWD survey protocols (Texas Park and Wildlife Department 2007).

A Robinson R44 helicopter and Bell Jet Ranger were used at different times to carry 3 passengers and a pilot. The Bell Jet Ranger is the aircraft that TPWD uses to survey mule deer populations annually. Availability of the aircraft and hourly cost of commercial Jet Ranger helicopters prohibited its sole use for data collection. The left-front and right-rear passengers were the primary observers, responsible for sighting deer and taking visual measurements for each group encountered. Like TPWD surveys, the pilot served as a secondary observer to help spot deer with the primary observers. The pilot flew transect lines based on 200 m intervals using an aviation GPS unit (Garmin GPSMap 496) in the aircraft for reference. The pilot maintained the helicopter at 15-20 m above ground level (AGL) with a targeted ground speed of 80 km/hr. I recorded time, temperature, wind direction and speed, percent cloud cover, and precipitation before and after each survey. The names of the pilot, recorder, and observers were also recorded. Unlike TPWD survey protocol, a left-rear passenger recorded data and recorded deer not seen by other observers for additional data on missed groups. The recorder used an additional GPS (Garmin Rino 530hcx) to track the helicopter's flight path and locations of observations which were used to correlate helicopter locations with collar locations for data analysis.

The recorder gave each observation of ≥1 deer an individual observation number based on the GPS waypoint number. The observer who saw the deer verbally noted a location relative to the aircraft to eliminate double-counting deer. Observers considered deer to be part of the same group if they were seen together or, if running separate, appeared to have begun running from the same area. Observers considered deer to be in different groups if there was ≥ 50 m between groups. For each group, the observer described the number, sex, and age class of animals, percent woody cover, dominant vegetation type, deer activity, light conditions, terrain, and distance deer were from the helicopter transect. Collared deer spotted only by the data recorder were classified as unseen deer for later analysis.

Classifying Observations

All observers participated in counting group size on larger groups to reduce bias from miscounting. Each deer was classified as fawn, doe, young buck, middle-age buck, mature buck, or unidentified. The recorder noted color combinations of each collared deer seen. Vegetation data for observed groups were derived from a 9-m radius circle around the first animal seen. Woody vegetation canopy cover was visually classified in 10% increments. Vegetation type was assigned to one of four classes: open, low brush, mixed brush, and piñon/juniper (Fig. 4). The open vegetation class included bare ground, agriculture fields, and open grasslands. Brush that was shorter than the back of the deer and did not include > 10% piñon-juniper was classified as low brush. Low brush often included purple sagebrush, lechuguilla, shinnery oak, cholla, and skunk-bush sumac. Taller brush that did not include > 10% piñon/juniper was classified as mixed brush. Mixed brush most often included mesquite, granjeno, hackberry, and whitebrush. If vegetation included > 10% piñon pine or redberry juniper, it was classified as piñon-juniper.

The first animal seen in the group was recorded as inactive or active. If the animal was not walking or running it was considered inactive. Light conditions of each survey were recorded as bright sunlight (bright light) or overcast skies (flat light). When skies were predominantly cloudy or sunny, light classification was unambiguous. On partly cloudy days, changes in cloud cover necessitated different light condition classes on a survey. If surveys began in flat light conditions but clouds dissipated, or vice versa, light conditions were changed accordingly. On partly cloudy days with 50% cloud cover or less, I considered light conditions as bright. When cloud cover increased over 50%, I assumed flat light conditions. Light conditions were not determined by each individual observation but on a more broad scale, most often by survey.

Terrain in which each group was observed was classified as flat, rolling, rough, or rugged (Fig. 5, pg. 29). Flat terrain had little relief (< 5% slope) and was common in grasslands of the Panhandle region and lower elevations of the Trans-Pecos study sites. Rolling terrain had greater relief (5 – 30% slope) than flat terrain, but shallow slopes. Rough terrain had 30 – 60% slope, and was common in mountainous portions of the

Figure 4. Vegetation cover was classified into 4 dominant vegetation types: open (A), low brush (B), mixed brush (C), and piñon/juniper (D). Open vegetation types included bare ground, agriculture fields, and grasslands.

A.

Figure 4 (Continued).

B.

Figure 4 (Continued).

C.

Figure 4 (Continued).

D.

Figure 5. Examples of flat(A), rolling(B), rough(C), and rugged (D) terrain types seen on sightability surveys in the Trans-Pecos and Panhandle regions of Texas, January-February, 2008-2010.

A.

Figure 5 (Continued).
B.

Figure 5 (Continued).
C.

Figure 5 (Continued).
D.

Trans-Pecos and the caprock escarpment in the Panhandle. Rugged terrain was steep (> 60% slope) with elevation changes >100 m common over short distances. Terrain was classified using features in a 50 m radius circle centered on the group to mitigate fine-scale irregularities within terrain classes.

Perpendicular distance between the flight line and the location where the group was first seen was estimated in 9.1 m (10 yard) increments. Deer seen > 91 m perpendicular from the transect were noted but not included in the data. Primary observers were equipped with laser rangefinders to help calibrate their visual distance measurements during the survey. Exact measurements were not recorded with a rangefinder because the time spent obtaining an exact measurement prevents observers from searching for additional deer.

When morning surveys were complete, the pilot and I used homing techniques with radio telemetry in the helicopter to locate collared deer that were not seen during the survey. We flushed the animals and recorded their group size. I obtained all other variables (vegetation type, terrain, etc.) for unseen collared deer during the surveys through remote sensing.

The GPS collars were fitted with a timed drop-off mechanism to facilitate retrieval of the collars. Volunteers and I located each collar via radio telemetry and homing techniques. Percent woody vegetation cover, vegetation class, and topography were measured visually by volunteers and myself with the same criteria used during the surveys. I downloaded the binary fix records from the collar via the Lotek host hardware and software to individual files for each collar.

Spatial Data and Imagery

I transferred location data from the GPS collars to a comma-delimited text format with the Lotek host software. In a spreadsheet I formatted data to display date and time for each location in separate columns and location failures were removed. Next, I converted the files to a comma separated values (.csv) file format, imported into Environmental Systems Research Institute ArcGIS 9.3 (ESRI, Redlands, CA, USA), created a shapefile from each collar's data, and displayed it on a map. Collar fix information had to be projected to Universal Transverse Mercator for activity analysis using the "calculate geometry" option in the attribute table. Finally, I combined date and time into one field using the field calculator to allow tracking analyst to properly display location data.

I used Garmin Mapsource software to download tracklogs and deer sighting locations from the GPS unit used in the helicopter. Tracklogs had to be exported in .dxf format to be added to the map project in ArcGIS where point data were converted to a shapefile for use in the tracking analyst extension. Once deer location and flight data were overlaid using ArcGIS it was possible to determine the number of deer available for sighting by observers using the tracking analyst extension of ArcGIS. Tracking analyst allowed me to replay individual surveys, showing only the most recent events to facilitate identifying where deer were relative to the helicopter at specific times. I added each data file via tracking analyst, choosing the proper column for temporal reference and selected to display only the most current event from the properties screen. I replayed each survey, one deer at a time, and deer within 91 m of the transect line immediately before the helicopter passed were considered available for observation. I measured perpendicular distance from the transect line using the measure tool. Collar frequency and estimated time of encounter were also a part of this spreadsheet of possible sightings, called the parent dataset.

I then copied location information for each possible encounter, one before the helicopter passed and one after, to the parent spreadsheet of observable deer. Sex, survey number, and study site were also important for each possible sighting, along with whether the deer was observed during the survey. I transcribed group size, percent cover, vegetation type, activity, light, terrain, distance, and aircraft data for observed deer from the flight datasheets to the spreadsheet for each survey. Then I imported spreadsheets for each survey back into ArcGIS and displayed the point where each deer was before the helicopter passed.

Vegetation analysis was based on the false color infrared National Agricultural Imagery Program (NAIP) imagery flown during summer 2008 at 1 m resolution by the US Department of Agriculture. On one ranch, dramatic changes had been made to the vegetative community through mechanical brush control between the time surveys were conducted and when the imagery was acquired. In this case, I used 2004 imagery for analysis. I used the NAIP imagery because of the high resolution, ability to detect photosynthetic differences, and ease of accessibility. Imagery taken during survey months was not suitable because the "leaf-off" conditions complicated assignment of vegetation types, which is based primarily on photosynthetic activity.

First, I delineated a polygon shapefile for each study location that encompassed all points where deer could have been observed. I used ERDAS Imagine 9.3 (ERDAS, Inc., Norcross, GA, USA) to clip the NAIP imagery to the area of interest by subsetting the image. Using an unsupervised classification technique on each area, I classified the image into 20 to 50 land cover classes depending on the spectral diversity of each site. A normalized difference vegetation index model was necessary for 2004 imagery because the results of the classified photosynthetic index produced more reliable results than the classification of raw imagery. I assigned each land cover class to one of the vegetation classes used when classifying deer during surveys based on my knowledge of each study site's vegetative communities and from aerial photo interpretation. I then combined like classes to create a final signature set and a supervised classification was run to create a vegetation map depicting the classes used during the surveys. The vegetation classes used in analysis were open, low brush, mixed brush, and piñon-juniper.

For data extraction, I buffered points where deer were available to be seen to 11 m to ensure all pixels within 9 m of the point were included in their entirety. The classified images were then clipped within ERDAS Imagine to the 11 m buffers using the subset function once the shapefiles were converted into areas of interest. The resulting raster datasets were analyzed within ArcMap. Raster vegetation data of the buffered areas were vectorized into polygon shapefiles using the Spatial Analyst extension in ArcGIS and data outside of buffered areas were removed. I merged like vegetation types into multipart shapes to simplify calculation of statistics because one vegetation type could have multiple entries in a single buffer area. Then I intersected 9 m buffers with the 11 m buffer shapefiles, to create 9 m buffer shapefiles with the appropriate vegetation classes for comparison. I added area and percent columns to the attribute table for each time a deer was available to be observed. Next, I calculated area of each vegetation type using the calculate geometry tool within the attribute table of ArcMap. Percent area was then computed for each vegetation class in the 9 m radius circle. The attribute table was then exported to a database file and joined to the percent vegetation composition in the parent spreadsheet in Excel.

Once all percent coverage of vegetation types were populated within the Excel spreadsheet, I developed a series of conditional statements to determine which vegetation type should describe each buffered location. If piñon-juniper comprised > 10% of the area, the location was described as piñon-juniper. If the 9 m circle could not be described as piñon-juniper, then if the combined brush was > 20%, it was described as being low or mixed brush. A separate determination was made between low brush and mixed brush by classifying a point as mixed brush if it comprised > 10% of the area. If the point could still not be described using the previous parameters, it was considered open. I assessed accuracy of the vegetation maps against visual estimates at known locations recorded during collar retrieval. I extracted data in the same manner as points for available deer and compared estimates from the vegetation map to the visual estimates.

Light conditions for deer were determined by assigning a single value for the entire survey unless a clear trend in cloud cover could be determined using light conditions assigned to observed deer. If cloud cover changed rapidly and the pattern in cloud cover was obvious, the trend was applied to unobserved deer; however, this method was only applied to 4 of the 46 surveys conducted during this study. The other 42 surveys were given a single light class for the entire survey.

I calculated activity of deer as the helicopter passed using movement between locations immediately before and immediately after the helicopter passed the deer. Accuracy of the GPS unit in the collar is ±10 m, such that 20 m is the maximum potential shift in location of an inactive deer. Therefore, if the collared deer moved >20 m, I considered it active.

I determined terrain measurements using ArcGIS and the 10 m National Elevation Dataset (United States Geological Survey, Sioux Falls, SD, USA). I buffered the points where deer were available to be seen to a radius of 50 m to avoid misclassifying terrain in cases of small inconsistencies in terrain such as a small, flat plateau in rolling terrain. All USGS quarter quadrangles national elevation 10 m data covered by each study area were combined through the mosaic tool in the ArcToolbox. I exported the resulting image as a grid (.grid) format and calculated a topographic ruggedness index (Riley et al. 1999) using ArcInfo. The terrain ruggedness index compares the elevation values of a pixel to the surrounding 8 pixels. The difference between the center pixel and the surrounding 8 pixels is calculated, each value is squared, and averaged; the square root of the average value is reported for each pixel, creating a scaled image depicting ruggedness. I then converted the resulting raster dataset to a polygon shapefile using spatial analyst. A polygon incorporating all buffered points had to be generated and intersected with the shapefile produced from the terrain ruggedness index to reduce analysis time during the spatial join process. I used a spatial join to create a dataset of only the buffered areas for each point and then exported the terrain ruggedness index (TRI) data. To develop the criteria for each terrain category, I compared index values to visual terrain estimates at known locations recorded during helicopter surveys and modified the criteria for terrain estimates from the index to best fit the index estimates to the visual estimates of observed deer. Using the dataset, I determined terrain class through a series of conditional statements in a MS Excel spreadsheet using the criteria created for each terrain class.

Though the general terrain classes were similar, criteria for each class changed among study sites because of inherent variations in terrain between study sites. For Black Mesa, if the TRI value was ≤ 10, the point was considered flat. If the TRI value was > 10 but ≤ 25, I considered it rolling. For TRI values > 25 but ≤ 50, the point was considered rough. TRI values > 50, were considered rugged terrain.

Data recorded during helicopter surveys were considered superior to data obtained from remote sensing and GPS collars. Therefore, when collared deer were not seen by observers, but were seen by the recorder, I used attributes estimated by the recorder instead of estimated from GIS and GPS data. I then combined each survey dataset into one worksheet and included data on the study site, survey number, collar frequency, sex, whether or not the collared deer was seen, group size, percent cover of brush, vegetation class, activity, GPS fix number, light, terrain, distance from transect, and aircraft. This was the final dataset used in the logistic regression analysis.

Statistical Analyses

I tested models incorporating group size, vegetation type, activity, light, terrain and perpendicular distance from the transect and biologically sensible two-way interactions, using a logistic regression procedure in the computer program SAS 9.3 (SAS Institute, Inc., Cary, NC). I assessed support for candidate models by the data, using Akaike information criterion (AIC; Burnham and Anderson 1998) and model selection techniques.

I was able to estimate all attributes for unseen groups using data from my GIS and GPS locations, except group size. By locating unseen groups after surveys and using groups seen only by the recorder, I acquired group size for 97 groups that were not seen by observers during the survey, or 11.7% of unseen groups. Because group size has regularly been found to influence sightability of large mammals during surveys, assessing its influence in my study was important. To assess the importance of group size, I first compared the distribution of group sizes of seen and unseen groups. I further assessed the effect of group size by randomly selecting 97 seen groups using the RANUNI function in SAS, combining those observations with the 97 observations of unseen groups, and repeating the logistic regression procedure with the subset of 194 observations. I added group size to the top model from the analysis without group size, tested the fit of the model to the subset of data. I repeated this procedure 5 times such that a different 97 observations of seen groups were combined with the 97 observations of unseen groups. The effect of group size ($P < 0.05$ for all 5 datasets) justified further investigation of group size.

Having evidence that group size was important, I used an ad hoc procedure to generate group sizes for all missing group sizes using the distribution of group sizes I had for unseen groups. Group sizes of unseen groups varied by vegetation type, with the distribution of group size for open habitats approximated by a normal distribution with a mean of 1.8. Group sizes in brushy habitats approximated a Poisson distribution with a mean of 2.2. Group sizes were generated using the Random Normal (RANNOR) or Random Poisson (RANPOI) functions in SAS and rounded to nearest non-zero whole number. Using logistic regression, I then tested a set of candidate models, some of which included group size and meaningful two-way interactions, and used AIC values (Burnham and Anderson 1998) to determine if there was support for a single model including group size. I completed 11 trials of the candidate model set with unique randomization of group sizes to analyze stability of coefficients under different randomly generated group sizes. I used the trial with the median group size coefficient as the final model.

Model Validation

Validating population estimates from the sightability model is important for justifying implementation of the model. I compared population estimates from the sightability model to estimates derived from a mark-resight procedure, incorporating resightings of collared deer calculated using the computer program MARK (White and Burnham 1999, McClintock et al. 2009). I applied the sightability model to the survey data (collared and non-collared deer) to obtain population estimates using the sightability model. These population estimates were divided by the area surveyed to obtain a density estimate. I then developed encounter histories for each deer and used the Poisson log-normal model of the mark-resight section in program MARK with 16 candidate models to create population estimates for each study site. I tested similar models (Appendix 1) for each and chose the model that best fit the data based on the lowest AICc value. Mark-resight estimates of population size for each survey were divided by the area surveyed to estimate population density. Average population density for each study area derived from sightability models was compared to the population density derived independently from the mark-resight models.

I calculated the coefficient of variation from density estimates for each study area and compared the sightability model and mark-resight variation to density estimates derived from deer seen during surveys without correcting for visibility bias.

RESULTS

In total, 2,006,125 GPS fixes were collected by collars on 88 bucks and 126 does. One collar was not used during year 3 because of battery failure. Additionally, one collar was not recovered during year 3 because its VHF signal could not be located. Sixteen collared deer died during the study from predation by mountain lions and coyotes and from vehicle collisions.

Average area surveyed varied among study sites from 24 to 33 km^2 (Table 4). Area surveyed varied by study site due to the distribution of collared deer and the amount of available habitat. Variation among surveys on individual study sites was due to varying weather conditions and efficiency of the survey crew at identifying deer and classifying observations. For personnel safety, surveys were cancelled due to adverse weather conditions.

Fifty surveys were flown during the three years of the study (Appendix 2); forty-six were flown with a Robinson R44, and four were flown with the TPWD Bell Jet Ranger. Eight surveys were flown on each of the Black Mesa, Longfellow, Miller, and Sierra Diablo WMA sites. Nine surveys were flown on each of the Mott Creek and NWPH sites. Fifteen different observers were used during the study, including the author, 13 TPWD biologists, and 1 landowner. Environmental conditions during surveys ranged from calm, sunny, and warm with high temperatures reaching 18°C, to light snow, high wind, and temperatures as low as -11°C. Snow never accumulated on the ground in an amount to justify investigation.

Across all surveys, 869 does and 436 bucks with collars were available for observation. Some deer were available to be seen from the helicopter > 1 time during a

Table 4. Area (km^2) surveyed from helicopter, by study site and individual survey, during development of a sightability model for mule deer in western Texas, January and February, 2008-2010.

	Survey Number									
Study Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
Black Mesa	29.4	27.9	26.6	28.9	24.9	26.5	28.3	29.0		27.7
Longfellow	22.0	28.2	25.1	28.3	24.6	29.1	33.5	35.0		28.2
Mott Creek	24.6	30.2	24.3	29.2	28.9	28.3	27.9	27.1	26.9	27.5
NWPH	26.0	28.9	32.0	39.7	35.6	39.7	30.6	32.9	32.9	33.1
Sierra Diablo	30.3	34.4	25.2	36.7	31.1	32.9	20.9	32.9		30.6
Miller	24.4	26.6	26.5	23.8	26.6	19.1	28.2	20.9		24.5

in a dataset of 1,527 potential observations for logistic regression analysis. Observers counted 6,591 mule deer, including both collared and uncollared deer. Mean (± SD) sightability of collared deer was 41.9% ± 15.6% and varied among surveys from 18.8% to 77.4%. Mean sightability for bucks and does was 39.4% ± 15.9 and 44.5% ± 15.1%, respectively. The top mark-resight models did not include a sex effect on sightability of deer in 5 of 6 study locations (Appendix 1).

Only 4% of inactive deer were sighted on surveys (Table 5), but to correct for inactive deer missed on a survey, at least some inactive deer need to be seen. During my research, 1 inactive group was seen per 170 km of survey. At this rate, TPWD would expect to observe 23 to 24 inactive groups of deer on the 3,950 km of annual survey lines.

Accuracy of Remote Sensing

With 4 vegetation classes, I found accuracy of classification ranged from 45.5% (NWPH) to 76.9% (Longfellow). To increase accuracy, I combined the woody species (low brush, mixed brush, and piñon-juniper) into a single class, brushy habitat. Simplifying the classes increased accuracy of the vegetation maps to an acceptable level. Both Panhandle locations had 81.1% accuracy, Miller had 84.2%, SDWMA had 92.9%, Longfellow had 96.2%, and Black Mesa had 100% accuracy. The final analysis included 2 vegetation classes, open habitat and brushy habitat. Few sightings occurred in rugged terrain, so I collapsed rough and rugged into a single class, leaving 3 terrain classes: flat, rolling, and rough.

Table 5. Number of observed and unobserved groups of collared mule deer by individual factor during aerial surveys in the Trans-Pecos and Panhandle regions of Texas, January and February, 2008-2010. Group size was only observed for 11.7% of unseen groups and therefore proportion seen was not calculated.

		Number of Groups		
Variable	**States**	**Unobserved**	**Observed**	**Proportion Seen**
Group size	1	44	218	
	2	27	135	
	3	11	84	
	4	8	70	
	5	2	58	
	6		43	
	7	4	31	
	8		11	
	9	1	8	
	10		12	
	11		4	
	12		10	
	13		1	
	14		5	
	15		3	
	16		2	
	17		1	
Vegetation Class	Open	68	94	0.58
	Low Brush	138	106	0.43
	Mixed Brush	131	133	0.50
	Piñon-Juniper	370	366	0.50
Activity	Inactive	289	11	0.04
	Active	539	688	0.56
Light	Bright	672	497	0.43
	Flat	156	202	0.56
Terrain	Flat	100	126	0.56
	Rolling	367	412	0.53
	Rough	309	150	0.33
	Rugged	52	11	0.17
Distance (m)	0	71	109	0.71
	9	54	66	0.57
	18	66	72	0.50
	27	83	65	0.54
	36	87	100	0.43
	45	86	61	0.37

Table 5 (Continued).

Variable	States	Number of Groups Unobserved	 Observed	Proportion Seen
Distance (m)	55	93	53	0.37
	64	89	52	0.34
	73	101	46	0.20
	81	100	27	0.32
	91	108	48	0.44

Analysis Without Group Size

Of the 32 candidate models, the top models contained all 5 variables evaluated (Vegetation, Activity, Light, Terrain, Distance), and the top model contained an interaction between activity and vegetation (Table 6). Evidence in support of the interaction was strong with the top model receiving 97.8% of the weight among all models; the ΔAIC was 9.472 units below the model without the interaction (Tables 6 and 7, pg. 50). Overall, activity made little difference in open habitats, but positively affected sighting in brushy habitats (Fig. 6, pg. 51). Deer had a higher probability of being seen in open habitat, irrespective of activity, and were less likely to be seen in brushy habitat if inactive (Fig. 6, pg. 51).

All other effects in the model without group size were additive. Deer were more visible in flat light than bright light (Fig. 7, pg. 52). The difference in probability of sighting between lighting conditions was not as great as some other variables.

Sightability decreased as terrain ruggedness increased (Fig. 8, pg. 53). Probability of observation was inversely related to distance from the helicopter. In the raw data, there were spikes in observations at 27 to 36 m and 82 to 91 m (Table 5, pg. 45), but their effect was constricted in the final model. Sightability on the transect line ranged from 62% for deer that were inactive, in bright light, brushy habitat, and rough terrain to 88% for active deer in flat light, open habitat, and flat terrain.

Analysis With Group Size

Seventy-three percent of mule deer groups not seen during aerial surveys contained1-2 deer and 17% contained > 3 deer, whereas 38% of groups that were seen

Table 6. Logistic regression analysis results of candidate models without group size including biologically logical interactions (*) fitted to sightability data for collared mule deer in the Trans-Pecos and Panhandle regions of Texas collected in January and February, 2008-2010.

Model	AIC	ΔAIC	exp(-1/2d)	w(i)
Active, Dist, Veg, Light, Terr, Veg*Active	1790.07	0.000	1.000	0.978
Active, Dist, Veg, Light, Terr	1799.542	9.472	0.009	0.009
Active, Dist, Veg, Light, Terr, Dist*Active	1800.478	10.408	0.005	0.005
Active, Dist, Veg, Light, Terr, Dist*Terr	1801.075	11.005	0.004	0.004
Active, Dist, Veg, Light, Terr, Dist*Veg	1801.34	11.270	0.004	0.003
Active, Dist, Light, Terr	1804.088	14.018	0.001	0.001
Active, Dist, Veg, Terr	1812.549	22.479	0.000	0.000
Active, Dist, Terr	1817.654	27.584	0.000	0.000
Active, Veg, Light, Terr	1868.101	78.031	0.000	0.000
Active, Light, Terr	1872.6	82.530	0.000	0.000
Active, Veg, Terr	1877.832	87.762	0.000	0.000
Active,Terr	1882.813	92.743	0.000	0.000
Active, Dist, Veg, Light	1887.588	97.518	0.000	0.000
Active, Dist, Veg	1899.483	109.413	0.000	0.000
Active, Dist	1900.329	110.259	0.000	0.000
Dist, Veg, Light, Terr	1924.759	134.689	0.000	0.000
Dist, Veg, Terr	1942.355	152.285	0.000	0.000
Dist, Terr	1952.358	162.288	0.000	0.000
Active, Veg, Light,	1952.645	162.575	0.000	0.000
Active, Light	1953.346	163.276	0.000	0.000
Active, Veg	1961.444	171.374	0.000	0.000
Active	1962.321	172.251	0.000	0.000

Table 6 Continued.

Model	AIC	ΔAIC	exp(-1/2d)	w(i)
Dist, Light	2005.064	214.994	0.000	0.000
Veg, Light, Terr	2015.083	225.013	0.000	0.000
Dist, Veg	2019.238	229.168	0.000	0.000
Dist	2023.409	233.339	0.000	0.000
Light, Terr	2024.872	234.802	0.000	0.000
Veg, Terr	2028.682	238.612	0.000	0.000
Terr	2039.221	249.151	0.000	0.000
Veg, Light	2088.853	298.783	0.000	0.000
Light	2093.136	303.066	0.000	0.000
Veg	2102.552	312.482	0.000	0.000

[1] Variables are VEG = vegetation type, open, brushy; ACTIVE = deer either active or inactive (standing or bedded); LIGHT = light conditions either bright or flat; TERRAIN = terrain ruggedness, flat, rolling, rough; DIST = perpendicular distance from the transect line to the group.

Table 7. Odds ratios for top model without group size from logistic regression analysis of mule deer sightability data (N = 1,527 observations) collected in January to February, 2008-2010 in the Trans-Pecos and Panhandle regions of Texas.

R = 0.7385 + Vegetation Class + Activity + Light + Terrain - 0.0174 * Distance + Active*Vegetation

where:

R = Odds ratio

Vegetation class = [0.5405 Open Habitat]
[0 Brushy Habitat]

Activity = [0 Inactive]
[0.4746 Active]

Light = [-0.2598 Bright]
[0 Flat]

Terrain = [0.6246 Flat]
[0.2060 Rolling]
[0 Rough]

Active*Veg = [-0.4305 Active*Open Habitat]
[0 Active*Brushy Habitat]

Figure 6. Sightability of active and inactive mule deer without group size for deer in open and brushy habitat in flat light and rolling terrain at various 30 m from the helicopter survey transect in the Trans-Pecos and Panhandle regions of Texas, January-February, 2008-2010.

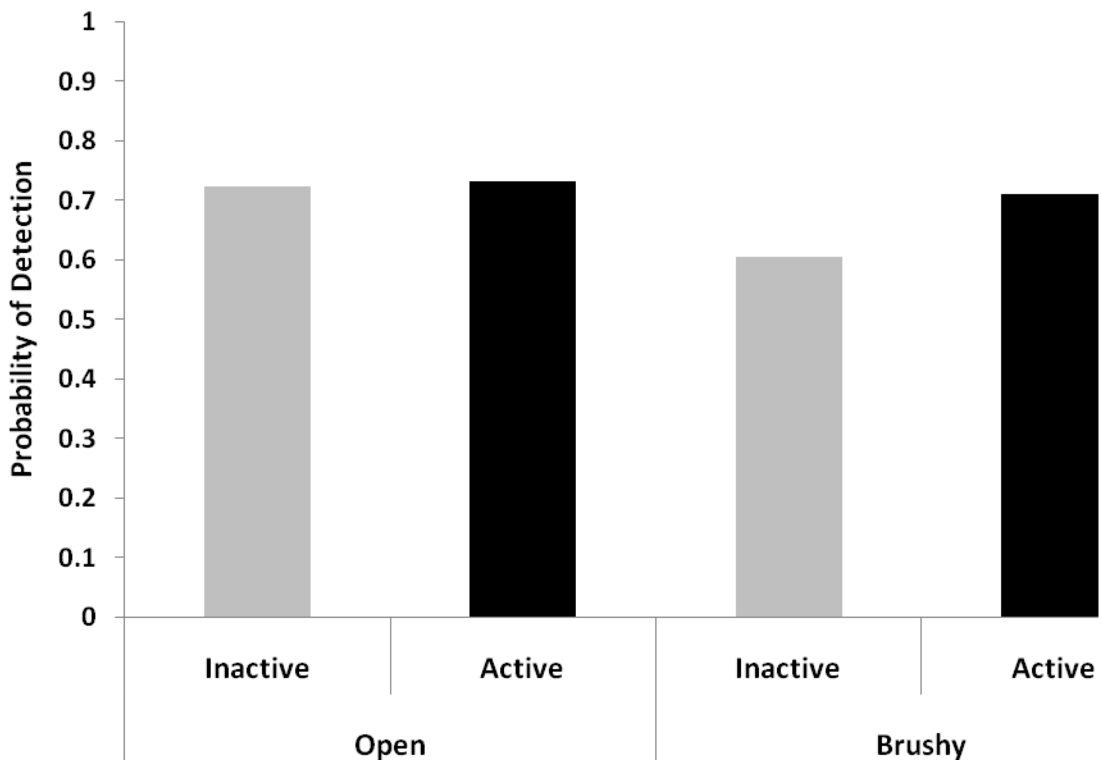


Figure 7. Estimates of the influence of light conditions on sightability of active mule deer during aerial surveys in brushy habitat and rolling terrain at various distances (m) from the transect line in the Trans-Pecos and Panhandle regions of Texas, January-February, 2008-2010. Flat light describes cloudy conditions where large areas or all of the suvey area are covered whereas bright light occurs on cloudless or partly cloudy days.

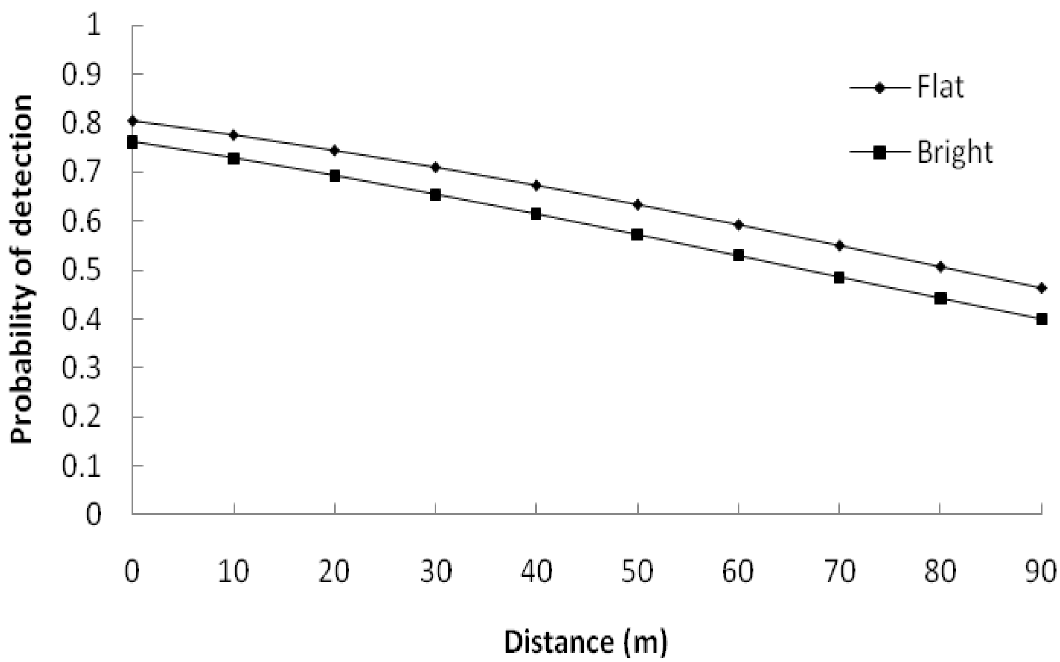
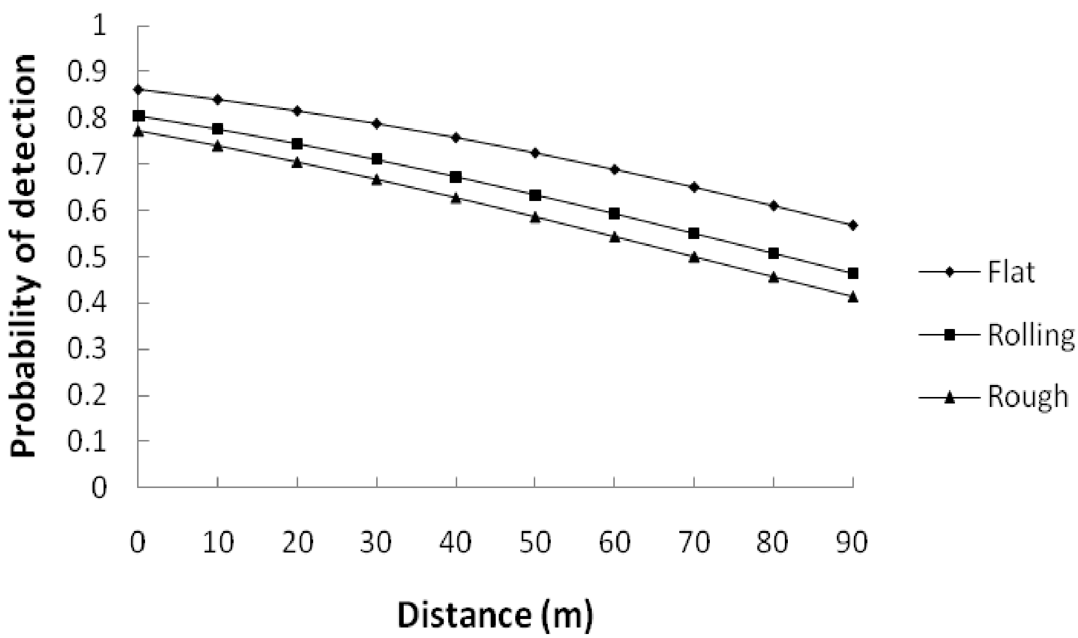


Figure 8. Predicted influence of terrain on sightability of mule deer across various distances (m) without considering group size in the Trans-Pecos and Panhandle regions of Texas, January-February, 2008-2010. Terrain classes are characterized as: flat, little to no change in elevation; rolling, moderate changes in elevation; rough; considerable elevation changes over area. Estimates of sightability are for active mule deer in flat light and brushy habitat.



contained >3 deer (Fig. 9). The top model included the variables Group Size, Vegetation, Activity, Light, Terrain, and Distance with an interaction between Group Size and Vegetation (Tables 8 and 9, pg. 56-58). The model "Group Size, Vegetation, Activity, Light, Terrain, Distance, Group Size*Vegetation" ranked as the top model in 6 of 11 trials while the model, "Group Size, Vegetation, Activity, Light, Terrain, Distance, Activity*Vegetation, Group Size*Vegetation" ranked as top in the remaining 5. Support for the single interaction in this model over the two interactions was weak because the ΔAIC between the models was only 0.175 units and the one interaction model received 52.1% of the weight among the models considered. However, a model with 1 interaction is more parsimonious and allows for simpler interpretation. The model with two interactions and an averaged model between the top two models produced population estimates farther from the mark-resight estimates (84% and 82%, respectively) while estimates from the one interaction model were 93% of mark-resight estimates.

Because group size needed to be estimated for many of our unobserved groups, I used a different random draw for each of 11 logistic regression analyses of all candidate models. Using multiple random draws for group size allowed me to assess variability of model parameters caused by the randomly selected group sizes. The coefficient for the group size effect was sufficiently stable (range = 0.4630 - 0.5455; $N = 11$) to incorporate group size in the model. The model with the median group size coefficient (0.4981) was chosen (Table 9, pg. 58).

The probability of sighting a group increased as group size increased, but the effect differed by vegetation type (Fig. 10, pg. 59). The probability of seeing deer in

Figure 9. Percentage distribution of group size for collared mule deer observed (N = 567) and unobserved (N = 97) during aerial surveys across 6 study locations in the Trans-Pecos and Panhandle regions of Texas, January-February, 2008-2010.

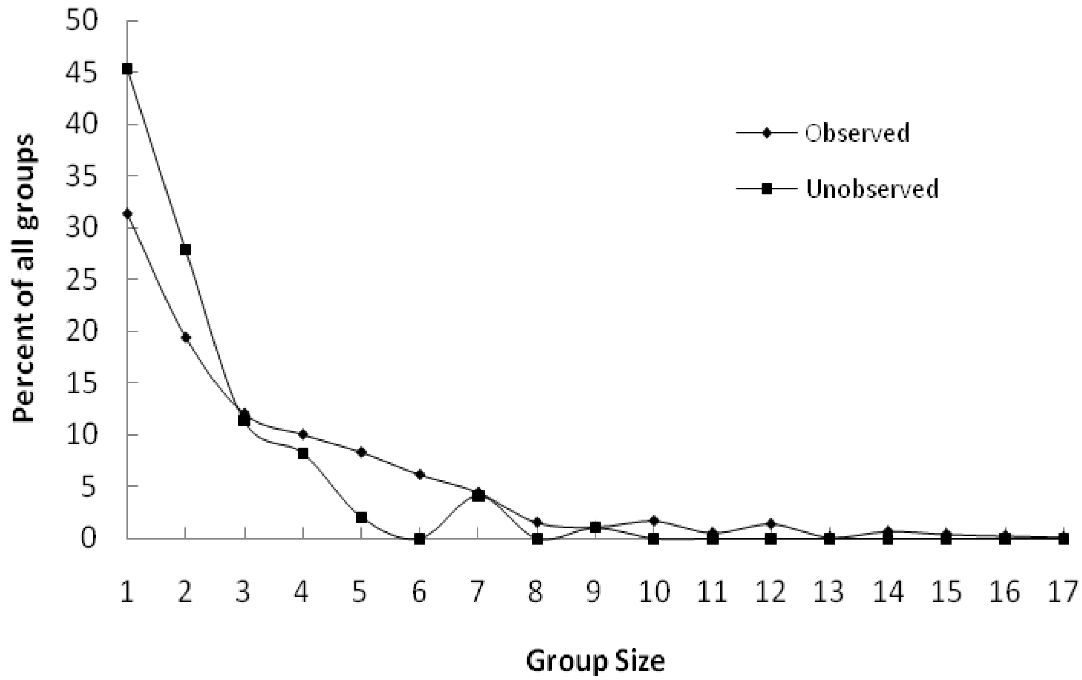


Table 8. Models and model selection data from logistic regression analysis (N = 1,527) of the effect of six variables and logical two-way interactions on the probability of sighting mule deer groups during aerial surveys in the Trans-Pecos and Panhandle regions of Texas, January to February, 2008-2010.

Model	AIC	ΔAIC	exp(-1/2d)	w(i)
Size, Veg, Active, Light, Terr, Dist, Veg*Size	1683.661	0.000	1.000	0.521
Size, Veg, Active, Light, Terr, Dist, Active*Veg, Veg*Size	1683.836	0.175	0.916	0.478
Size, Veg, Active, Light, Terr, Dist, Active*Veg	1697.628	13.967	0.001	0.000
Size, Veg, Active, Light, Terr, Dist, Active*Veg, Dist*Size	1698.429	14.768	0.001	0.000
Size, Veg, Active, Light, Terr, Dist	1702.852	19.191	0.000	0.000
Size, Veg, Active, Light, Terr, Dist, Terr*Size	1703.620	19.959	0.000	0.000
Size, Veg, Active, Light, Terr, Dist, Dist*Size	1703.853	20.192	0.000	0.000
Size, Veg, Active, Light, Terr, Dist, Active*Size	1704.812	21.151	0.000	0.000
Size, Active, Light, Terr, Dist	1705.688	22.027	0.000	0.000
Size, Veg, Active,Terr, Dist	1712.666	29.005	0.000	0.000
Size, Active, Terr, Dist	1716.063	32.402	0.000	0.000
Size, Veg, Active, Light, Terr	1774.411	90.750	0.000	0.000
Size, Active, Light, Terr	1776.793	93.132	0.000	0.000
Size, Veg, Active, Terr	1781.714	98.053	0.000	0.000
Size, Active, Terr	1784.538	100.877	0.000	0.000
Size, Veg, Active, Light, Dist	1791.448	107.787	0.000	0.000
Size, Veg, Active, Dist	1799.870	116.209	0.000	0.000
Size, Active, Dist	1800.028	116.367	0.000	0.000
Size, Veg, Light, Terr, Dist	1819.065	135.404	0.000	0.000
Size, Veg, Terr, Dist	1832.891	149.230	0.000	0.000

Table 8 Continued.

Model	AIC	ΔAIC	exp(-1/2d)	w(i)
Size, Terr, Dist	1840.586	156.925	0.000	0.000
Size, Active, Light	1859.271	175.610	0.000	0.000
Size, Veg, Active, Light	1859.765	176.104	0.000	0.000
Size, Active	1865.655	181.994	0.000	0.000
Size, Veg, Active	1865.965	182.304	0.000	0.000
Size, Light, Dist	1898.559	214.898	0.000	0.000
Size, Veg, Dist	1910.003	226.342	0.000	0.000
Size, Dist	1913.006	229.345	0.000	0.000
Size, Veg, Light, Terr	1913.118	229.457	0.000	0.000
Size, Light, Terr	1920.038	236.377	0.000	0.000
Size, Veg, Terr	1923.711	240.050	0.000	0.000
Size, Terr	1931.364	247.703	0.000	0.000
Size, Veg, Light	1987.551	303.890	0.000	0.000
Size, Light	1989.718	306.057	0.000	0.000
Size, Veg	1998.214	314.553	0.000	0.000
Size	2000.817	317.156	0.000	0.000

[1] Variables are SIZE = number of mule deer in a group; VEG = vegetation type, open, brushy; ACTIVE = deer either active or inactive (standing or bedded); LIGHT = light conditions either bright or flat; TERRAIN = terrain ruggedness, flat, rolling, rough; DIST = perpendicular distance from the transect line to the group.

Table 9. Odds ratios for sightability model "Group Size, Vegetation, Activity, Light, Terrain, Distance (m), Group Size*Vegetation" using estimated group sizes for missing data from logistic regression analysis of mule deer sightability dataset (N = 1,527 observations). Data were collected during , January-February, 2008-2010 in the Trans-Pecos and Panhandle regions of Texas.

R = -0.9077 + 0.5331*Group Size + Vegetation Class + Activity + Light + Terrain + -0.0184 * Distance + Group Size*(Group Size*Vegetation)

where:

R = Odds ratio

Vegetation class =	0.3032	Open Habitat
	0	Brushy Habitat

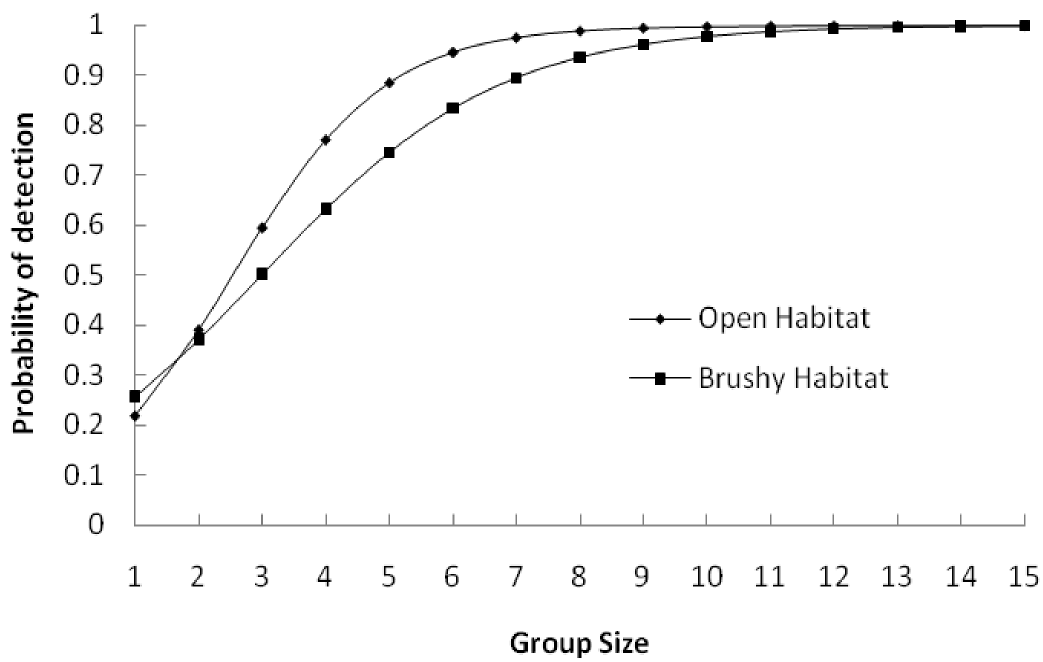
Activity =	0	Inactive
	0.8520	Active

Light =	-0.2284	Bright
	0	Flat

Terrain =	0.6266	Flat
	0.2358	Rolling
	0	Rough

Group Size*Vegetation =	0.2975	Open Habitat
	0	Brushy Habitat

Figure 10. Probablity of detection of collared mule deer during aerial surveys in two vegetation classes with a range of group sizes at 50 m. Sightability estimates are based on inactive animals on rolling terrain with flat light conditions from data collected in the Trans-Pecos and Panhandle regions of Texas during, January-February, 2008-2010.



open habitat increased dramatically as group size increased from 1 to 6 and plateaued with group sizes > 6. Larger group size was necessary in brushy compared to open habitat before sighting probability became high. This interaction caused sightability to be similar among habitats for small (< 2) and large (> 10) groups. Intermediate groups were more visible in open habitat than brushy habitats (Fig. 10, pg. 59). Groups above 10 animals had essentially 100% sightability, irrespective of other conditions (Figs. 10-14, pg. 59-64). Active deer were more likely to be observed than inactive deer, but the effect declined with increasing group size because of high sighting probability for large groups (Fig. 11).

Overcast conditions resulted in slightly higher sightability than bright conditions (Fig. 12, pg. 62). Influence of light intensity was minimal compared to other influences on sightability. Increasing topography and distance from the transect diminished sightability (Figs. 13 and 14, pg. 63-64).

Evaluation of Sightability Model

Population size estimated using the sightability model without group size averaged 86% and using the sightability model with group size was averaged 93% of mark-resight estimates (Table 10, pg. 65). By comparison, population estimates from uncorrected helicopter survey data averaged 52% of mark-resight estimates (Table 10, pg. 65). Population estimates using the sightability model with group size contained the mark-resight estimates within their 95% CI for 4 of 6 research sites (Table 10, pg. 65). Coefficients of variation from population estimates using mark-resight and sightability models decreased precision on ≥ 1 study site relative to uncorrected population estimates (Table 11, pg. 66). The model with group size had a lower coefficient of variation in 4

Figure 11. Influence of activity on sightability of mule deer for a range of potential group sizes in brushy vegetation in rolling terrain under flat light at 50 m in the Trans-Pecos and Panhandle regions of Texas during, January-February, 2008-2010. Sightability was calculated using the model "Group Size, Vegetation, Activity, Light, Terrain, Distance, Group Size*Vegetation".

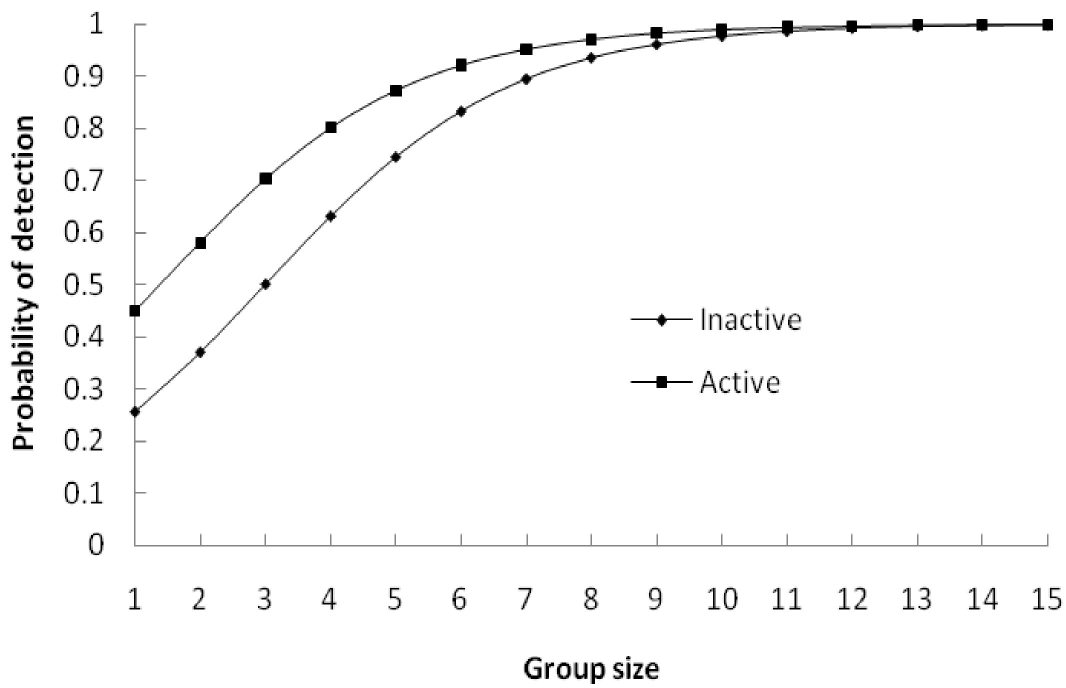


Figure 12. Influence of light intensity on sightability for various group sizes of active mule deer in brushy habitat and rolling terrain at 50 m from the transect in the Trans-Pecos and Panhandle regions of Texas during, January-February, 2008-2010.

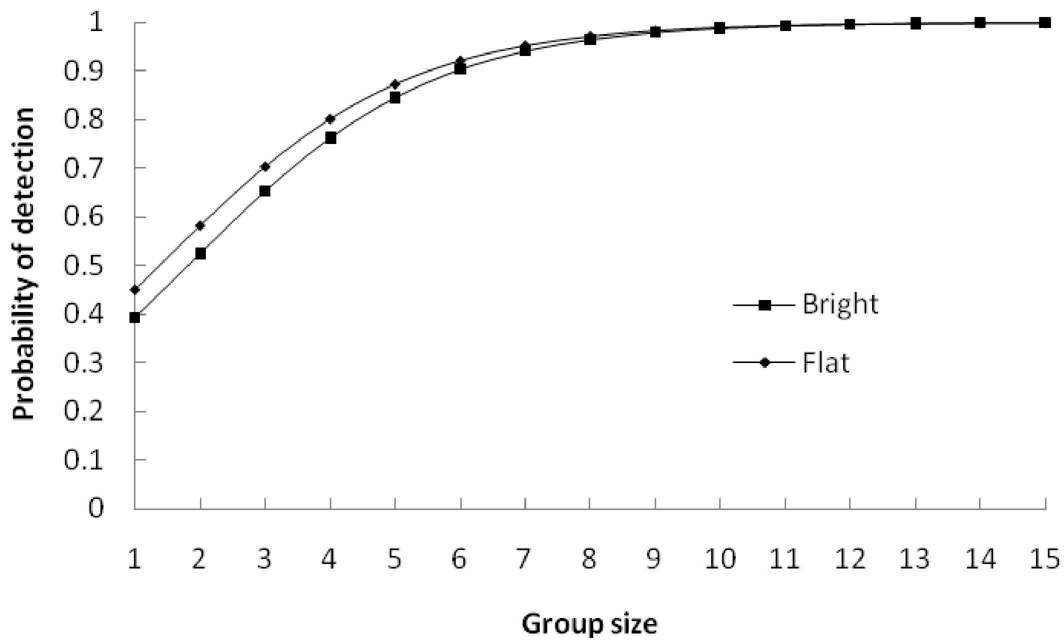


Figure 13. Model predicted influences of 3 terrain types on sightability for various group sizes of active mule deer in brushy habitat and flat light throughout the Trans-Pecos and Panhandle regions of Texas during, January-February, 2008-2010.

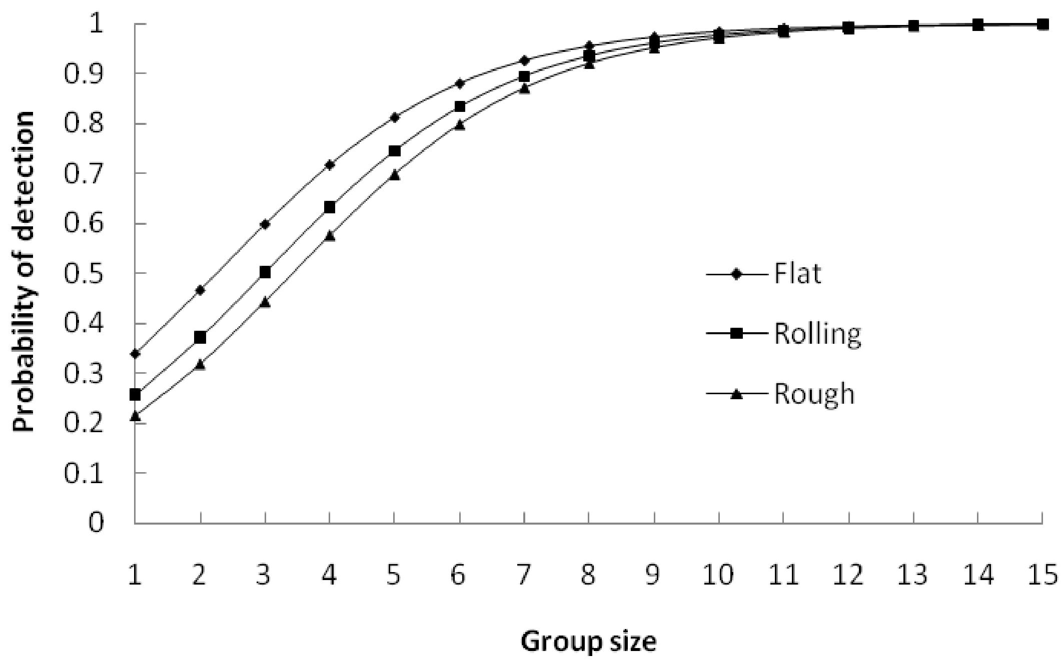


Figure 14. Effect of perpendicular distance from the transect line to the first spotted animal of a group on the sightability of mule deer. Estimates of sightability used the model “Group Size, Vegetation, Activity, Light, Terrain, Distance, Group Size*Vegetation.” Conditions for deer were active deer in brushy habitat with flat light and rolling terrain from data collected in the Trans-Pecos and Panhandle regions of Texas during, January-February, 2008-2010.

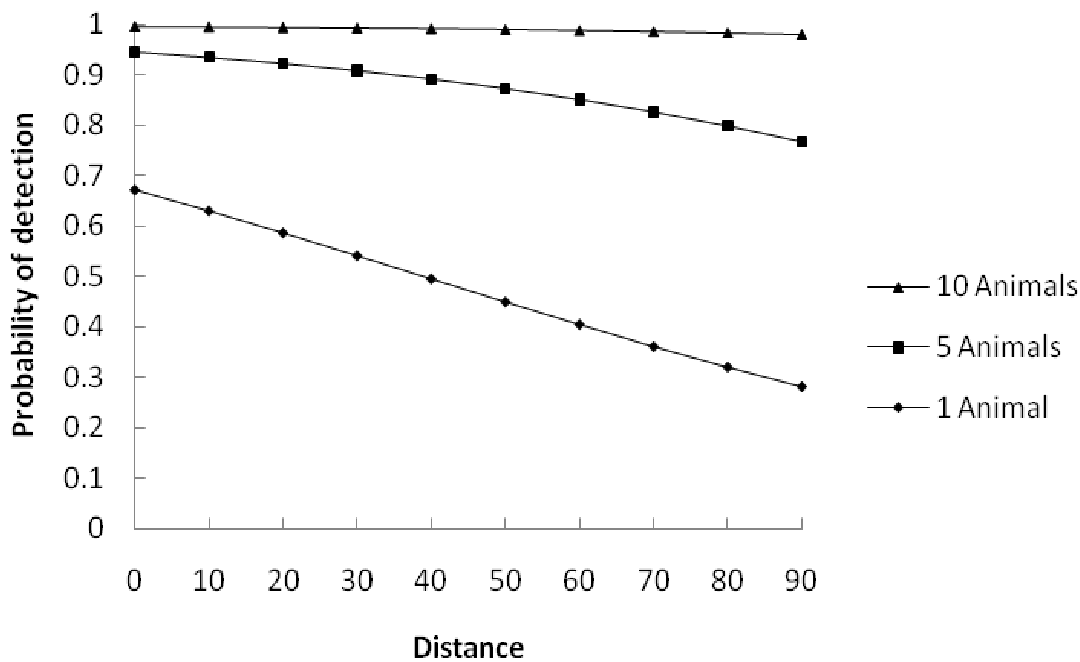


Table 10. Mean and 95 % confidence interval (CI) mule deer density (deer/km^2) derived from deer observed during aerial surveys, mark-resight from program MARK, and two sightability models by study location in the Trans-Pecos and Panhandle regions of Texas during January and February, 2008-2010.

					Sightability model			
	Observed		**Mark-Resight**		**Without group size**		**With group size**	
Study site	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Black Mesa	7.09	5.55 - 8.64	12.70	12.14 – 13.26	10.92	8.46 - 13.38	11.34	9.23 – 13.46
Longfellow	6.03	4.79 - 7.27	9.43	7.25 – 11.61	9.78	7.58 – 11.98	11.04	8.74 – 13.34
Mott Creek	4.25	3.95 - 4.57	8.74	8.19 – 9.29	7.44	6.61 – 8.27	8.66	7.41 – 9.90
NWPH	1.66	1.42 - 1.91	3.38	3.09 - 3.66	2.86	2.43 – 3.29	3.30	2.91 – 3.70
Miller	3.89	3.19 - 4.60	8.10	7.46 – 8.74	6.62	5.12 – 8.12	6.33	5.27 – 7.39
SDWMA	5.54	4.98 - 6.10	12.42	10.72 – 14.11	9.23	8.13 – 10.33	9.56	8.21 – 10.92

Table 11. Coefficient of variation for mule deer population size estimated using deer observed during aerial surveys and observed numbers corrected using mark-resight and sightability models for 6 study sites across the Trans-Pecos and Panhandle regions of Texas, January-February, 2008-2010.

			Sightability Model	
Study Site	**Observed**	**Mark-resight**	**W/O Group Size**	**W/ Group Size**
Black Mesa	0.31	0.06	0.32	0.27
Longfellow	0.30	0.33	0.32	0.30
Mott Creek	0.11	0.09	0.17	0.22
NWPH	0.23	0.13	0.23	0.18
Miller	0.26	0.11	0.32	0.24
Sierra Diablo	0.15	0.20	0.17	0.20

of 6 study sites (Table 11, pg. 69).

DISCUSSION

My study integrated GPS collars into the development of a sightability model. To my knowledge, this represents the first use of GPS data to develop sightability models for western big game. This technology and the number of collars deployed provided a large sample size and detailed information about animal movements and location during surveys. Whereas most other studies obtained information on unseen animals after the survey was completed, I was able to analyze deer location data taken every 5 minutes. Employing GPS technology and remote sensing provided accurate location, movement, and habitat use data compared to previous studies, where animals had the potential to move long distances in the time between the survey and collection of data on missed animals. Additionally, I was able to use multiple resighting opportunities of deer that moved during a survey, which would be impossible using radio-collared and tagged deer and could bias estimates if not included in the analysis.

While GPS technology was an excellent tool in data collection, my sample of marked deer was sufficiently large that I was only able to collect group size information from a small proportion of unseen deer during each survey. Group size was addressed post survey and had to be estimated for 88.3% of deer not seen during surveys. Percent of vegetation cover and detailed vegetation classes were not accurate enough for use in analysis because 1-m^2 resolution imagery was not detailed enough for such fine-scale analysis. The small sample size of rugged terrain made it necessary to combine it with the rough terrain class.

Unlike other states, Texas does not have prolonged snow cover and deer do not migrate and congregate on winter ranges. Smaller groups and lack of snow cover make deer more difficult to see. In contrast to other states, TPWD does not survey areas where vegetation, such as oak forest, prohibits observation because poor sightability and low deer density in such areas do not warrant the effort and expense of surveying.

One goal of a sightability model is to increase precision in population size estimates. My population estimation techniques increased precision of population estimates in 4 of 6 study locations while improving accuracy by accounting for deer not seen during surveys. Though Caughley (1974) summarized that accuracy is more important than precision when true population size is necessary for management having an increase in precision and accuracy is always desired. The sum of annual survey transects conducted by TPWD may further increase precision of population estimates from sightability models by reducing the impact of a small number of highly influential observations, such as observing a single bedded deer in a brushy habitat.

The effect of group size is taken into account because the sightability corrections are multiplied by the number of individuals in a group. Group size has been consistently found important in sightability of wildlife (Gasaway et al. 1985, Samuel et al. 1987, Ackerman 1988, Anderson and Lindzey 1996, Anderson et al. 1998, Cogan and Diefenbach 1998). This fact further necessitates the need for group size to be incorporated into the model. However, the inclusion of group size resulted in modest increases in average densitites (Table 10, pg. 68). This is likely because as the effect of group size was added, the estimates of other variables shifted to compensate for the added influence. Though this being the case in model development, applying the model without the group size variable to areas where group sizes are unlike those used in model development, could result in bias because sightability estimates would be based on a single group size. Populations with larger groups than used in model development, such as properties with supplemental feed programs which cause large groups of deer to congregate around feeders, would tend to be overestimated because the larger groups are more visible than the average group size assumed during model development. Similarly, populations with smaller groups than used in model development would be underestimated. The effect of group size was so important to the sightability of animals that its effect negates the effect of all other factors when group sizes are large. Sightability model estimates were not consistently biased high or low, suggesting that group size was not over or underestimated. Group size has been consistently found important in sightability of wildlife (Gasaway et al. 1985, Samuel et al. 1987, Ackerman 1988, Anderson and Lindzey 1996, Anderson et al. 1998, Cogan and Diefenbach 1998). The effect of group size on sightability is important and the sightability model incorporating group size should be used for annual surveys.

Previous sightability studies have reached conflicting conclusions about the importance of vegetation type, depending on the species and habitats involved (Gasaway et al. 1985, LeResche and Rausch 1974, Biggins and Jackson 1984, Anderson and Lindzey 1996, Cogan and Diefenbach 1998, Allen et al. 2005). Vegetation type was a significant factor influencing sightability in this study, reinforcing the need for tailroing sightability models to the habitats they are used in. Although I was unable to estimate percent woody cover for unseen deer, the vegetation type and percent woody cover are likely correlated, negating the need for both variables. In addition, percent cover estimates in the field are subjective and may vary among observers, potentially introducing another source of bias.

Activity had a large potential to affect sightability correction because only 4% of collared, inactive deer were seen during the study, compared to 56% of active deer . Other studies have seen an average of 48.4% (7% - 88%) of inactive elk and 15% of inactive mule deer. For the model to correct for low sightability of inactive deer, at least some inactive deer need to be sighted during surveys. Because observers saw an inactive group of mule deer every 170 km of survey on average, the 3,950 km of annual surveys TPWD flies may be sufficent for accurately correcting for missed, inactive deer. However, the model may not adequately correct for missed, inactive animals on smaller properties where transect length is only 100-200 km. As indicated earlier, the sightability correction may perform better as surveyed area increases.

The method of activity data collection lends itself to bias. If deer remained inactive while the helicopter passed and then ran, I would have incorrectly concluded they were active. Conversely, if deer ran from the helicopter, but returned to their original position in ≤ 5 min, I may have falsely concluded they were inactive when the helicopter passed. The most likely misclassification of activity is classifying a deer as active when it had been inactive as the helicopter passed. Because 64.5% of unobserved deer were classified inactive, my techniques were sufficient to recognize inactive deer. Animal activity has been investigated by other researchers developing sightability models and been found to be a factor influencing sightability from the helicopter for some, but not all studies. Gasaway et al. (1985), Ackerman (1988), Anderson et al. (1998), and Allen et al. (2005) found that animal activity had a significant impact on sightability during aerial surveys. However, Samuel et al. (1987), Anderson and Lindzey (1996), and Cogan and Diefenbach (1998) found that animal activity was not significant in sightability of animals. Anderson et al. (1998) notes that activity may not be significant during surveys with snow cover, but activity may be important during surveys with no snow cover.

I originally predicted deer would be more visible in bright light, but this was not the case. The study design did not allow me to verify the underlying cause of sunlight effects. However, bright sunlight increased contrast between sunny and shady areas, reducing the ability of observers to see deer in the shade. Furthermore, when it is sunny, at least one observer is likely to be looking into the sun, while other observers may be affected by glare from clothing or objects within the helicopter on the helicopter windows. The effects of light were found to be a significant factor influencing sightability by Allen et al. (2005) but Anderson and Lindzey (1996) did not. LeResche and Rausche (1974) commented that they felt high, overcast conditions would be ideal and offer higher sightability than bright conditions causing glare, but these ideas were left untested. The large sample size in my study may have provided sufficient power to detect a light intensity effect. However, the effect of light was small compared to other variables in the model.

Similar to the light effect, the effects of terrain on sightability were unexpected. I expected terrain would be a relatively minor factor influencing sightability of mule deer from helicopters. However, sightability decreased as terrain became rougher. Anderson and Lindzey (1996) found terrain did not affect sightability of moose. They attribute the failure to include terrain in the model to the relationship of vegetation type and terrain. Sightability decreased with increased ruggedness, perhaps because hills created blind spots.

I found that a deer's perpendicular distance from the transect inversely influenced its probability of detection. While sightability decreased with distance in the model estimates, the observation data showed spikes in observations at 40 m and 90 m. Bisset and Rempel (1991) and Siniff and Skoog (1964) noted that observers tended to report animals close to the edge of the survey area. A spike in observations at 40 m may have been caused by observers incorrectly estimating distance or focusing efforts at longer distances. Burnham and Anderson (1984) and Anderson and Lindzey (1996) failed to find a relationship between sightability and perpendicular distance from the transect line.

Furthermore, my data and other studies show that not all deer on the transect are observed (DeYoung et al. 1989, Polllock and Kendall 1987, White et al. 1989), thus violating a key assumption of the distance sampling technique to estimate animal density (Burnham et al. 1980). One reason distance from the transect has not been reported as an important variable in sightability models by other studies is that methods used by other studies may have not allowed measurement of distance from the transect for animals that were not detected. Use of GPS collars during my study allowed me to evaluate the effect of distance from the transect, demonstrating it is an important variable in sightability models.

The model "Group Size, Vegetation, Activity, Light, Terrain, Distance, Group Size*Vegetation" included an interaction I felt was biologically sensible. The impact of group size is intuitively less in open vegetation types where deer have little to hide behind or blend in with. Sightability in vegetation types where cover is tall and thick logically is more inclined to be influenced by group size as more animals provide additional opportunities for observation of the group. Conversely, once group sizes increase over 10 animals, additional animals are less important to detection of the group in either vegetation type.

Additional Recommendations

While sightability models can improve the estimate of a mule deer population, logic and planning are necessary for valid surveys. It is imperative for observers to maintain focus on the survey or biased results are likely. Distractions should be minimized during survey time and those individuals that lack experience flying should take an antiemetic a sufficient time before flying to reduce the chance of air sickness. Those lacking experience should also be placed in the right-rear position in the helicopter. This position requires the observer to scan less area than the left-front position allowing the observer more attention to the survey area. Observers are encouraged to wear light-weight clothing and bring layers for comfort. Dark-colored clothing and sunglasses should also be worn to reduce the impact of light reflection on windows which can impede vision on sunny days.

Laser rangefinders should be used by each observer in the helicopter to calibrate distance estimates. While the currently used Bell Jet Ranger has smaller windows with more visual obstruction than the Robinson R44, its ability to climb and travel safely at slow speed make it a desirable aircraft in the mountains of the Trans-Pecos region. Maneuverability and a marked increase in visibility associated with the Robinson R44

Raven II make it desirable in gently rolling terrain. Lower hourly costs make Robinson helicopters appealing for private landowners.

The presence of a third passenger to record observations or the use of an audio recording system with GPS technology along with familiarity of observers with codes for data collection increases the time observers can spend looking for animals, and will more closely match conditions under which sightability models were developed. I added the fourth person because extensive data collection during model development could have compromised research objectives by distracting primary observers had they been responsible for data recording.

While scheduling pilots may be out of the wildlife department's control, experienced pilots comfortable with low speed, low altitude flying are essential. High altitudes and high speeds may overextend observers' capabilities to search for deer, thus adding bias to counts.

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APPENDICES

Appendix 1. Results from Program MARK mark-resight analysis of mule deer in the Trans-Pecos and Panhandle regions of Texas. The unmarked deer parameter is signified by "U". Constant is represented with ".", sex with "g", and time with "t".

Black Mesa

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Parameters	Deviance
{alpha(g*t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	609.865	0.000	0.806	1.000	22	561.559
{alpha(t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	614.105	4.239	0.097	0.120	14	584.376
{alpha(g*t) sigma(.) U(.) Phi(.) Gamma"(.) Gamma'(.) PIM}	614.214	4.348	0.092	0.114	21	568.298
{alpha(t) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	619.967	10.101	0.005	0.006	28	556.875
{alpha(g*t) sigma(.) U(t) Phi(.) Gamma"(.) Gamma'(.) PIM}	624.644	14.779	0.001	0.001	28	561.553

Longfellow

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Parameters	Deviance
{alpha(t) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	655.190	0.000	0.346	1.000	28	590.775
{alpha(.) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	655.311	0.122	0.326	0.941	21	608.691
{alpha(g) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	657.225	2.036	0.125	0.361	22	608.140
{alpha(g*t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	657.351	2.161	0.117	0.339	22	608.266
{alpha(t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	657.979	2.789	0.086	0.248	14	627.950

Appendix 1 Continued.

Mott Creek

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Parameters	Deviance
{alpha(.) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	650.580	0.000	0.683	1.000	7	636.101
{alpha(g) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	652.591	2.011	0.250	0.366	8	635.973
{alpha(t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	655.250	4.670	0.066	0.097	15	623.126
{alpha(g*t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	667.997	17.417	0.000	0.000	24	614.467
{alpha(.) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	669.165	18.585	0.000	0.000	23	618.101

Northwest Panhandle Ranch

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Parameters	Deviance
{alpha(t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	711.956	0.000	0.933	1.000	15	679.948
{alpha(g) sigma(.) U(t) Phi(.) Gamma"(.) Gamma'(.) PIM}	718.592	6.636	0.034	0.036	15	686.583
{alpha(.) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	719.875	7.920	0.018	0.019	23	669.096
{alpha(g) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	721.711	9.755	0.007	0.008	24	668.493
{alpha(.) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	723.407	11.451	0.003	0.003	7	708.954

Appendix 1 Continued.

Miller Ranch

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Parameters	Deviance
{alpha(t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	600.124	0.000	0.878	1.000	14	569.959
{alpha(g) sigma(.) U(t) Phi(.) Gamma"(.) Gamma'(.) PIM}	605.358	5.234	0.064	0.073	14	575.193
{alpha(g*t) sigma(.) U(.) Phi(.) Gamma"(.) Gamma'(.) PIM}	606.800	6.677	0.031	0.036	21	559.859
{alpha(g*t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	608.018	7.894	0.017	0.019	22	558.577
{alpha(.) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	610.616	10.492	0.005	0.005	21	563.674

Sierra Diablo Wildlife Management Area

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Parameters	Deviance
{alpha(t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	674.184	0.000	0.587	1.000	14	644.456
{alpha(g*t) sigma(.) U(g) Phi(.) Gamma"(.) Gamma'(.) PIM}	676.013	1.829	0.235	0.401	22	627.706
{alpha(g*t) sigma(.) U(.) Phi(.) Gamma"(.) Gamma'(.) PIM}	677.027	2.842	0.142	0.241	21	631.111
{alpha(.) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	681.084	6.900	0.019	0.032	21	635.169
{alpha(t) sigma(.) U(g*t) Phi(.) Gamma"(.) Gamma'(.) PIM}	683.240	9.055	0.006	0.011	28	620.148

Appendix 2. Dates of deer capture and deployment of collars and dates and time of day (AM = morning; PM = afternoon) of aerial surveys for data collection in mule deer sightability model development on 6 study sites in the Trans-Pecos and Panhandle regions of Texas.

		Survey Number								
Study site	Capture	1	2	3	4	5	6	7	**8**	**9**
Black Mesa	17 Dec 2007	23 Jan 2008 PM	25 Jan 2008 AM	25 Jan 2008 PM	6 Feb 2008 PM	7 Feb 2008 AM	7 Feb 2008 PM	19 Feb 2008 AM	19 Feb 2008 PM	
Longfellow	18 Dec 2007	22 Jan 2008 AM	22 Jan 2008 PM	23 Jan 2008 AM	5 Feb 2008 AM	5 Feb 2008 PM	6 Feb 2008 AM	18 Feb 2008 AM	18 Feb 2008 PM	
Mott Creek	17 Dec 2008	12 Jan 2009 PM	13 Jan 2009 AM	15 Jan 2009 AM	15 Jan 2009 PM	16 Jan 2009 AM	16 Jan 2009 PM	18 Feb 2009 AM	18 Feb 2009 PM	19 Feb 2009 AM
NWPH	18-19 Dec 2009	8 Jan 2009 AM	8 Jan 2009 PM	17 Jan 2009 AM	17 Jan 2009 PM	18 Jan 2009 AM	18 Jan 2009 PM	20 Feb 2009 AM	20 Feb 2009 PM	21 Feb 2009 AM
Sierra Diablo	6 Jan 2010	27 Jan 2010 AM	27 Jan 2010 PM	10 Feb 2010 AM	10 Feb 2010 PM	15 Feb 2010 AM	15 Feb 2010 PM	25 Feb 2010 AM	26 Feb 2010 PM	
Miller	7-8 Jan 2010	30 Jan 2010 AM	30 Jan 2010 PM	9 Feb 2010 PM	12 Feb 2010 AM	14 Feb 2010 AM	14 Feb 2010 PM	26 Feb 2010 AM	28 Feb 2010 AM	

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Partner and Consulting Biologist, Orion Wildlife Management Services, Corpus Christi, TX, 2006-2011: Assisted in conducting wildlife surveys, harvest recommendations, and managing harvest data and samples for reporting to Texas Parks and Wildlife Department.

Hunting Guide, Sanchez Oil and Gas, Laredo, TX, 2004-2008: Guided deer, hog, nilgai, and quail hunts and fishing trips on two ranches. Prepared data for reporting and processed deer for hunters.

Manager and Salesman, South Texas Deer Company, Laredo, TX, 2006-2011: Maintained records of captive deer inventory and prepared permits for annual renewal of operating permits from Texas Parks and Wildlife Department and Texas Animal Health Commission.

Technician, CKWRI, Texas A&M University-Kingsville, TX, 2006: Fed and performed routine maintenance at captive deer pens for deer used in research.

Independent Landman, PFM, LLC. Bellaire, TX, 2007-2008: Researched mineral ownership of property and prepared reports and integrated GIS mapping of project progress for reports and reference.