USING MARK-RECAPTURE DISTANCE SAMPLING IN AERIAL SURVEYS OF LARGE MAMMALS IN SOUTH TEXAS

A Thesis

by

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ABSTRACT

Using Mark-Recapture Distance Sampling in Aerial Surveys of Large Mammals in South Texas

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Aerial surveys are an efficient technique for counting animals over large areas. However, only 15– 80% of the population is counted, biasing population estimates low. Distance sampling can be used to account for animals unseen, but only under the assumption that all animals on the transect are observed. Because sightability on the transect is not 100% during surveys, distance sampling conducted in conjunction with a mark-recapture technique, termed “mark-recapture distance sampling,” (MRDS) is an approach that has been used to correct for the undercount on the transect. I flew surveys on 4 study sites in southern Texas to evaluate the feasibility of the MRDS technique. Data were analyzed in Program Distance 6.2. Probability of detection on the survey line for all species ranged from 0.82–0.97 (SE = 0.01–0.07). Probability of detection within the survey area for all species ranged from 0.32–0.64 (SE 0.01–0.06). The MRDS technique addressed imperfect detection on the survey line and provided probabilities of detection in the survey area consistent with previous studies done in Texas. Mark-recapture distance sampling can be used in South Texas to increase accuracy of large mammal aerial surveys, though it may be more economical to use conventional distance sampling.

DEDICATION

I dedicate this thesis to my family in Michigan and friends in Texas. First, I thank my friends for the wonderful family dinners, days at the beach, and trips away from Kingsville. I would like to thank Stephanie Shea for being my outlet for sports, country music, and constant laughter. I would also like to thank Matthew Wojda. His support, advice (even when I wasn't asking for it), and friendship made all the difference these past 2 years.

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CHAPTER I

RESEARCH OBJECTIVES

INTRODUCTION

Aerial surveys are used to estimate wildlife populations because they are efficient for extensive tracts of land, especially when road access is limited. Furthermore, aerial surveys provide observers a better vantage point than is possible on the ground. Because of these advantages, aerial surveys are commonly used to obtain demographic data about large mammal populations. The focus of my research is the rangelands of southern Texas, where the large mammal community includes white-tailed deer (*Odocoileus virginianus*), cattle (*Bos taurus*, *Bos indicus*), nilgai (*Boselaphus tragocamelus*), collared peccary (*Pecari tajacu*), and feral hogs (*Sus scrofa*). Populations of these species are commonly monitored so that data-driven management plans can be developed and implemented.

White-tailed Deer

White-tailed deer are the most important game animal in Texas and the United States (Adams and Hamilton 2011). The estimated Texas white-tailed deer population was 3.6 million in 2013 (Texas A&M Agrilife Extension 2014). This large population results in high hunter success rates (Texas A&M Agrilife Extension 2014). Hunting is commonly used as a management tool for white-tailed deer and is an important source of economic revenue. Deer are hunted for meat as well as highly priced trophies (Brown and Cooper 2006).

Cattle

Cattle ranching has had a major presence in Texas for almost 300 years (Richardson and

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Hinton 2010). Texas has 248,800 cattle ranches, the highest number of any state or province in North America; cattle are the top agricultural commodity, with $10.5 billion in yearly earnings (Texas Department of Agriculture 2015). Cattle ranches provide about 270 kg/cow of meat to a growing population (Texas FFA 2014). Cattle grazing has been extensively studied to understand its impact on habitat for livestock and wildlife (Ortega-S. and Bryant 2005).

Nilgai

Nilgai were introduced to Texas when they were released on the Norias division of the King Ranch in 1924 (Sheffield et al. 1971, Sheffield 1983) as game animals (Davis and Schmidly 1994). By 1971, nilgai were found in 9 Texas counties and northern Mexico (Leslie 2008). Currently, nilgai are the most abundant free-ranging exotic ruminant in Texas (Davis and Schmidly 1994). Information on nilgai ecology and management in Texas is lacking as few studies have been conducted since their introduction (Sheffield et al. 1971, Sheffield 1983).

Collared Peccary

Texas landowners sometimes consider collared peccaries pests, while peccaries are a prized game animal in Arizona and New Mexico. Their popularity for hunting is growing in Texas due to limited hunting opportunities of other large game on private lands (Taylor and Synatzke 2008). This popularity could be detrimental because they can be hunted year-round and overharvesting could occur due to their common occurrence in large groups (Taylor and Synatzke 2008). In addition to recreational value, collared peccary are valuable for their ability to control cacti deemed undesirable by ranchers (Davis and Schmidly 1994).

Feral Hogs

Domestic swine (*Sus domesticus*) have been in the United States since the early 1500's. Feral hog populations arose from domestic pigs becoming wild, and from introduced European wild boar (*Sus scrofa*). The number of feral hogs has increased dramatically in the past 50 years (Rollins et al. 2007). The average estimated feral hog population in Texas was 2.6 million in 2014 (Mayer 2014). Feral hogs are a huge concern in Texas and cause millions of dollars of agricultural damage each year, spread disease, depredate nests of native avifauna, and pose a substantial threat to native ecosystems (Rollins et al. 2007).

Management of Large Mammals in South Texas

Proper management of private lands is crucial for the presence of wild and domestic large mammals (Berger 1973). Landowners have to take an active role in animal management. Game animals and livestock in South Texas are managed through recreational hunting and ranching. Landowners are encouraged to manage responsibly through landowner incentive programs, recreational and agricultural profit, Farm Bill programs, wildlife management co-ops, and federal tax incentives (Texas Parks and Wildlife Department 2015b).

Managers cannot make responsible decisions unless they know the species that inhabit their properties and the size and structure of those populations (Berger 1973, Walter and Hone 2003). Large mammals will thrive only if their habitat can maintain them. Habitat manipulation can alter an area's carrying capacity but will not be beneficial if overcrowding still occurs (Benson 1991). Thus, estimates of population size and trends are an important component of management (Young et al. 2005).

Wildlife Population Estimation

Populations of wild ungulates, such as white-tailed deer and nilgai, have been surveyed using a variety of techniques. Pellet count indices (Fuller 1991), road counts, camera traps (Roberts et al. 2006), and aerial surveys (DeYoung 1985) are frequently used to attempt to obtain estimates of abundance over large or small areas of land (Roberts et al. 2006). However, without evaluation against populations of known size, the precision and accuracy of many survey techniques is unknown (Fuller 1991). In contrast to wildlife, domestic populations of large ungulates, such as cattle, are frequently counted during round-ups (Hood and Inglis 1974) or can be estimated using aerial surveys (Bayliss and Yeomans 1989).

Few studies have estimated abundance of collared peccaries (Altrichter and Boaglio 2003). The state of Arizona includes peccary counts in their aerial and ground-based surveys for mule deer (Rabe et al. 2002). Abundance indices from harvest records can be used to obtain population estimates but are inaccurate due to differences in hunter perception (Altrichter and Boaglio 2003).

Currently, few reliable population estimate techniques exist for feral hogs (Mellish et al. 2014). Mark-recapture techniques using tetracycline hydrochlorine in bait were used in southern Texas to attempt to monitor wild populations (Reidy et al. 2011). Traditional techniques used to obtain estimates for ungulates are typically not effective for feral hogs in rangelands (Reidy et al. 2011). Feral hogs have high reproductive rates and populations are often unaffected by harvest, making trends difficult to detect (Reidy et al. 2008).

Aerial Surveys

Aerial surveys are an efficient technique for estimating large mammal populations (Caughley 1977, Cook and Jacobson 1979, Anderson and Lindzey 1996, Walter and Hone 2003). Surveys can be conducted using fixed-wing aircraft or helicopters (Marsh and Sinclair 1989). The benefit of this technique is that one can survey large or remote areas from a viewpoint that maximizes opportunities to detect animals (Potvin et al. 2004).

Although aerial surveys have many benefits for monitoring large mammals, not all animals in the survey area are counted and it is difficult to know the proportion of animals observed (Caughley 1977, Choquenot 1995, Potvin et al. 2004). Thus, population estimates from aerial surveys are consistently biased low (Caughley et al. 1976, DeYoung et al. 1989) and are considered a "rough estimate" at best (Caughley 1974).

Two common sources of error result in biased population estimation: perception bias (Cook and Jacobson 1979, Samuel and Pollock 1981, Choquenot 1995) and availability bias (Anderson and Lindzey 1996, Jachmann 2002). Perception bias occurs when animals are available to be seen in the survey area, but are not detected. Availability bias occurs when animals are within the survey area, but are not available to be seen (Jachmann 2002, Buckland et al. 2004). Together, both biases can be referred to as "visibility bias" (Buckland et al. 2004).

Trends in populations can still be shown, despite the inaccuracy, when the error is held constant throughout consecutive surveys (Caughley 1974). However, general trends may not be sufficient to answer management questions (Anderson and Lindzey 1996, Jachmann 2002). To make some management decisions, for example, setting harvesting quotas, estimates need to be treated as absolute measures of abundance, making accuracy important (Caughley 1974, Anderson et al. 1998).

CORRECTING FOR VISIBILITY BIAS

Correction Factors

Standard correction factors have been developed through mark-recapture techniques by collaring animals and recording how many of those animals are observed within a specified transect width during an aerial survey (DeYoung 1985, Beasom et al. 1986). The proportion of marked animals seen during surveys represents the proportion of animals seen from the entire population. That proportion can then be used to obtain a true population estimate (DeYoung 1985). A flight-specific correction factor is not always feasible as a known population of marked animals must exist (DeYoung 1985). Key assumptions associated with the population estimates (e.g. no mortality within population, all collars accounted for, etc.) must also be met (DeYoung et al. 1989).

Sightability Models

Sightability models are another method used with aerial surveys to estimate animal populations. Caughley (1974) defines sightability as, “the probability that an animal within an observer’s field of search will be seen by that observer.” The probability in question is influenced by (1) the distance from the observer to the observed animal, (2) characteristics of the location of the animal, such as habitat type, background color and lighting, and (3) characteristics of the animal itself, such as size and behavior (Anderson and Lindzey 1996).

Sightability models are created by collaring animals, flying surveys, and determining which collared animals were seen or missed. For each observation during the survey, the probability of observing the animal (or group) is calculated using the sightability model. Probability is then used to correct the number of animals detected during the survey (Caughley 1974). The elements discussed above can greatly change the sightability of an animal, so ensuring those elements are modeled correctly is key for a sightability model to be effective (Bodie et al. 1995)

Varying degrees of visibility can introduce bias into population estimates (Anderson et al. 1998). Sightability models attempt to correct for perception bias, but cannot correct for availability bias (Bodie et al. 1995). Population estimates are less biased than simple counts using standard correction factors when sightability factors are taken into account (Bodie et al. 1995), but sightability models still have disadvantages. Observers, survey platform, flight path, speed, altitude, animal behavior, habitat types, weather conditions, and season could all bias the estimates if they are not included in the model. Modeling all factors possibly influencing sightability may be difficult and the technique may not be widely applicable (Anderson et al. 1998).

Conventional Distance Sampling

Another approach to account for visibility bias in population estimation is through a technique called "conventional distance sampling" (CDS) (Buckland et al. 2001). This methodology involves observers searching for animals within a designated strip along the transect line. When an observation is made, the perpendicular distance from the animal to the transect line is taken (White et al. 1989, Fewster et al. 2009). Plotting the number of observations with their respective distance from the transect line creates a detection function, $g\ (x)$ (Buckland et al. 2001). This detection function is used to calculate the probability, P, of detecting an animal given its perpendicular distance, x, from the survey line, or $g\ (x) = (P\ (\text{detection} \mid \text{distance } y))$, (Buckland et al. 2001, Marques et al. 2007). Applying P to the equation $\widehat{D}= n\ /a*\widehat{P}$ results in a density estimate $\widehat{D}$, where n is the number of animals counted and a equals the total area surveyed. The total area surveyed is determined by taking the width of one side of the transect (w), doubling it to account for both sides ($2w$), and multiplying by the total length of the transect (l), making the final product a=2wl (Buckland et al. 2001).

Several assumptions must be met for distance sampling to provide an accurate population estimate (Buckland et al. 2001). The 3 most critical assumptions are:

1. All animals on the survey line are detected (i.e., the probability of detection at distance 0 equals 100% ($g\ (0) = 1$)).
2. Animals are fixed at the location they were initially sighted and none are counted twice.

3. Distances are measured correctly.

An advantage to conventional distance sampling is the benefit of utilizing model robustness. With distance sampling, it is assumed that distance from the transect line is the only factor that affects detection probability (Borchers et al. 2006); however, this is not always true. Models are considered pooled robust if data can be merged across factors that may affect detection probability and still yield a realistic density estimate. By making the model general and flexible, it can take various shapes to fit the detection function (Buckland et al. 2001).

Population and density estimates resulting from CDS are consistently biased low, as with using correction factors or sightability models (Anderson and Lindzey 1996). This undercount is partially attributed to the violation of the assumption that all animals on the survey line are detected, $g\ (0) = 1$ (White et al. 1989, Anderson and Lindzey 1996). The intensity of the population undercount is related to the severity of the imperfect detectability on the line, and therefore, correcting for animals not seen on the line is necessary for CDS to provide accurate population estimates (Buckland et al. 2004).

Mark-Recapture Distance Sampling

The consistent violation of perfect detection on the line created the need for a different technique (Graham and Bell 1989). Mark-recapture framework applied to CDS relaxes the assumption by providing an estimate of detection on the line, instead of assuming $g\ (0)=1$ (Potvin and Breton 2005). Mark-recapture distance sampling (MRDS), also referred to as double-observer distance sampling, was first used by Pollock and Kendall (1987) and involves multiple independent surveyors carrying out the CDS methodology. Each sighting is considered a "mark." If the same animal is also seen by the other observer, it is considered a "recapture" (Marsh and Sinclair 1989, Southwell et al. 2002). The possible observations for capture history, ($\underline{w}$), are:

$$\underline{w} = (1{,}0): detection\ by\ observer\ 1\ but\ not\ observer\ 2;$$

$$\underline{w} = (0{,}1): detection\ by\ observer\ 2\ but\ not\ observer\ 1;$$

$$\underline{w} = (1{,}1): detection\ by\ both\ observers.$$

Using this method allows researchers to obtain more precise detection functions and population estimates (Buckland et al. 2004). However, this method is still subject to biases. Mark-recapture distance sampling can address perception bias but is not able to correct for availability bias. In addition, unmodeled heterogeneity creates bias that further complicate analysis (Buckland et al. 2004) With MRDS, the detection function is sensitive to factors that affect sightability and it is not always possible to stratify the data by these factors. Pooling detection covariates for robust models cannot occur as it does in CDS (Borchers et al. 2006).

Because MRDS models are not robust to detection covariates, factors other than distance from the survey line have a greater effect on the detection function (Bayliss and Yeomans 1989, Borchers et al. 2006). Animal size, sex, activity, group size, and habitat type in which the animal is seen can all influence detection probability (Marsh and Sinclair 1989, Borchers et al. 2006). These covariates can be included in the analyses and their effect on sightability can be assessed. The bias introduced with unmodeled heterogeneity can be reduced by adding these covariates, but only when they are modeled correctly (Buckland et al. 2004, Borchers et al. 2006).

By accounting for imperfect detection on the survey line, MRDS yields more precise estimates for multiple species, especially marine mammals (Laake et al. 1997, Okamura et al. 2003, Cañadas et al. 2004, Southwell et al. 2007, Southwell et al. 2008). It accounts for imperfect detection on the survey line and yields more precise estimates (Potvin et al. 2004, Walsh et al 2010, Cumberland 2012). Quicker responses to management actions can be observed if estimate precision is improved (Potvin et al. 2004).

SOUTH TEXAS AERIAL SURVEYS

Multiple studies involving aerial surveys for large mammals have been conducted in South Texas, as aerial surveys are widely considered the most practical method of white-tailed deer population estimation (Beasom 1979). Land managers desire population estimates and information on herd characteristics to set harvest quotas (Shupe and Beasom 1987). Because of additional biases other than visibility bias associated with aerial surveys, individual aspects of the methodology in South Texas have been assessed to improve population estimate precision (Beasom et al. 1986, Leon et al. 1987, Shupe and Beasom 1987).

Refinement of Techniques

Repeated strip counts of 100% coverage were conducted in the late 1970's and mid 1980's to assess precision of South Texas aerial surveys (Beasom 1979, DeYoung 1985). The earliest study reported coefficient of variation values under 20% for about 75% of pasture-based estimates, precision was highest in the spring before leaf-out, and repeated counts are necessary (Beasom 1979). When mark-recapture techniques were introduced, it was suggested that traditional counts of deer were low and visibility biases need to be taken into account to increase precision (DeYoung 1985).

Although increased precision is desirable, optimal harvest rates and management decisions cannot be made without increased accuracy (DeYoung et al. 1989). The negative bias associated with aerial surveys can be decreased by refining the estimation techniques (Caughley 1974). In 1989, reduced strip widths were tested as a way to minimize bias and were found to have improved accuracy without sacrificing precision. During the same study, a correction factor was used based on frequency distribution of white-tailed deer groups observed to estimate populations. Both availability bias and visibility bias were attempted to be accounted for by using the equation:

$$c = 2.0 + 0.02x$$

Where *c* is the correction factor, and *x* is the proportion of animals missed during the survey. Estimates resulting from the correction factor were 42% higher than those from the strip counts, suggesting increased accuracy (DeYoung et al. 1989).

Techniques within the survey can also be improved to decrease biases (Caughley 1974). Various sampling intensities of aerial surveys were tested in 1986 to determine their effect on precision and accuracy of population estimates. Survey coverage of 100%, 50%, 25%, and 10% were tested. It was found that when compared to white-tailed deer population estimates from drive counts, accuracy was not influenced by sampling intensity. However, survey intensity and number of replications did affect precision of population estimates (Beasom et al. 1986).

The speed and altitude in which the survey is conducted can also impact population estimates and population demographic information. Shupe and Beasom (1987) found that higher speeds (96 kph vs 48 kph and 72 kph) and altitudes (55m vs 18m and 37m) resulted in fewer deer seen and could potentially affect precision of population estimates. It was also noted that small-antlered bucks could not be distinguished as accurately as altitude and speed increased (Shupe and Beasom 1987). However, no bias was detected in sex or age of deer encountered during surveys, so population demographic data is accurate (Leon et al. 1987).

OBJECTIVES

The East Foundation is a non-profit organization that manages over 87,000 ha of native rangeland in South Texas. It was established through the estate of Robert C. East in 2007. The Foundation's mission is to "support wildlife conservation and other public benefits of ranching and private land stewardship." This mission is achieved through research, education, and outreach (East Foundation 2015).

Habitat and population parameters must be measured over the long term to understand wildlife populations. Currently, there are no established monitoring programs or standardized survey protocols for large animals on the East Foundation lands. To address this issue, a research project was launched in 2013 to establish a long-term monitoring program for large mammals on the Foundation's lands.

The specific objectives of the project were to:

1. Conduct aerial helicopter surveys of the East Foundation lands to estimate the size and composition of large mammal populations.
2. Develop a data system for recording information in the helicopters that can easily be transferred to a computer database.
3. Evaluate the effectiveness of surveys during different seasons (autumn vs. winter)
4. Evaluate the effects of covariates on survey observations and population estimates, including habitat type, distance from the transect, animal age, etc.
5. Determine an optimal survey design and percentage of land surveyed (25%, 50%, etc.)
6. Make management recommendations to the East Foundation on an efficient long-term monitoring program for large mammals.

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CHAPTER II

USING MARK-RECAPTURE DISTANCE SAMPLING IN AERIAL SURVEYS OF LARGE MAMMALS

INTRODUCTION

Aerial surveys are the most efficient way to survey animals over large tracts of land or water (Caughley 1977, Cook and Jacobson 1979, Anderson and Lindzey 1996, Walter and Hone 2003). However, because not all animals in the survey area are seen during flights, population estimates derived from aerial surveys are consistently biased low (Caughley et al. 1976, DeYoung et al. 1989). Precision of aerial surveys can be reduced by faulty methodology (Caughley 1974, Buckland et al. 2004), changes in survey intensity (Beasom et al. 1986), and survey execution (Shupe and Beasom 1987).

Surveys are often flown in South Texas to obtain population estimates of white-tailed deer (*Odocoileus virginianus*) for harvest prescriptions (Beasom 1979, DeYoung 1985, Beasom et al. 1986, Leon III et al. 1987, and Shupe and Beasom 1987). Only 36-75% of animals are traditionally seen in South Texas surveys (DeYoung 1985). Although it is difficult to determine the accuracy of surveys, precision amongst surveys is desired (Beasom 1979).

Conventional distance sampling (CDS) can be used to eliminate some of the perception bias associated with unseen animals during a survey (Buckland et al. 2001). Conventional distance sampling can correct for perception bias if 3 assumptions are satisfied:

1. All animals on the survey line are detected (the probability of detection at distance 0 equals 100% (g (0)=1)).
2. Animal groups are fixed at the location they were initially sighted and none are counted twice.

3. Distances are measured correctly (Buckland et al. 2001).

The assumption that 100% of animals are seen on the transect line (*g* (0) =1) is often violated (White et al. 1989, Anderson and Lindzey 1996). Conventional distance sampling can be combined with mark-recapture methodology, an approach termed “mark-recapture distance sampling” (MRDS), to relax this assumption. Mark-recapture distance sampling can correct for the undercount found in aerial surveys by accounting for decreased visibility with increasing distance from the survey line and imperfect detection on the line (Pollock and Kendall 1987, Graham and Bell 1989, Marsh and Sinclair 1989, Southwell et al. 2002, Potvin and Breton 2005). Mark-recapture distance sampling also allows inclusion of covariates that could affect sightability (Marsh and Sinclair 1989, Borchers et al. 2006), which eliminates reliance on pooling robustness to account for sightability in the model. Despite including explanatory covariates, unmodeled heterogeneity can still bias estimates (Buckland et al. 2004, Borchers et al. 2006).

Mark-recapture distance sampling has been used to study marine mammals by accounting for perception bias associated with surfacing animals (Laake et al. 1997, Okamura et al. 2003, Cañadas et al. 2004, Southwell et al. 2007, Southwell et al. 2008). The technique has also been applied to terrestrial animals of varying sightability and habitat, including white-tailed deer (Potvin et al. 2004), feral livestock (*Bos taurus, Bubalis bubalis, Camelus dromedaries, Capra hircus, Equus asinus, E. caballus, Sus scrofa*; Bayliss and Yeomans 1989), moose (*Alces alces*; Cumberland 2012), and brown bear (*Ursus arctos*; Walsh et al. 2010).

The effectiveness of MRDS in Texas ecosystems and its applicability to some large mammal species are unknown. Reliable population estimates are crucial for management of both exotic and native species. Long-term trends in estimates can help make effective management decisions for habitat improvement and healthy wildlife populations (Burgdorf and Weeks 1997).

I employed the MRDS technique over 2 years of surveys for white-tailed deer, nilgai (*Boselaphus tragocamelus*), collared peccary (*Pecari tajacu*), cattle, and feral hogs (*Sus scrofa)* in South Texas. My primary objective was to test the feasibility and usefulness of the MRDS technique, assess probability of detection of large mammals on the line, and to build upon previous work done on large mammals found in rangeland ecosystems in South Texas. Results will be applied toward a long-term monitoring program for large mammals on the East Foundation lands in South Texas. A second objective was to test 2 data collection techniques for efficiency and ease of use. I predicted that MRDS would decrease bias in population estimates of all large mammal species by correcting for animals not seen on the survey transects and including imperfect detection on the line, and more advanced data collection techniques would be most efficient.

STUDY AREA

I surveyed 4 of the East Foundation ranches in South Texas, USA: San Antonio Viejo, Buena Vista, El Sauz, and Santa Rosa. These ranches encompass 84,530 ha of native Texas rangeland. Tamaulipan thornscrub encompasses 82% of the land, open grassland encompasses 16%, and oak woodland encompasses 2%. All of the properties are contained by 1.2-m livestock fences and the eastern border of El Sauz is the Laguna Madre. Portions of each ranch's boundary have fencing 2.5 m tall. In general, cattle are contained by low fences and wildlife species can enter and exit freely (Fig. 2.1).

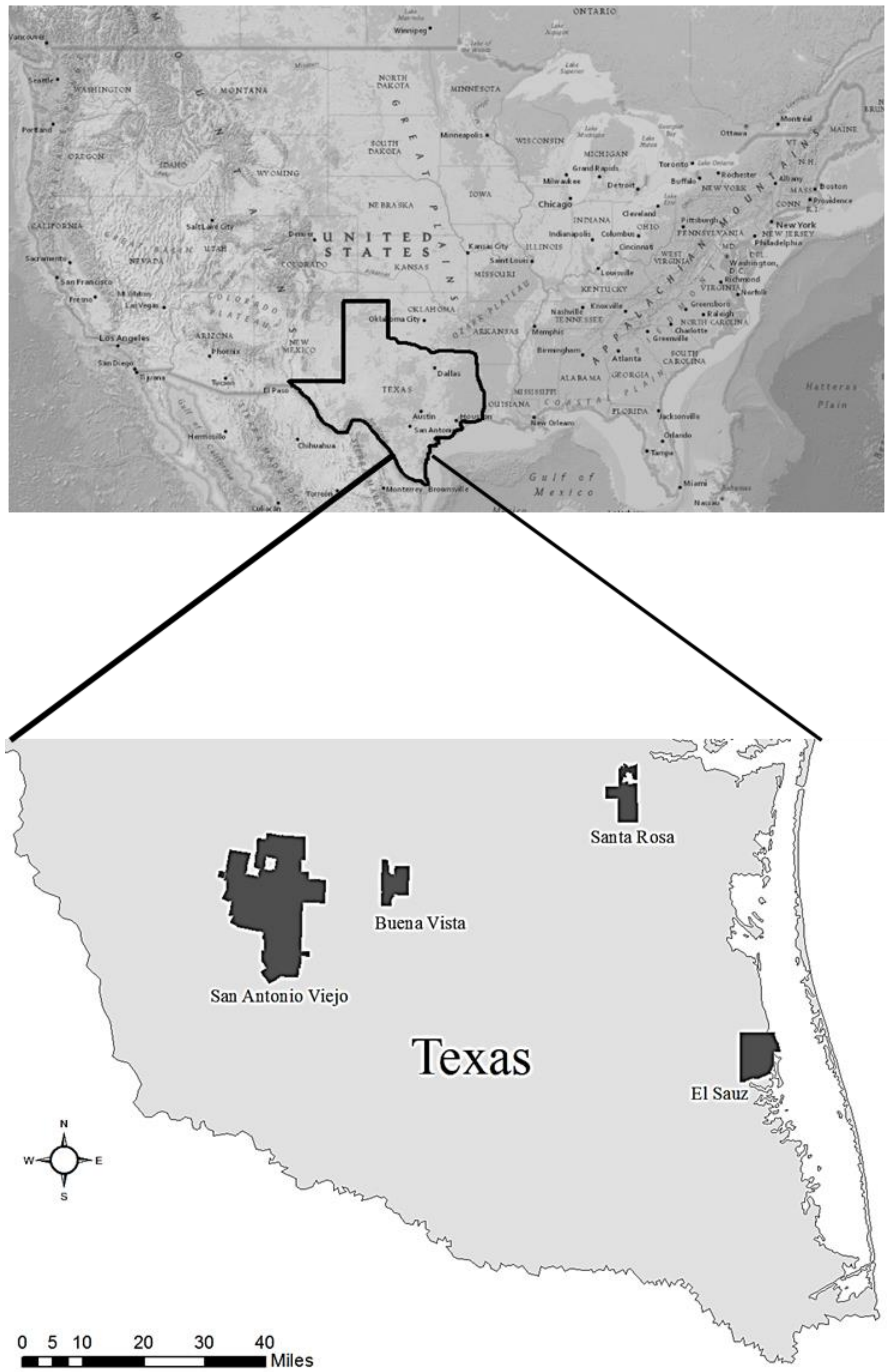

Figure 2.1. Map of the United States of America. Highlighted are the state of Texas and the South Texas area of interest, with East Foundation lands shaded.

San Antonio Viejo (57,011 ha) lies partly in the Coastal Sand Plains ecoregion and partly in the Texas-Tamaulipan Thornscrub ecoregion (Griffith et al. 2007) and is 58 km southwest of Hebbronville, Texas. Most of the ranch is composed of Tamaulipan thornscrub and grassland. Buena Vista (6,110 ha) is 30 km southeast of Hebbronville, Texas. The ranch is within the Coastal Sand Plains ecoregion (Griffith et al. 2007) and is dominated by a savannah of grasslands and widely spaced patches of woody vegetation. El Sauz (11,021 ha) borders the Laguna Madre and is adjacent to Port Mansfield, Texas. This ranch is also found within the Coastal Sand Plains ecoregion and is also within the Lower Rio Grande Valley and Laguna Madre Barrier Islands and Coastal Marshes ecoregions (Griffith et al. 2007). Closed-canopy live oak (*Quercus virginianus*) woodlands dominate the northwest portion of the ranch, and the remaining area is grassland, widely spaced patches of woody vegetation, wetlands, and sand dunes. Santa Rosa (7,471 ha) is 20 km south of Kingsville, Texas within the Coastal Sand Plains ecoregion. The property is closed woodland habitat dominated by live oak in the southern portion and Tamaulipan thornscrub throughout the rest of the ranch. Common vegetative species found throughout all of the ranches include live oak, honey mesquite (*Prosopis glandulosa.*), prickly pear (*Opuntia spp.*), granjeno (*Celtis pallida*), and various grasses and forbs.

METHODS

Data Recording

Observers recorded data using 2 methods to evaluate differences in efficiency and ease of use. The first was a paper data sheet. Observers wrote information on the sheet using pencils and clipboards. Global positioning system (GPS) coordinates of animal locations were marked using Garmin Rhino 120 (Garmin International, Inc., Olathe, Kansas, USA) handheld GPS units. Each observer in the helicopter recorded their own data and marked their own waypoints, except for the pilot. The front observer recorded observations made by the front 2 seats.

The second was a customized application on a portable laptop. During the November 2014 surveys, observers recorded observations using touchscreen computers (Toughbook; Panasonic, Osaka, Japan) and CyberTracker software (CyberTracker Conservation, Cape Town, South Africa). One Toughbook was controlled by the front passenger and one by a back passenger. A data recording application created in CyberTracker used a touchscreen interface to record and store data. Audio tracks of each observation were recorded in the CyberTracker software using PA-80H/Digital Audio Recorder Adapters from Pilot Communications USA, for the helicopter headsets. The GPS points were marked through the CyberTracker program using Garmin 18X USB GPS sensors (Garmin International, Inc., Olathe, Kansas, USA). When the flights were completed, all data were stored in CyberTracker and later uploaded into a master database.

Aerial Survey Protocol

I conducted flights in November 2013, February 2014, November 2014, and February 2015 to note differences in results by season. Each ranch was flown once during each survey occasion. The survey platform was a Robinson-44 helicopter (Robinson Helicopter Company, Torrance, California). The doors were removed to increase visibility.

I used systematic north-south transects established using ArcMap 9.3.1 with a random starting location along a north or south border. Target survey coverage was 50% on Buena Vista, Santa Rosa, and El Sauz and 25% on San Antonio Viejo. We placed transects uniformly across each ranch. Transects were evenly spaced and extended from northern to southern borders of the property. The target flight altitude was 15 m above ground level and varied depending on terrain. The target flight speed ranged from 35-45 knots and fluctuated with weather conditions. Observers recorded animals within 100 m from the transect line so that transects were 200 m wide. Shapefiles of each ranch boundary and corresponding transects were loaded into a Garmin Nuvi-LM52 (Garmin International, Inc., Olathe, Kansas, USA) navigation unit which the pilot used to follow the survey transects (Fig. 2.2).

I used MRDS during all surveys. The observer and pilot in the front 2 seats were on a separate intercom system from those in the rear of the helicopter to ensure observer independence. Two Sigtronics SPA-4Si Dual Bus kits (Sigtronics Corporation, San Dimas, California, USA) were wired to create independent intercom systems for each set of observers. All 4 observers were connected into a single system for communication outside of survey periods. Observers were also instructed not to motion or point at an observation as they could draw attention to animals that would otherwise not be seen by the other observer group. The front passenger and the pilot were considered “Observer 1,” and the 2 back passengers were considered “Observer 2” for analysis purposes. During the surveys, the pilot followed the predetermined transects and observers scanned the area for white-tailed deer, nilgai, collared peccary, cattle, and feral hogs. When a target species was detected, the observer recorded a GPS coordinate, perpendicular distance from the transect line, sex and age (adult or young of the year) of the animal(s), and group size. The observers estimated perpendicular distance in the following classes:

0: 0-5 m from the transect line

10: 5-15 m from the transect line

20: 15-25 m from the transect line

30: 25-35 m from the transect line, etc.

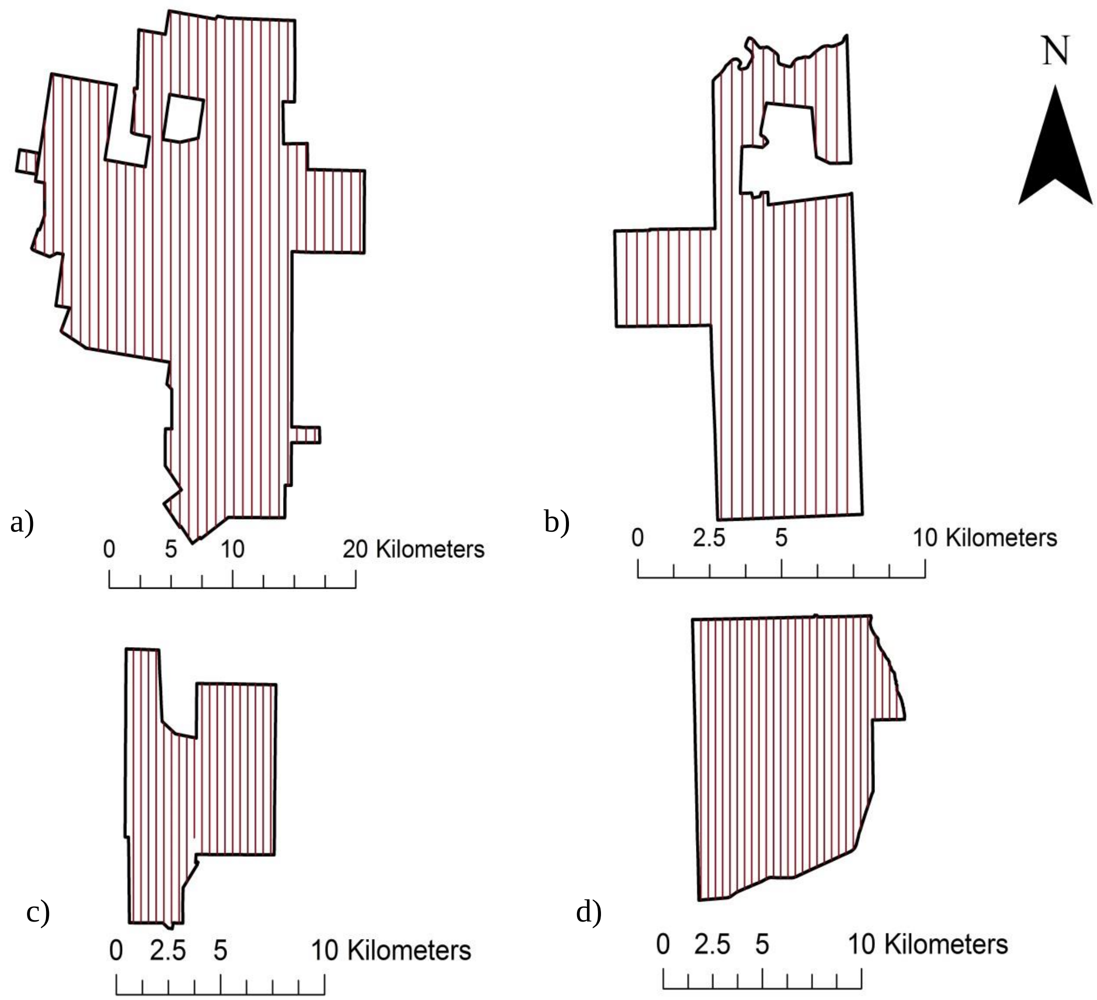

Figure 2.2. Transects flown on a) San Antonio Viejo (25% coverage), b) Buena Vista, c) Santa Rosa, and d) El Sauz (50% coverage) East Foundation ranches in Texas during aerial surveys for large mammals from November 2013-February 2015.

These distance classes continued out to 100 m. Observations in the last distance class (i.e., >95 m) were truncated in final analyses (Buckland et al. 2004).

Distances between animals and the transect could not be measured using rangefinders because the helicopter had to continue moving to preserve observer independence. If the helicopter were to stop and hover to measure a distance, other observers would become aware that a sighting had occurred. Observers were trained to estimate distances that animals were seen from the transect. Metal posts were placed at 20-m increments out to 100 m at the beginning of each flight. The pilot flew by the posts at the beginning of the survey so that observers could calibrate themselves. Additionally, the pilot flew over the posts each time the helicopter refueled. The observers used laser rangefinders (Leupold RX-1000i; Leupold Optics, Beaverton, OR, USA) to calibrate their distance measurements at the completion of each transect. Objects were found at distances unknown to the observers away from the transect during each survey to measure the accuracy of each observer's distance estimation. Observers were instructed to estimate the distance to the object from a certain point. The actual distance to the object was measured once estimates were recorded. These tests were conducted before each survey.

Data Analysis

One hour trials were conducted 5 times after the completion of the surveys to compare post-processing time for each data recording method to evaluate efficiency. Data were entered into a computer database for 1 hour and the number of lines of data entered from the data sheets or the CyberTracker program was recorded. Observer experiences expressed through verbal communication on the ease of use and accuracy during surveys were also considered in evaluation of the benefits of data recording approaches.

I compared observations between observers in the front and back of the helicopter to determine whether they were single observations (marks) or matched observations (recaptures). This was done by reviewing data recorded for each observation and comparing waypoint locations in ArcMap 9.3. Each observation waypoint was assigned to a habitat type using habitat data layers from each ranch provided by the East Foundation. Habitat types were categorized as "grassland," "Tamaulipan thornscrub," or "oak woodland."

I analyzed data using the MRDS Engine in Program Distance 6.2 (Thomas et al. 2010) that runs in conjunction with the MRDS package in Program R (The R Foundation, Auckland, New Zealand). I pooled data across all 4 ranches and analyzed per survey occasion. For the mark-recapture component for all surveys, I used a generalized linear model with a logit link function.

Population demographic data were compiled from the surveys and ratio analyses were performed using Microsoft Excel. Data were analyzed by survey period and year. Adult males, adult females, young, and animals of unknown sex or age were recorded. Doe to buck and fawn to doe ratios were calculated for white-tailed deer, and cow to bull and calf to cow ratios were calculated for nilgai and cattle.

A minimum of 60 observations are needed for distance sampling to produce reliable estimates (Buckland et al. 2001). Data for feral hogs and collared peccary were combined during each survey because there were not enough detections to analyze the species individually. The 2 species have similar physical characteristics (body size, locomotion patterns, herd formation; Davis and Schmidley 1994), and their detection probability is expected to be comparable. I did not calculate species-specific population estimates or detection probabilities. Instead, the proportion of observations made of each species was applied to combined density estimates to provide a general estimate of each species' density.

Data were stratified in Program Distance by ranch to obtain population estimates for each species on San Antonio Viejo, Buena Vista, Santa Rosa, and El Sauz individually. Cattle estimates were calculated to compare my population estimates with those provided by the East Foundation. The East Foundation provided unpublished data of their cattle inventory from each pasture on each ranch in May 2015.

I compared white-tailed deer population estimates derived from MRDS to a previously published technique to correct for deer not seen during aerial surveys in southern Texas rangelands (DeYoung et al. 1989). DeYoung et al.'s (1989) correction factor equation states:

$$c = 2.0 + 0.02x$$

where c represents the correction factor applied to the count of animals during the survey, and x represents the proportion of animals missed within the 200 m transect width. Therefore, to estimate the proportion of animals not detected during the survey, I ran white-tailed deer data from all surveys using an approach akin to conventional distance sampling and corrected for the proportion of the study area flown. I then analyzed the data using the CDS engine in Program Distance and estimated x as $1 - p$ (sighting probability).

Model Selection

I truncated distance data at 90 m and ran models in Program Distance that included perpendicular distance, cluster size (group size), habitat type, and observer as covariates. I considered models with perpendicular distance as the sole covariate and perpendicular distance with each remaining covariate. More complex models were considered but were not competitive. An appropriate model was selected based on Akaike Information Criterion (AIC; Cavanaugh

2007) values produced by Program Distance (Buckland et al. 2004). My analyses produced detection functions, detection probabilities, and density estimates for each species. An estimated *g* (0) was derived, as detection on the transect line was <100% (*g* (0) <1). A protocol for MRDS data entry and analysis is presented in Appendix A due to the complexity of the process.

RESULTS

Survey Execution

Data Recording.— Pencil and paper was the most efficient technique to enter data into a database, with an average of 241 ± 4.1 (SE) lines of data entered into the computer per hour vs. 188 ± 4.2 lines per hour for the CyberTracker program. Cybertracker was less efficient in part because some data were recorded in audio files and had to be transcribed.

In addition to being able to enter data into the master database at a faster rate, pencil and paper was more reliable in the helicopter and ensured data recording accuracy. There were multiple instances where the CyberTracker program took too much time to record an observation, which resulted in marking a subsequent observation at the incorrect location or even missing the following observation. There were also multiple instances of equipment failure. The CyberTracker program periodically froze and the GPS connection was not reliable. Only one charging cord could be used due to limited outlet space in the helicopter. It took organization between survey crew members to pass the charging cord back and forth to ensure Toughbooks remained charged the entire survey. Use of pencil and paper did not present any of these problems and reduced the chances for complications during the survey.

Accuracy of Distance Measurement.— There was a linear relationship between estimated perpendicular distances and distance to known markers (R^2=0.90, P<0.001, N=44, Fig. 2.3). The relationship shows an overestimate of 4.3 m for objects 20 m from the transect line and an

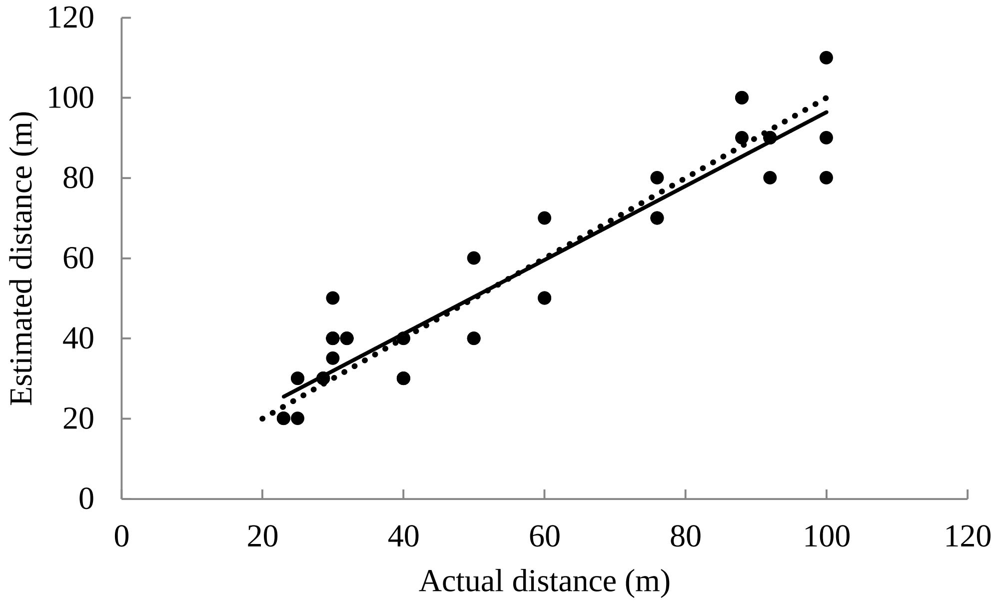

Figure 2.3. Linear relationship between estimated perpendicular distance measurements and actual distance measurements of stationary test objects during aerial surveys conducted for large mammals on East Foundation lands, Texas, USA from November 2013-February 2015. Dotted line represents y = x.

underestimate of 3.7 m at 100 m. However, there was no linear relationship between perpendicular distance measurement error and distance (R^2=0.04, *P*=0.179, Fig. 2.4). Out of 44 distance estimation tests, 18 (41%) were ≤ 5 m of the actual distance, 22 (50%) were > 5 m and ≤ 10 m of the actual distance, and only 4 were > 10 but ≤ 20 m of the actual distance.

Survey Coverage.—Survey coverage was inconsistent between survey occasions due to multiple instances of navigational equipment failure. The target coverage for each ranch was not met until the February 2015 surveys, though coverage still fell short on El Sauz. Coverage was exceeded on some properties in February and November 2014 (Table 2.1).

Observations

Total Number of Observations.—I met the requirement of 60 observations during every survey for each species or species group (i.e., feral hogs and collared peccaries; Table 2.2). Observations of nilgai were only recorded on 2 ranches because established populations only exist on Santa Rosa and El Sauz.

Proportions of Observations.—The proportion of observations made solely by the front or the back observers (categorized as “marks”) and observations seen by both (categorized as “recaptures”) varied among survey periods. For the November 2013 surveys, the front had a higher percentage of observations than the back. For the remaining surveys, the back saw a higher percentage of observations. The percentage of observations seen by both increased after the first period and remained at about 55% in subsequent surveys (Table 2.3).

Modeling Results

Detection Function.—A half-normal distribution best fit the shape of the detection function produced by Program Distance for all survey occasions and all species. The function was created using the “independent observer, point independence” method for all surveys, which

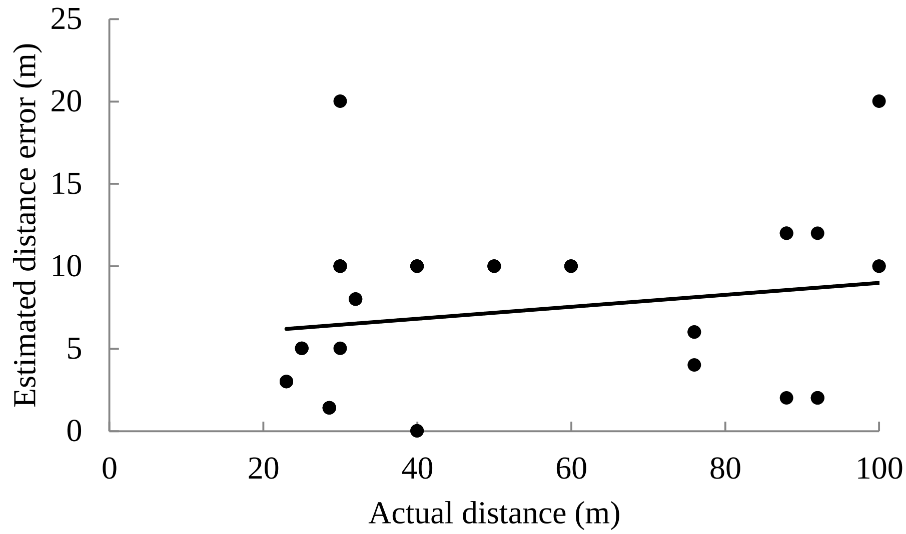

Figure 2.4. Relationship between estimated perpendicular distance measurement error and actual perpendicular distance of stationary test objects made during aerial surveys for large mammals on East Foundation lands, Texas, USA from November 2013-February 2015.

Table 2.1. Target and actual survey coverage flown on each ranch for large mammal aerial surveys on East Foundation lands, Texas, USA from November 2013-February 2015.

Survey occasion	Ranch	Target % coverage	% Coverage flown
November 2013	San Antonio Viejo	25	17
	Buena Vista	50	38
	El Sauz	50	27
	Santa Rosa	50	34
February 2014	San Antonio Viejo	25	35
	Buena Vista	50	35
	El Sauz	50	69
	Santa Rosa	50	40
November 2014	San Antonio Viejo	25	15
	Buena Vista	50	36
	El Sauz	50	55
	Santa Rosa	50	35
February 2015	San Antonio Viejo	25	28
	Buena Vista	50	51
	El Sauz	50	41
	Santa Rosa	50	49

Table 2.2. Number of groups observed of each species during each aerial survey occasion for large mammals on East Foundation lands, Texas, USA from November 2013-February 2015.

Survey Occasion	Species	# Observations
November 2013	White-tailed deer	505
	Nilgai	89
	Cattle	319
	Feral hogs and Collared peccaries	61
February 2014	White-tailed deer	1134
	Nilgai	172
	Cattle	441
	Feral hogs and Collared peccaries	154
November 2014	White-tailed deer	553
	Nilgai	94
	Cattle	439
	Feral hogs and Collared peccaries	97
February 2015	White-tailed deer	910
	Nilgai	150
	Cattle	524
	Feral hogs and Collared peccaries	136

Table 2.3. Proportion of observations seen by front and back seat observers of the helicopter during large mammal aerial surveys on East Foundation lands, Texas, USA from November 2013—February 2015.

Survey Occasion	% Seen by front only	% Seen by back only	% Seen by both
November 2013	31	23	46
February 2014	17	28	55
November 2014	15	29	56
February 2015	21	23	56

lessens the negative bias associated with sensitivity to unmodeled heterogeneity and requires fewer assumptions (Borchers et al. 2006).

Covariates.— Models including perpendicular distance and cluster size as covariates best explained results for white-tailed deer, nilgai, cattle, and feral hogs-collared peccary for the majority of surveys based on the lowest AIC value (Table 2.4). Any survey that was not best explained by perpendicular distance and cluster size was most adequately explained by perpendicular distance and observer as covariates. Perpendicular distance and observer proved to be the best model for feral hogs and collared peccary during the November 2013 surveys, for white-tailed deer during the February 2014 surveys, for nilgai and cattle during the November 2014, and for nilgai during the February 2015 surveys.

Detection Probability

Probability of Detection on the Survey Line g (0).—The proportion of animals seen on the line ranged from 0.82—0.97. The lowest estimates tended to be associated with collared peccary and feral hogs. The highest estimates tended to be associated with cattle (Table 2.5).

Overall Detection Probability.—Cattle generally had the highest estimated detection probability (*P*) with values ranging from 0.57—0.60. For 2 of the 4 surveys, nilgai had the lowest estimated detection probability with values of 0.52 for November 2013 and 0.48 for February 2015. Feral hogs and collared peccaries had the lowest estimated detection probability for the remaining 2 surveys with values of 0.43 for February 2014 and 0.32 for November 2014 (Table 2.6).

Population Estimates

Population Composition.—White-tailed deer doe to buck ratios were consistently about 3:1 (2.6–3.2:1), whereas fawn to doe ratios varied between 0.13–0.23:1. Nilgai cow to bull

Table 2.4. Model sets ran in Program Distance with Delta AIC and AIC values included for large mammal aerial surveys on East Foundation lands in South Texas, USA from November 2013-February 2015. *PD=Perpendicular Distance, CS=Cluster Size, HT=Habitat Type, O=Observer*

Survey Occasion	Species	Covariates	Δ AIC	AIC
November 2013	White-tailed deer	PD + CS	0.00	3354.24
		PD	0.58	3354.81
		PD + O	1.68	3355.92
		PD + HT	4.50	3358.74
	Nilgai	PD + CS	0.00	542.34
		PD + HT	4.42	546.76
		PD	6.90	549.24
		PD + O	7.09	549.43
	Cattle	PD+CS	0.00	2045.29
		PD + O	2.32	2047.61
		PD	2.60	2047.89
		PD + HT	6.35	2051.64
	Feral hogs and Collared peccary	PD + O	0.00	400.42
		PD + HT	6.80	407.22
		PD + CS	9.30	409.72
		PD + HT	10.56	410.98
February 2014	White-tailed deer	PD + O	0.00	7593.69
		PD + CS	6.69	7600.37
		PD	32.94	7626.63
		PD + HT	34.30	7627.99
	Nilgai	PD + CS	0.00	1067.41
		PD + O	5.02	1072.43
		PD	9.34	1076.75
		PD + HT	12.41	1079.81
	Cattle	PD + CS	0.00	2825.46
		PD	23.31	2848.78
		PD + HT	26.56	2852.02
		PD + O	27.36	2852.32
	Feral hogs and Collared peccary	PD + CS	0.00	985.76
		PD + O	0.81	986.56
		PD	5.12	990.88
		PD + HT	8.19	993.95
November 2014	White-tailed deer	PD + CS	0.00	3497.96
		PD + O	18.40	3516.36
		PD + HT	32.10	3530.07
		PD	36.63	3534.59
	Nilgai	PD + O	0.00	580.83
		PD	0.39	581.22
		PD + CS	1.58	582.41

Survey Occasion	Species	Covariates	Δ AIC	AIC
		PD + HT	1.67	582.50
	Cattle	PD + O	0.00	2867.42
		PD + CS	7.75	2875.25
		PD + HT	22.35	2889.35
		PD	25.63	2893.12
	Feral hogs and Collared peccary	PD + CS	0.00	571.33
		PD + O	5.83	577.16
		PD	12.82	584.16
		PD + HT	13.61	584.94
February 2015	White-tailed deer	PD + CS	0.00	5116.78
		PD + HT	30.86	5147.64
		PD	32.86	4149.64
		PD + O	34.17	5150.95
	Nilgai	PD + O	0.00	818.91
		PD + CS	7.90	826.81
		PD	9.52	828.43
		PD + HT	11.17	830.08
	Cattle	PD + CS	0.00	3203.29
		PD	14.41	3217.70
		PD + O	16.22	3219.51
		PD + HT	18.79	3222.07
	Feral hogs and Collared peccary	PD + CS	0.00	917.05
		PD + O	0.37	917.43
		PD	2.06	919.12
		PD + HT	5.13	922.18

Table 2.5. Probability of detection on the line, *g* (0), estimates by survey occasion for each species with standard errors (SE) and percent coefficients of variation (CV) during aerial surveys for large mammals on East Foundation lands, Texas, USA from November 2013–February 2015.

Survey Period	Species	*g*(0)	SE	CV (%)
November 2013	White-tailed deer	0.91	0.02	2.3
	Nilgai	0.97	0.02	2.0
	Cattle	0.92	0.02	2.3
	Feral hogs and Collared peccary	0.95	0.03	3.2
February 2014	White-tailed deer	0.97	0.01	0.5
	Nilgai	0.85	0.05	6.0
	Cattle	0.95	0.01	1.5
	Feral hogs and Collared peccary	0.87	0.05	5.3
November 2014	White-tailed deer	0.94	0.01	1.4
	Nilgai	0.88	0.01	5.2
	Cattle	0.96	0.01	1.0
	Feral hogs and Collared peccary	0.82	0.07	9.0
February 2015	White-tailed deer	0.95	0.01	0.9
	Nilgai	0.97	0.01	1.4
	Cattle	0.96	0.01	0.9
	Feral hogs and Collared peccary	0.93	0.03	3.1

Table 2.6. Detection probabilities (P) within the surveyed region with associated standard errors (SE), coefficients of variation (CV), and effective strip widths (ESW) in meters for each species during each survey period of aerial surveys for large mammals, conducted on East Foundation lands, Texas, USA from November 2013-February 2015.

Survey occasion	Species	P	SE	CV (%)	ESW (m)
November 2013	White-tailed deer	0.55	0.02	4.2	49.5
	Nilgai	0.52	0.04	8.6	46.8
	Cattle	0.60	0.03	5.0	54.0
	Feral hogs and Collared peccary	0.60	0.06	10.5	54.0
February 2014	White-tailed deer	0.64	0.02	2.7	57.6
	Nilgai	0.50	0.04	8.2	44.6
	Cattle	0.59	0.03	4.3	53.1
	Feral hogs and Collared peccary	0.43	0.04	8.2	38.7
November 2014	White-tailed deer	0.48	0.02	3.6	43.2
	Nilgai	0.43	0.04	8.7	38.7
	Cattle	0.57	0.02	4.0	51.3
	Feral hogs and Collared peccary	0.32	0.03	11.0	28.8
February 2015	White-tailed deer	0.51	0.01	2.7	45.9
	Nilgai	0.48	0.03	5.6	43.2
	Cattle	0.57	0.02	3.8	51.3
	Feral hogs and Collared peccary	0.51	0.04	7.0	46.0

ratios ranged from 1.3–2.2:1, and calf to cow ratios ranged from 0.13–0.34:1. Cattle cow to bull ratios varied widely (14.8–44.5:1) and calf to cow ratios ranged from 0.30–0.56:1 (Table 2.7). Fawn:doe ratios were similar in autumn and winter of the same year. San Antonio Viejo, El Sauz, and Santa Rosa ranches all showed little change from November surveys to February surveys in 2013-2014 and in 2014-2015. However, Buena Vista ranch had lower fawn:doe ratios in autumn than winter of the 2013-2014 survey year and higher ratios in autumn than winter during the 2014-2015 survey year (Fig. 2.5). Population ratios were not calculated for feral hogs and collared peccaries because it was not possible to reliably determine the sex of a feral hog or collared peccary from the air.

Density and Population Estimates.—White-tailed deer were counted on all 4 study areas. Density estimates for deer varied by season and were lower in autumn than winter. Population estimates for the first 3 survey occasions were not significantly different, based on overlap of 95% CIs. However, the estimated deer population size in February 2015 was significantly larger than in November 2013 and November 2014. Furthermore, estimates of deer population size were about 25% lower during both autumn surveys (November 2013, 2014) compared to winter surveys (February 2014, 2015) (Table 2.8, Fig. 2.6). This pattern continued on all ranches except for Buena Vista (Table 2.9). In addition, my deer population estimates were 32-42% less than estimates calculated using DeYoung et al.'s (1989) correction factor (Table 2.10).

Cluster density remained relatively consistent from November 2013-November 2014 (5.1–5.7 clusters/km^2). Cluster density increased in February 2015 (6.6 clusters/km^2). Expected cluster size changed seasonally. Average cluster sizes in autumn surveys were similar (1.60 and 1.59 animals/cluster) and smaller than average cluster sizes in winter surveys (2.0 and 1.97 animals/cluster; Table 2.11).

Table 2.7. Population ratios for white-tailed deer, nilgai, and cattle by survey period during aerial surveys for large mammals on each of the East Foundation lands, Texas, USA during November 2013-February 2015. Numbers were calculated using raw counts.

		White-tailed deer		Nilgai		Cattle	
Survey Occasion	Ranch	Doe:Buck	Fawn:Doe	Cow:Bull	Calf:Cow	Cow:Bull	Calf:Cow
November 2013	San Antonio Viejo	2.8:1	0.22:1	0:0	0:0	12.7:1	0.38:1
	Buena Vista	2.6:1	0.13:1	0:0	0:0	1.0:0	0.53:1
	El Sauz	3.8:1	0.19:1	1.2:1	0.25:1	16.4:1	0.42:1
	Santa Rosa	4.6:1	0.29:1	1.2:1	0.53:1	25.0:1	0.26:1
	Total	3.0:1	0.19:1	1.3:1	0.34:1	16.3:1	0.38:1
February 2014	San Antonio Viejo	2.4:1	0.22:1	0:0	0:0	13.7:1	0.59:1
	Buena Vista	3.8:1	0.25:1	0:0	0:0	25.0:1	0.53:1
	El Sauz	3.5:1	0.23:1	1.7:1	0.29:1	13.0:1	0.63:1
	Santa Rosa	2.3:1	0.26:1	2.8:1	0.22:1	39.0:1	0.20:1
	Total	2.6:1	0.23:1	1.8:1	0.27:1	14.8:1	0.56:1
November 2014	San Antonio Viejo	2.4:1	0.16:1	0:0	0:0	17.0:1	0.38:1
	Buena Vista	3.3:1	0.19:1	0:0	0:0	20.0:1	0.71:1
	El Sauz	3.9:1	0.11:1	1.6:1	0.08:1	16.5:1	0.98:1
	Santa Rosa	4.5:1	0.17:1	1.8:1	0.28:1	25.0:1	0.59:1
	Total	2.9:1	0.16:1	1.6:1	0.15:1	44.5:1	0.56:1
February 2015	San Antonio Viejo	3.3:1	0.13:1	0:0	0:0	43.5:1	0.42:1
	Buena Vista	4.1:1	0.10:1	0:0	0:0	1.0:0	0.40:1
	El Sauz	1.7:1	0.11:1	1.7:1	0.15:1	22.5:1	0.10:1
	Santa Rosa	3.5:1	0.21:1	2.5:1	0.83:1	39.6:1	0.20:1
	Total	3.2:1	0.13:1	2.2:1	0.14:1	36.2:1	0.30:1

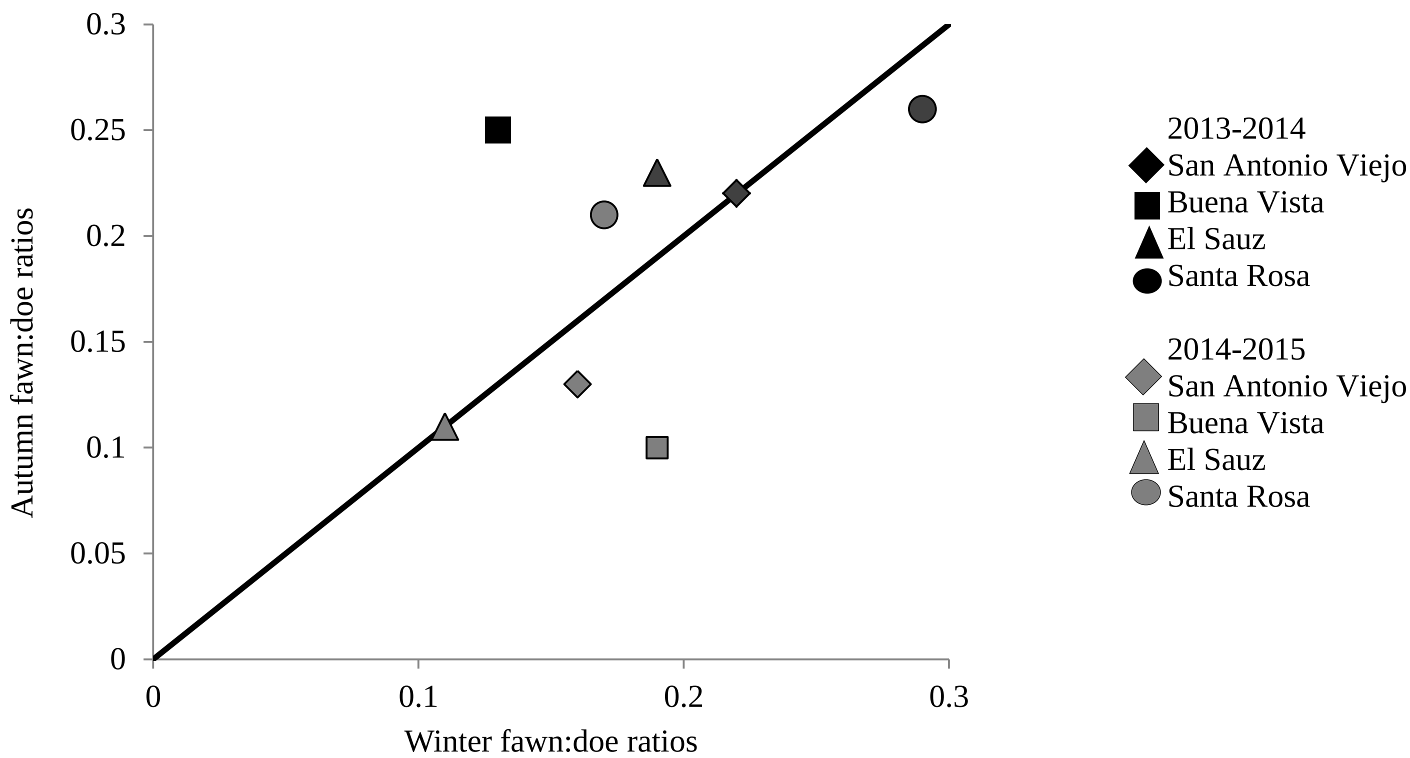

Figure 2.5. White-tailed deer fawn:doe ratios compared between seasons from aerial surveys conducted in autumn and winter on East Foundation Lands, Texas, USA from November 2013-February 2015.

Table 2.8. Density estimates (animals/km^2) with standard errors (SE) and coefficients of variation (CV) for all species from aerial surveys for large mammals on East Foundation lands, Texas, USA from November 2013-February 2015.

Survey occasion	Species	Density	SE	CV (%)
November 2013	White-tailed deer	8.23	± 0.49	8.0
	Nilgai	5.84	± 0.99	17.0
	Cattle	13.34	± 1.88	13.9
	Feral hogs and Collared peccary	2.69	± 0.61	22.9
February 2014	White-tailed deer	9.92	± 0.54	5.4
	Nilgai	8.75	± 1.24	15.0
	Cattle	13.92	± 1.37	9.9
	Feral hogs and Collared peccary	5.41	± 0.70	13.0
November 2014	White-tailed deer	9.12	± 0.66	7.2
	Nilgai	4.25	± 0.84	19.9
	Cattle	20.06	± 2.15	10.7
	Feral hogs and Collared peccary	8.36	± 1.62	19.4
February 2015	White-tailed deer	13.29	± 0.74	5.7
	Nilgai	10.47	± 1.90	18.2
	Cattle	21.94	± 1.98	9.2
	Feral hogs and Collared peccary	6.62	± 0.99	15.1

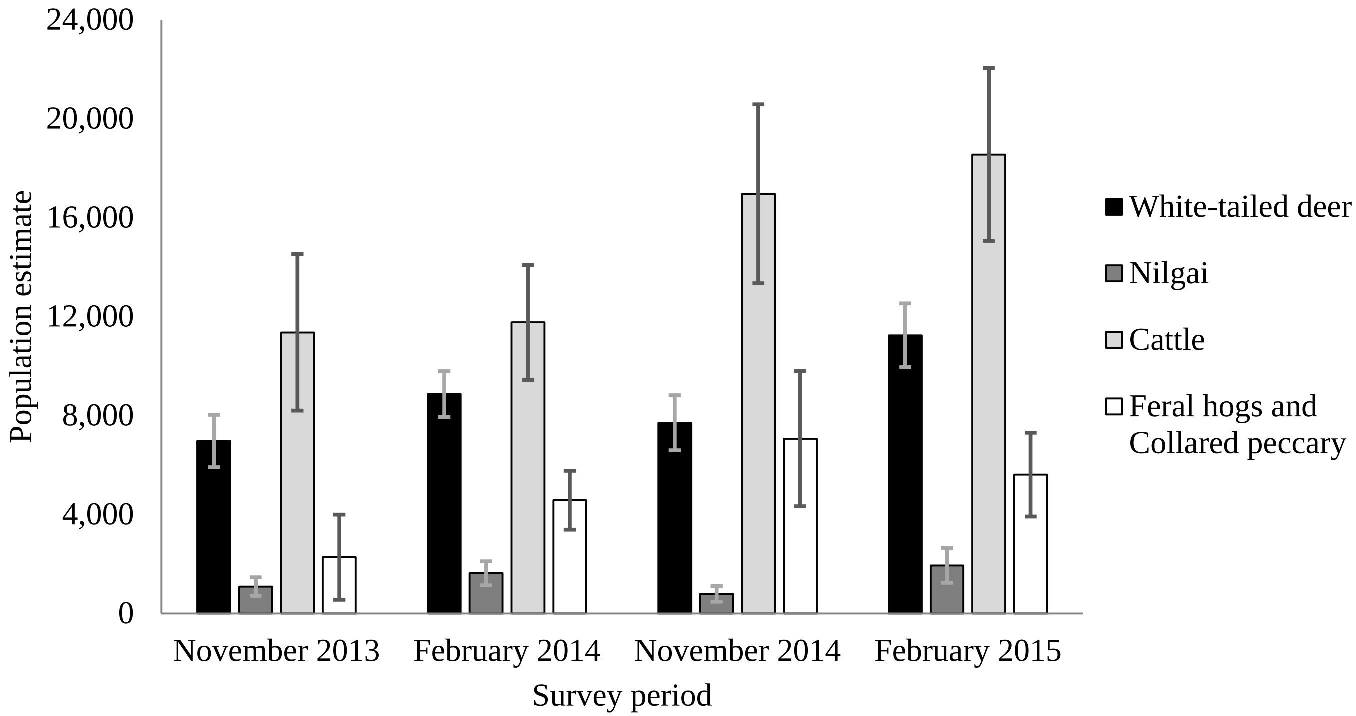

Figure 2.6. Population estimates with 95% confidence intervals for all species from large mammal aerial surveys on East Foundation lands, Texas, USA across 4 survey occasions from November 2013-February 2015.

Table 2.9. Population and density (animals/km^2) estimates for each species by ranch and survey period for aerial surveys of large mammals on East Foundation Lands, Texas, USA from November 2013-February 2015.

Species	Ranch	Survey Period	Population Estimate	SE	Density	SE
White-tailed Deer	San Antonio Viejo	November 2013	5082	462	8.48	0.77
		February 2014	6764	428	11.29	0.69
		November 2014	6427	489	10.73	0.82
		February 2015	8301	581	13.49	0.89
	Buena Vista	November 2013	716	84	11.69	1.36
		February 2014	780	102	12.78	1.66
		November 2014	879	125	14.38	2.05
		February 2015	1057	110	17.17	1.78
	El Sauz	November 2013	522	121	4.74	1.09
		February 2014	894	101	8.13	0.91
		November 2014	480	70	4.37	0.64
		February 2015	951	151	8.10	1.36
	Santa Rosa	November 2013	610	112	8.08	1.48
		February 2014	785	124	10.38	1.63
		November 2014	755	137	10.00	1.81
		February 2015	985	138	13.10	1.80
Nilgai	El Sauz	November 2013	679	163	6.18	1.48
		February 2014	2655	719	4.60	0.99
		November 2014	438	123	24.22	6.55
		February 2015	646	172	11.24	3.63
	Santa Rosa	November 2013	347	76	3.99	1.11
		February 2014	848	275	5.56	1.48
		November 2014	420	121	5.88	1.48
		February 2015	1293	296	17.12	3.93
Cattle	San Antonio Viejo	November 2013	5843	719	9.64	1.21
		February 2014	7826	962	13.07	1.61
		November 2014	13233	2171	21.99	3.71
		February 2015	12373	1472	20.66	2.45
	Buena Vista	November 2013	204	109	3.34	1.78
		February 2014	365	144	5.96	2.36
		November 2014	1340	388	21.92	6.35
		February 2015	730	363	11.94	5.93
	El Sauz	November 2013	4033	782	36.82	6.92
		February 2014	2169	361	19.75	3.28

Species	Ranch	Survey Period	Population Estimate	SE	Density	SE
		November 2014	2130	338	19.27	3.09
		February 2015	2982	457	27.16	4.15
	Santa Rosa	November 2013	792	153	10.38	1.98
		February 2014	823	241	10.91	3.20
		November 2014	981	184	13.10	2.45
		February 2015	2254	544	29.90	7.17

Table 2.10. Comparison of white-tailed deer population estimates using Program Distance and DeYoung et al.'s (1989) correction factor by survey period for aerial surveys of large mammals conducted on East Foundation lands from November 2013-February 2015.

Survey Occasion	Program Distance Estimate	SE	Correction Factor Estimate
November 2013	6,963	531	11,453
February 2014	8,667	464	15,129
November 2014	7,709	558	11,697
February 2015	11,243	645	16,414

Table 2.11. Cluster density (clusters/km^2) and expected cluster size (animals/cluster) for white-tailed deer estimates from aerial surveys of large mammals on East Foundation lands, Texas, USA from November 2013-February 2015.

	Cluster density		Expected cluster size	
Survey occasion	Estimate	Standard error	Estimate	Standard error
November 2013	5.2	0.37	1.60	0.05
February 2014	5.1	0.10	2.0	0.02
November 2014	5.7	0.40	1.59	0.04
February 2015	6.6	0.32	1.97	0.04

Nilgai were counted on 2 of the 4 study areas and followed the same trend as white-tailed deer, with lower population estimates in autumn than winter (Table 2.9). November 2014 population estimates were significantly different based on confidence intervals than February 2014 and February 2015 estimates (Table 2.8, Fig. 2.6).

Cattle were present on all 4 ranches and showed an increasing trend for population estimates with each survey overall, but did not follow this pattern on individual ranches (Table 2.9). Cluster size was highly variable and ranged from 1-94 animals (Fig. 2.7). Estimates from the first 2 surveys (November 2013, February 2014) were significantly different from population estimates in February 2015. Surveys in November 2014 were not significantly different from any of the other population estimates (Table 2.8, Fig. 2.6). My cattle population estimates were higher than the cattle inventory provided by the East Foundation for the February 2015 surveys and were 151–335% greater than the cattle inventory provided by the East Foundation for each ranch (Table 2.12).

Feral hogs and collared peccary showed a steady increase in estimates through November 2014 surveys, and in February 2015, estimates dropped (Table 2.7, Fig. 2.6). More collared peccaries were seen during each survey occasion, making their population estimate consistently higher than feral hogs (Table 2.13).

DISCUSSION

The MRDS technique provided a correction for imperfect detection on the line and for imperfect detection with increasing distance from the survey transect. Although accuracy of the technique cannot be assessed with the data available, the technique provided a correction for known undercounts in aerial surveys, could be applied in South Texas rangelands, and was able to produce estimates for multiple species from a single survey. However, high estimates of

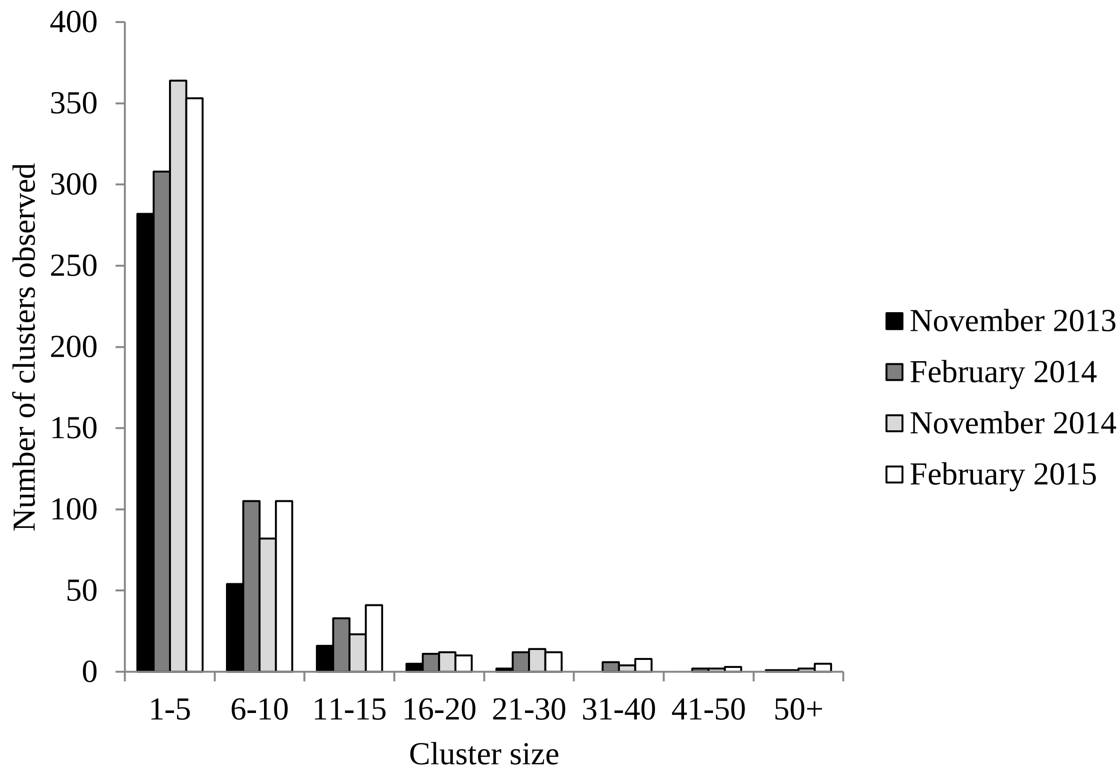

Figure 2.7. Frequency distribution of cattle clusters, by size, observed during large mammal aerial surveys on East Foundation lands in Texas, USA from November 2013-February 2014.

Table 2.12. Population estimates of cattle on East Foundation lands, by ranch, from aerial surveys conducted in February 2015 and from ranch records obtained in May 2015 in Texas, USA.

Ranch	Aerial survey population estimate	East Foundation cattle inventory	% Over count
San Antonio Viejo	12,373 ± 1472	5,523	224
Buena Vista	730 ± 363	484	151
El Sauz	2,982 ± 457	889	335
Santa Rosa	2,254 ± 544	867	260

Table 2.13. Estimated densities (animals/km^2) of feral hogs and collared peccaries using the proportion of observations made for each species. Figures were calculated from aerial surveys on East Foundation lands, Texas, USA from November 2013-February 2015.

Survey occasion	Total observations	% Feral hogs	% Collared peccaries	Combined density	Standard error	Feral hog density	Collared peccary density
November 2013	126	44.4	55.6	2.69	±0.61	1.19	1.50
February 2014	312	25.0	75.0	5.41	±0.70	1.35	4.06
November 2014	200	36.0	64.0	8.36	±1.62	3.01	5.35
February 2015	278	39.6	60.4	6.62	±0.99	2.62	4.00

sightability on the line may make the extra cost, effort, and time required for MRDS impractical. For rangelands in southern Texas, conventional distance sampling may be adequate if the remaining assumptions are addressed.

Survey Methodology Review

Data Recording.— Two separate data recording techniques were tested during the surveys to determine which was more efficient. From a post-processing standpoint, recording data from the paper data sheets was less time consuming than audio recorded data from the CyberTracker program. In addition, observers reported more time spent recording observations during surveys using CyberTracker than pencil and paper. Greater recording time was problematic when multiple observations occurred close together. The CyberTracker program took too long to enter the data into the system and individual observations had to be completely entered before the next observation could be made. It was much easier to record multiple observations quickly using the pencil and paper. Time spent recording data takes away from search time. The time spent searching can be maximized when the recording process is as efficient as possible.

The CyberTracker program malfunctioned during flights, which could delay completion of surveys or even compromise integrity of the data. The voice recording feature should have enabled observers to spend more time watching the search area. However, due to malfunctions and the time it took the program to process the observation, the voice recording feature was a hindrance rather than an advantage. There is potential for a different application to be created in the CyberTracker program that could increase its efficiency. This option would eliminate voice recording by requiring the observer to manually enter the data using the touch-screen capabilities, but this may still present problems when groups of animals are encountered at a rapid rate.

Survey coverage.—Survey coverage was inconsistent throughout the 4 surveys. A target coverage was determined prior to surveys and transects were mapped out. However, due to multiple navigation equipment failures, target survey coverage was not fully met on San Antonio Viejo, Buena Vista, and Santa Rosa until the February 2015 surveys. Despite inconsistent coverage, each survey produced enough observations to estimate population density for each species other than feral hogs and collared peccary. Survey coverage varying from 10-100% also produced reliable population estimates in a study done in South Texas to determine the precision of data at different sampling intensities (Beasom et al. 1986), and thus variable coverage in my surveys should not be problematic. In the future, survey coverage should not vary for the sake of consistency. Back-up navigation equipment should be available for use when primary equipment fails. In addition, it is crucial that the helicopter company conducting the surveys understands the importance of following survey protocols.

Application to Multiple Species.—Mark-recapture distance sampling was successful in producing population estimates for species with an adequate number of sightings. A number of studies have performed distance sampling on multiple species (van Hensbergen et al. 1996, Jathanna et al. 2003). There were incidents during surveys when groups of >1 species were present in a short section of transect, giving observers little time to record all observations. These incidents may have reduced the time observers were able to dedicate to searching for animals. However, the average overall detection probabilities in the area surveyed ranged from 45-60% depending on the species, indicating we saw approximately half of the animals in the survey area. These estimates agree with work previously done in South Texas for white-tailed deer, where detection probabilities ranged from 32–65% (DeYoung 1985, DeYoung et al. 1989), indicating the observations may not have been compromised. There would be merit in focusing survey efforts on one species to maximize search time and minimize recording time (Jathanna et al. 2003); however suggesting surveys for each species would not be productive nor cost effective if multiple species are of interest.

Covariates.—Perpendicular distance, cluster size, habitat type, and observer were used as covariates in the analysis process. Models with perpendicular distance and either group size or observer fit the data best. Group size affected sightability of feral horses, donkeys, and double-crested cormorants (Graham and Bell 1989, Ridgeway 2010). There were many first-time observers that took part in my surveys. This would explain the effect of observer in the model for the November 2013 and November 2014 surveys and indicated that observers should be trained and experienced prior to conducting surveys to reduce biases (Buckland et al. 2001). The February 2015 surveys also produced a model where observer impacted the sightability of nilgai. These observers were experienced, but one observer that always sat in the front and one that always sat in the back traded positions for El Sauz and Santa Rosa surveys. The impacts of this change in observers may have gotten lost when observations were pooled across ranches for other species. However, because nilgai are only found on those 2 ranches, any differences in observers could have been detected in the MRDS models for nilgai. To avoid this, observer configuration in the helicopter should stay consistent during each survey occasion or observer should be included in the model.

Meeting Conventional Distance Sampling Assumptions

(1) All Animals on the Survey Line are Detected

Using MRDS mitigates the assumption of CDS that all animals on the transect line are detected by incorporating an estimate of the proportion of animals on the line that are detected. My results suggested a high proportion of animals on the survey line are detected, and therefore

MRDS resulted in about a 10% increase in the estimated population relative to the estimate derived from CDS.

(2) Animals are Fixed at the Location they were Initially Sighted and None are Counted Twice

This assumption could be violated if animals are running when first seen, animals are double counted, or when animal distribution is affected by the observer. Because most animals were running when first observed during my surveys, animal movement in response to the helicopter could have biased my results. However, if this movement is random and slower than the observer's speed, no serious bias occurs (Buckland et al. 2001). Animal movement that alters population estimates can be discovered by abnormalities in the detection function, such as a low number of detections on the transect line and a high number of detections at farther distances (Buckland et al. 2001). Because no significant abnormalities were detected in my models, biases associated with animal movement away from the transect line may not have had a meaningful effect on population estimates.

Bias associated with helicopter movement changing animal distribution may be an explanation for the high population estimates of cattle relative to East Foundation inventories. Cattle frequently drifted to fence lines and gathered at the sound of a helicopter, resulting in groups of >50 animals and potential double counting as cattle moved. These problems could potentially be avoided by the use of drones for surveys (Jones et al. 2006, Vermeulen et al. 2013). The animals may not be as disturbed by the sound of the drone and viewing recorded images or video may allow observers to see where the animal was located when it initially flushed. Animals that do not flush are much less visible, so this technique would only be effective if the drone was loud enough to persuade the animals to make themselves available to be seen. Large undercounts could occur if techniques are used that do not cause animals to flush (Buckland et al. 2004).

Animal movement also creates potential for double counting. This is particularly a problem on the smaller ranches where there was less space between transects (Buckland et al. 2001). There is potential that animals moved among transects during my surveys, and therefore an unknown amount of double counting may have occurred. To reduce double counting, it may be beneficial to fly every other transect and then go back and fly the intervening transects. The issue of double counting could also be remedied by using marked animals to observe drifting or availability bias.

(3) All Distances and Angles are Measured Correctly

The results from my assessment of perpendicular distance estimates indicated that error in distance estimates was small and did not increase with increasing distance from the transect line. Had error increased with distance, I would have had to use larger distance bins for the farther distances during the analyses (van Hensbergen et al. 1996).

Population and Density Estimates

White-tailed deer.—White-tailed deer population estimates from MRDS were lower than those calculated using DeYoung et al.'s (1989) correction factor applied to my survey data. The correction factor attempts to correct for both perception and availability bias. Perception bias was addressed using a distance sampling approach to account for deer not seen and marked deer were used to estimate availability bias. The MRDS technique does not account for availability bias, so the discrepancy between estimates is arguably a result of availability bias. Because population estimates derived from MRDS are 32-42% lower than estimates derived from DeYoung et al.'s correction factor, uncorrected availability bias may be large.

White-tailed deer population estimates were lower in autumn versus winter. A population increase between autumn and winter surveys is difficult to explain. The annual reproductive pulse occurs during the summer months and therefore reproduction cannot be the reason the populations apparently increased. There are 3 possible reasons deer populations appeared to increase between autumn and winter surveys. First, visibility of deer during surveys may have changed between survey periods. Second, deer may have moved onto the study sites from adjacent properties. Third, changes in cluster size between the survey periods may have influenced population estimates. Each of these possibilities will be addressed in turn.

The first potential reason for the changes in my white-tailed deer estimates is changes in visibility due to availability bias. Seasonal differences in vegetative cover could affect sightability or movement of deer. Woody plants found on the ranches typically did not lose their leaves until December or January, making deer more visible during the February surveys. In addition, temperatures are warmer during fall surveys and deer may be less mobile. Mark-recapture distance sampling models should respond to changing leaf cover, but cannot respond to availability bias due to movement. Higher detection probabilities and effective strip widths would be present if sightability truly changed, and population estimates would be corrected for this change. However, there was a larger population estimate increase from autumn to winter when there was a little change in detection probability (November 2014–February 2015), and a smaller population estimate increase from autumn to winter when there was a greater increase in detection probability (November 2013–February 2014).

Visibility may also change due to the habitat selection by deer. If deer were less visible in oak woodlands than mixed brush or grassland habitats, then movements among these habitat types could explain differences in population estimates among seasons. However, models including habitat type as a covariate were never the top models in the analyses, meaning habitat type had little impact on sightability. Sightability on the line and overall detection probability increased each winter for white-tailed deer. Changes in sightability must be due to reasons other than changes in habitat type because of the lack of justification in the models and the fact that the San Antonio Viejo and Buena Vista ranches have little live oak and woody plant habitat, and density estimates of deer on these sites still varied seasonally.

A second possible reason for inconsistencies in deer population estimates is deer movement across property lines. Hunting for white-tailed deer does not occur on East Foundation ranches. However, hunting does occur on adjacent properties. It is possible that deer from the surrounding ranches use my study sites as a refuge during the hunting season. Evidence against this theory is that harvest rates are typically low on surrounding ranches and such large shifts in distribution have not been documented for deer in South Texas. Home range size of white-tailed deer in southern Texas ranges from 84-218 ha (Inglis et al. 1979, Cohen et al. 1989, Webb et al. 2007, Currie 2013). During their 11-month study, Cohen et al. (1989) also found that deer traveled the most during the spring, least during the summer and autumn, and moderately through the winter. The size of the home ranges in these studies indicates that movement on and off the study sites is not a probable cause for our population trends.

The third potential reason for changes in population size estimates is differences in cluster size. The density of deer clusters was similar during each survey period (with a slight increase in February 2015), but the expected cluster size was consistently larger during winter surveys. Larger groups without a change in the density of groups encountered would result in increased population estimates. The changes in cluster size could be due to behavioral responses to the December rut (November is pre- or early rut; February is post-rut). Deer group sizes are often smaller in the autumn than in the winter (Lagory 1986, Sorensen and Taylor 1995).

Seasonal changes in cluster size could have an impact on their sightability. A larger cluster of animals is more likely to be seen than a smaller group. This could have resulted in an underestimate of density during autumn surveys when clusters were smaller. If differences in cluster size were solely due to changes in behavior, then the density of clusters in autumn would be higher and the expected cluster size would be lower. Conversely, the density of clusters would then be lower in the winter but have a higher expected cluster size. Because the density of clusters stayed relatively consistent, a combination of changes in cluster size due to animal behavior and differences in cluster detectability are plausible explanations for the differing population estimates.

Because I do not know the true population size, I am unable to determine the accuracy of the estimates and therefore to reliably evaluate various sources of bias. Given that undercounts are common during aerial surveys, I speculate that larger population estimates may result from less negative bias and should be preferred.

Nilgai.—Differences in nilgai numbers among survey periods could, unlike deer, be explained by nilgai movements. Average home range size of female nilgai in South Texas is 5,500 ha and that for males is 7,000 ha (Moczygemba et al. 2012). These large home ranges indicate the potential for movement and changing population sizes when measured at the scale of most ranches. For example, Santa Rosa is 7,471 ha and El Sauz is 11,021 ha. Thus, seasonal movements could occur between autumn and winter surveys that could result in changing population estimates. Jathanna et al. (2003) reported population estimates during a November survey of ungulates in India that were lower than previous surveys done in February. They attributed difference to seasonal movement, so I feel this and the large home range size may be the case for the differences in my population estimates.

Cattle.—My cattle estimates were greater than the East Foundation cattle inventory. Large groups consisting of > 50 cattle could skew data when detection probabilities of large groups are greater than calculated by Program Distance. Such a difference in detection probability could inflate population estimates by over-correcting for the large clusters. However, there were ≤5 clusters of >50 animals per survey occasion. The small number of large clusters would not drastically impact my population estimates. Furthermore, cluster size was a co-variate in all the top models for cattle and the analysis addressed the effect of detection probability varying with cluster size. Therefore, this potential bias does not explain the large population estimates.

Cattle movement could result in potential double counting of animals on smaller ranches. This occurs when individuals or herds are driven to the next transect where they are counted again. Double counting results in positive bias towards population estimates. However, over counts were not higher on the smaller ranches where double counting was more likely. This indicates that double counting was not the main driver in our inflated population estimates.

Feral hogs and Collared peccary.—There was no significant difference in feral hog and collared peccary population estimates among surveys. Estimates increased with each survey occasion and then decreased during the final survey. This pattern could be due to changes in vegetative conditions or hog control in surrounding areas. I also acknowledge the variability that is potentially present in my estimates by combining data for 2 species. Ideally, future surveys will allow for a sufficient number of detections to estimate each species' population size.

MANAGEMENT IMPLICATIONS

Mark-recapture distance sampling corrects for imperfect detection on the line and yields less biased population estimates than conventional distance sampling. High visibility of large mammals on the survey line during aerial surveys in southern Texas reduces the value of MRDS relative to conventional distance sampling, especially because of the large effort necessary to implement MRDS. A reasonable alternative could be to use conventional distance sampling and then increase population estimates and standard errors by 10% to account for the small proportion of animals missed on the line.

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CHAPTER III

LARGE MAMMAL MONITORING PROGRAM RECOMMENDATIONS

Objective 1: Conduct aerial helicopter surveys of the East Foundation lands to estimate the size and composition of large mammal populations.

Aerial surveys were conducted during November 2013, February 2014, November 2014, and February 2015. An additional set of surveys will be conducted during November 2015 or February 2016. Large mammal population estimates and densities were calculated for each species (with feral hogs and collared peccary combined; Table 2.7) as well as population demographic data (excluding feral hogs and collared peccary; Table 2.6). I recommend continuing annual surveys.

Objective 2: Develop a data system for recording information in the helicopters that can easily be transferred to a computer database.

Two methods of recording data during the large mammal aerial surveys were tested. Each method was evaluated on efficiency, ease of use, and dependability. One method consisted of using pencils to record observations on paper data sheets. Handheld Garmin Rhino 120 global positioning system (GPS) units were used to manually mark waypoints of each observation. The second method was using Panasonic Toughbook computers with a customized CyberTracker application installed. This system utilized voice recording technology to log observations into the application. Waypoints of each observation were taken using Garmin 18X USB GPS sensors that automatically logged waypoints when audio data from observations were recorded.

A controlled test of the efficiency of post-processing data from each of the methods was carried out after the completion of all of the surveys. Five 1-hour trials were conducted for each method to see how many observations could be recorded from the paper datasheets or the

CyberTracker program for post-processing. Data collected using pencil and paper could be entered faster than data collected using CyberTracker (241 ± 4.1 (SE) vs. 188 ± 4.2 lines/hr).

Based on the opinions of the surveyors, pencil and paper datasheets were easier to use than the Toughbook computers with the CyberTracker program. Using pencil and paper allowed the observers to make multiple observations in a short amount of time with the ability to multi-task. The CyberTracker program only allows one observation to be entered at a time and because it took 10–30 seconds to complete an entry, some observations received inaccurate locations when >1 group was encountered in a short period of time. In addition, the Toughbook computers and CyberTracker program frequently malfunctioned. The program periodically froze, did not record observations, or the GPS sensors did not consistently maintain satellite signal. Finally, the Toughbooks also had to remain charged throughout the whole flight, which required coordination to use the single charging cord. None of these problems occurred when using pencil and paper.

There is potential for the CyberTracker program to be more efficient. A different application could be designed so that each observation solely relies on touchscreen data recording. This would eliminate the potential for voice-recording failures and may streamline the observation process. However, difficulties with program dependability and functionality would remain and a touchscreen program for surveying several species may still be sufficiently complex that it would be difficult to enter data when groups of animals are encountered at a high rate.

Objective 3: Evaluate the effectiveness of surveys during different seasons (autumn vs. winter).

Several criteria were assessed to determine which season (autumn-November, winter-February) would be most suitable for aerial surveys. Survey data were combined with experience from observers on this project to determine which season was better for each criterion. A 1 was assigned for a positive effect, 0 for a neutral effect, and a -1 for a negative effect (Table 3.1).

The recommended survey season is February. There was a positive effect on the criteria more frequently during February surveys than November surveys. Population estimates, detectability on the line, and overall detectability are higher in February. There is no potential for biases due to animal disturbance from fall deer captures, and the average February temperatures are lower, which may make animals easier to observe due to increased movement.

Objective 4: Evaluate the effects of covariates on survey observations and population estimates

Data that were recorded with each observation in the field were perpendicular distance to the transect line, cluster size, observer, sex, and approximate age. Habitat type was added to the data after the surveys were complete. Perpendicular distance, cluster size, observer, and habitat type were modeled as covariates to determine their effect on sightability (Appendix B). Age and sex data were used to determine population demographics.

Most survey occasions by species showed that the best model contained perpendicular distance and cluster size as covariates. When these covariates did not best explain the model, perpendicular distance and observer did. Based on these results, it is important to record cluster size accurately during distance sampling and it is essential that observers are adequately trained to perform aerial surveys.

Table 3.1. Selection criteria for determining ideal survey season (autumn vs. winter) for aerial surveys of large mammals on East Foundation lands, Texas, USA based on results from surveys conducted on the lands from November 2013-February 2015.

	Season rating		
Criteria	November	February	Explanation
Reliable Population Estimates	0	1	Assuming aerial surveys consistently have an undercount, February surveys produce higher population estimates, so more of the undercount may be eliminated (Table 2.7, Fig. 2.7).
Fawn:Doe Ratios	0	0	Ratios showed little difference between seasons by year. Buena Vista showed higher ratios in the winter for the 2013-2014 survey year and lower in the winter for the 2014-2015 survey year (Fig. 2.6). This indicates a neutral rating for each season.
Calf:Cow Ratios	0	0	No consistent pattern with ratios, indicating each season is neutral (Table 2.6).
Female:Male Ratios	0	0	No consistent pattern with ratios, indicating each season is neutral (Table 2.6).
Deer Capture Disturbance	-1	1	White-tailed deer captures occur in the autumn (October), making them potentially negative towards November surveys. Deer could be reacting negatively towards the helicopter due to deer capture disturbance.
Deer Capture Use for Surveys	1	-1	White-tailed deer captures occur prior to scheduled November aerial surveys. Deer captures could be used to mark animals in order to further assess mark-recapture efforts or drifting effects.
Favorable Survey Weather	0	1	February temperatures are much cooler than in November. The average temperature in Kingsville, Texas in November is 24 degrees Celsius and the average temperature in February is 22 degrees Celsius. For animals, cooler temperatures may increase activity, making them more available to be seen.
Favorable Survey Habitat	0	1	A small percentage of the habitat surveyed is wooded. However, of the proportion that is, it is much easier to see animals in February after leaf fall.
Detectability on the Line	0	1	Average g(0) values were higher for February surveys (except for nilgai and feral hogs and collared peccary 2013-2014), and the associated error was lower (Table 2.4).
Overall Detectability	0	1	Detection probabilities were higher for February surveys in the 2014-2015 survey year and the associated error was lower. Detection probabilities for the 2013-2014 survey year were higher in the winter for only white-tailed deer (Table 2.5).
Grouping of animals	0	0	Groups of white-tailed deer were larger in the winter and smaller in the autumn (Table 2.9). It is unclear which is a more favorable situation.
Total	0	5	
Survey recommendation	-	X	

Objective 5: Determine an optimal survey design and percentage of land surveyed

Survey design should consist of evenly-spaced transects. Ideally, these transects should run north to south so that surveys are not flown into the sun. Placement of transects should have a random starting point, and evenly spaced transects should follow. Preferably, 20 transects should be flown on each ranch. Transects used during the surveys from November 2013-February 2015 are shown in Fig. 2.2.

Target survey coverage on each ranch for all aerial surveys flown was 50% on Buena Vista, El Sauz, and Santa Rosa, and 25% on San Antonio Viejo. The minimum survey coverage needed to produce enough observations (≥60) and low enough coefficients of variation (≤20%) for reliable estimates was calculated using data from the surveys (Table 3.2). These figures were found by manually deleting transects from the data and running models in Program Distance. Transects were deleted 1 at a time until the number of observations or the coefficient of variation reached its limit. Occasionally, the original survey data from a particular ranch did not initially meet the criteria for reliable estimates. When this occurred, no transects were deleted and the minimum survey coverage needed was derived from the coverage flown on that survey.

After the minimum amount of survey coverage needed for reliable estimates was calculated, recommended survey coverage was produced (Table 3.2). Recommendations were first based on survey coverage necessary to provide reliable estimates for all species. Recommendations were also derived to provide reliable estimates for all species except feral hogs and collared peccary. These species were seen infrequently throughout all of the ranches. It would be difficult to fly enough coverage to obtain an adequate number of observations needed to reliably estimate their populations.

Table 3.2. Calculated minimum coverage, resulting coefficients of variation (% CV), and resulting number of observations for reliable estimates of all species for aerial surveys on East Foundation lands, Texas, USA, as well as recommended coverage for all species and only deer and nilgai.

Ranch	Species	Minimum coverage	% CV	# Observations	Recommended Coverage: All species	Recommended Coverage: Deer and nilgai
San Antonio Viejo	White-tailed deer	5	20	70		
	Nilgai	-	-	-	30	10
	Cattle	11	21	90		
	Feral hogs and collared peccary	28	19	82		
Buena Vista	White-tailed deer	25	17	60		
	Nilgai	-	-	-	100	50
	Cattle	51	48	24		
	Feral hogs and collared peccary	51	36	16		
El Sauz	White-tailed deer	39	17	63		
	Nilgai	69	27	145	100	75
	Cattle	54	19	132		
	Feral hogs and collared peccary	69	32	25		
Santa Rosa	White-tailed deer	46	19	67		
	Nilgai	49	22	76	100	50
	Cattle	49	24	84		
	Feral hogs and collared peccary	49	23	31		

Objective 6: Make management recommendations to the East Foundation on an efficient long-term monitoring program for large mammals

To summarize the above findings, I recommend

1. Surveys conducted in February of every year.
2. San Antonio Viejo should be flown at 30%, and Buena Vista, El Sauz, and Santa Rosa at 100% coverage. For ranches being flown at 100%, every other transect should be flown. Skipped transects should then be flown later in the day to reduce double counting.
3. Pencils and paper datasheets with handheld GPS units are the most efficient and reliable form of data collection,
4. Perpendicular distance, cluster size, sex and age of all animals, and observer should be recorded in the field. Habitat type can be added to each observation during data entry.
5. Observers need to be trained prior to surveying in order to reduce their biases on the data.

In addition to these recommendations, I suggest the East Foundation conduct the surveys using conventional distance sampling. The MRDS technique, while potentially useful in many situations, does not make a large correction in South Texas rangelands. For the convenience of data entry and analysis, survey methodology, and reducing individual observer biases by utilizing multiple observers and eliminating observer independence, conventional distance sampling is the preferred technique.

To account for imperfect detection on the line, population estimates and standard errors can be increased by 10%. Visibility on the line varied little between survey occasions and frequently was >90%. These results support adding 10% to population estimates and standard errors and make not carrying out MRDS reasonable.

The following recommendation is added:

6. Large mammal aerial surveys should be conducted using the conventional distance sampling technique. Population estimates and standard errors should be increased by 10% to account for imperfect detection on the survey line.

APPENDICES

APPENDIX A. Data entry and analysis protocol for MRDS in Microsoft Excel, ArcMap, and Program Distance.

PART 1: DATA ENTRY AND FORMATTING

Step 1: Data Collection

1. Make datasheet for flight containing the following preliminary information:
    a. Study site
    b. Date
    c. Observer
    d. Start Time
    e. End Time
    f. Notes
2. Include the following headings for data collection:
    a. Waypoint
    b. Species
    c. # Adult Male
    d. # Adult Female
    e. # Young
    f. # Unknown
    g. Perpendicular Distance

Step 2: Data Entry

1. Make copies of original data sheets
2. Create Microsoft Excel spreadsheet reflecting datasheet
3. Record data to exactly match recorded information on datasheet

Step 3: Load Waypoints and Tracks Into ArcMap

1. Save waypoints and tracks as shapefile
2. If waypoints are separate files, merge files into one shapefile per GPS unit

Step 3: Assign Habitat Type to Each Line of Data

1. Join waypoint files with habitat file to assign each waypoint a habitat type in ArcGIS
2. Copy and paste habitat types and latitude/longitude values into database

Step 4: Determine Observation Match-ups

1. Focus on one ranch, one transect at a time
2. Determine which waypoints represent which line of data
3. If waypoints are close to one another, refer to data and determine if it is a match or "recapture"
    a. Waypoints that are more than 200 m apart are likely to not be matches

b. It is possible for matching observations to not be exact. Number of animals seen and perpendicular distance may differ.

4. Use your best judgment to determine which observations are independent “marks” or matched “recaptures.”
5. This is a very long and tedious process. Take your time and work slowly to ensure accuracy.

Step 5: Format Matches and Independent Observations

1. List all waypoints from GPS 1 (front observers) in a column (Waypoint ID = C#). For observations that were a match, list the corresponding waypoint in the column next to the appropriate waypoint. If the waypoint was an individual observation, it should not have a waypoint in the next column. Below is an example of how this data should be formatted.

C1	J1
C3	J2
C5	
C6	J3
C8	
C9	J5
C10	M2
C11	M3
C12	
C13	J7
C15	M5

2. For the remaining individual observations from the other GPS units (Waypoint ID= J# or M#), list them below the matches in the second column. Below is an example of this format.

C149	J80
C150	M70
C152	J81
	J13
	J20
	J28
	J29
	J30
	J33
	J36
	J37
	J45

3. An “Object ID” needs to be created for each <u>set</u> of observations (matches or independent). Make this ID by listing sequential numbers next to each set of observations.

C1	J1	100
C3	J2	101
C5		102
C6	J3	103
C8		104
C9	J5	105
C10	M2	106
C11	M3	107

4. Then, take the observations from the other GPS units (in this case, “J” and “M,” and make a separate column of these observations in order, with the already given Object ID.

C1	J1	100		J001	100
C3	J2	101		J002	101
C5		102		J003	103
C6	J3	103		J005	105
C8		104		J007	109
C9	J5	105		J008	111
C10	M2	106		J010	119
C11	M3	107		J011	121

5. Once your data is correctly formatted, return to your main database. You should create an “Object ID” column. In the first row of this column, we need to fill in the established Object ID. The formula to insert this ID is as follows:
   =VLOOKUP(Cell containing Waypoint ID, Highlighted cells from matchups, 3)

From original data

Waypoint ID	Object ID
C1	100

From formatted data

C1	J1	100

This formula can be applied to all waypoints for GPS 1.

6. For the remaining GPS units, use the following formula:
   =VLOOKUP(Cell containing Waypoint ID, Highlighted cells from remaining units, 2)

From original data

J1	100

From formatted data

J1	100

This should completely fill in the "Object ID" column with the appropriate number. Double check a few columns to make sure the "matches" have the correct Object ID.

Step 6: Create New Database

1. Create a new database so the appropriate formatting can now take place.
2. Sort the "Object ID" column from smallest to largest values. This will organize your matches next to each other, which is the proper formatting.
3. In order for Program Distance to analyze the data, two rows need to be made for each observation, regardless if there's a match or not. Because the matches already have two rows per observation, an additional duplicate row needs to be added for the individual observations.
4. To carry this out, make sure "Object ID" is in Column A.
5. At this point, the following Macro to create duplicate rows needs to be run:

```
Sub Duplicate_Rows()
Dim lr As Long, r As Long

lr = Range("A" & Rows.Count).End(xlUp).Row
Application.ScreenUpdating = False
For r = lr To 2 Step -1
        If Cells(r, 1).Value <> Cells(r - 1, 1).Value And
Cells(r, 1).Value <> Cells(r + 1, 1).Value Then
 Rows(r).Copy
Rows(r).Insert
End If
 Next r
Application.CutCopyMode = False
Application.ScreenUpdating = True
End Sub
```

*If a "Run-time" error occurs, break the data up into sections and run the Macro on each section. It is unknown why the Macro sometimes works on the whole data set and sometimes only works on part on the data set.

This should create 2 rows of data for each observation. Matched observations should be paired, and individual observations should be copied.

Step 7: Further Format the Distance Data

1. In order to format the data for Program Distance, the following columns need to be present in the database:
    a. Region ID- Your preference
    b. Region Label- Your preference
    c. Region Area- Acreage or hectares of the entire ranch or area of interest
    d. Transect ID-Each transect must have an ID #
    e. Transect Label-Each transect must have a label

f. Transect Length- Obtain the length of each individual transect
    i. Associate each set of data with the appropriate transect it was found on

2. An "Observer" column needs to be formatted to "1's" and "2's." so that Program Distance can read the data correctly. Names need to be removed and a pattern of 1,2,1,2 should be entered.
3. A "Detected" column needs to be created. This is a binary code that Program Distance can read. A "1" represents that the observer detected the observation. A "0" represents that the observer did not detect the observation. For each pair of data lines, the possible combinations are:

1 -Observer "1" saw the observation
0 - Observer "2" did not see the observation

0 –Observer "1" did not see the observation
1 –Observer "2" saw the observation

1 –Observer "1" saw the observation
1 –Observer "2" saw the observation

In order to fill in this column, use the following formula:

```
=IF(A2=A3,1,IF(B2<>B1,1,0))
```

*Making sure you choose the correct columns. It will differ with each dataset

*If this option does not work, take the "Observer" and "Waypoint ID" columns and place them in a separate spreadsheet. Then run the following Macro:

```
Sub CompleteDetected()

Dim lr As Long, a As Variant, i As Long
Application.ScreenUpdating = False
lr = Cells(Rows.Count, 1).End(xlUp).Row
a = Range("A1:D" & lr)
For i = 2 To lr Step 2
If a(i, 2) <> a(i + 1, 2) Then
a(i, 4) = 1
a(i + 1, 4) = 1
Else
 a(i, 4) = 1
 a(i + 1, 4) = 0
End If
Next i
Range("A1:D" & lr) = a
Application.ScreenUpdating = True
End Sub
```

***Take careful note that your data is formatting correctly. Double check for GPS units 2 and 3 that the notation of an independent observation was formatted as "0,1," not "1,0."

If it is not formatted in this way, Program Distance will result in an error and will not run the data.

4. Now each pair of data lines must match exactly in the columns that describe the data. For example, the data collected for each observation, such as "Species," "# Adult Males," "# Adult Females," "# Young," "# Unknown," "Perpendicular Distance," etc. needs to all match. Go through the data and edit as appropriate.
    a. If distances differ, use the shorter distance for both
    b. If cluster sizes differ, or group composition size differs, use the larger cluster size.

    *This is a very tedious process. A more efficient method may exist, but from experience, it is best to personally go through each line of data to ensure accuracy.

5. Once these steps are complete, save your data as a Text file (tab delimited).

PART 2: IMPORTING DATA

Step 1: Program Distance

1. Familiarity with Program Distance is imperative to properly running data analysis.
2. If the data is formatted correctly, importing it into Distance should be successful.
3. In addition, if the data is formatted correctly, models should run without errors.
4. If there are errors in the data import or analysis process, you must try to pinpoint the exact line of data where the problem occurs. Try running separate chunks of data to find the problem more efficiently, as this will be very time consuming with large data sets.

Step 2: Starting a new project

1. Open Program Distance and select File, then New Project.
    a. Name your new project and make sure it will be located in the right folder
    b. Select Create
2. The "New Project Set-up Wizard" will appear. Select "Analyze a survey that has been completed" then Next.
3. Select Next again. This screen simply explains what you have selected and what you need to do in the further screens.
4. The "Survey Methods" screen now appears. Select the following options:
    a. Type of survey → Line Transect
    b. Observer configuration → Double Observer
    c. Distance measurements → Perpendicular Distance
    d. Observations → Clusters of objects
5. Select Next.
6. The "Measurement Units" screen will appear. Select the following options:

    a. Distance → Meter
    b. Transect → Meter
    c. Area → Acres or Hectares (dependent on preference)
7. Once you have made these selections, hit Next.
8. Once you reach the "Multipliers" screen, do not select any of the options. Simply hit Next.
9. When you are on the final screen ("Finished") of the "Project Setup Wizard," select Proceed to Data *Import* Wizard and hit Finish.

Step 3: Importing the Data

1. When the Data Import Wizard opens, hit Next to pass through the introduction.
2. Then, find your data file and select OK
    a. Remember, your data had to be saved as a text file.
3. The Data Destination window then appears. This specifies how the data is imported. The following selections should be made:
    a. Lowest Data Layer → Observation
    b. Highest Data Layer → Region
    c. Parent Data Layer → Study area
    d. "Add all new records under the first record in the parent data layer"
    e. "Create one new record for each line of the import file."
4. Select Next and proceed to the "Data File Format" window.
5. In the "Data File Format" window, make the following selections:
    a. Delimiter → Tab
    b. Ignore rows → Check the box to ignore the first row, which is just column labels
    c. Decimal Symbol → Use Regional Settings
6. Hit Next.
7. The "Data File Structure" window now appears. This is a crucial process that must be completed correctly in order for the data to import.
    a. Each layer (or column) must be specified correctly
    b. Each layer that will be used in the data analysis process has to be defined
    c. Each layer will have 3 levels: Layer name, field name, and field type.
        i. The layer name only has 4 options: Region, Line Transect, Observation, or Ignore
            1. Region labels deal with the study area
            2. Line Transect labels deal with the transects
            3. Observations deal with the details associated with each observation
            4. The Ignore option will ignore that column and not include it in the import or analysis process.
        ii. The field name will have some options already available, and some will need to be typed in.

iii. The field type will automatically fill itself in depending on the nature of the data (Text, decimal, integer, etc.).

8. Define the columns in the following format (Layer name, field name, field type):
   Note: If your columns are not in the same order as the instructions, that is OK. Just locate the correct column and make the selections.
   a. Region ID → Region, type in "ID", then "ID" will automatically fill in for field type.
   b. Region Label → Region, Label, Label
   c. Region Area → Region, Area, Decimal
   d. Transect ID → Line Transect, ID, ID
   e. Transect Label → Line Transect, Label, Label
   f. Transect Length → Line Transect, Line length, decimal
   g. Observation ID → Observation, ID, ID
   h. Object ID → Observation, Object, Integer
   i. Perpendicular Distance → Observation, Perp Distance, Decimal
   j. Cluster Size → Observation, Cluster Size, Decimal
   k. Observer → Observation, Observer, Integer
   l. Detected → Observation, Detected, Integer
   m. Species → Observation, Species, Text
   n. Adult Male → Observation, Adult Male, Integer
   o. Adult Female → Observation, Adult Female, Integer
   p. Young → Observation, Young, Integer
   q. Unknown → Observation, Unknown, Integer
   r. Habitat Type → Observation, Habitat Type, Integer

   If you have more covariates that you would like to include, follow the pattern of the other covariates and add them.

   For those columns you wish to leave out of the analysis, simply leave them with "Ignore" in the layer name.

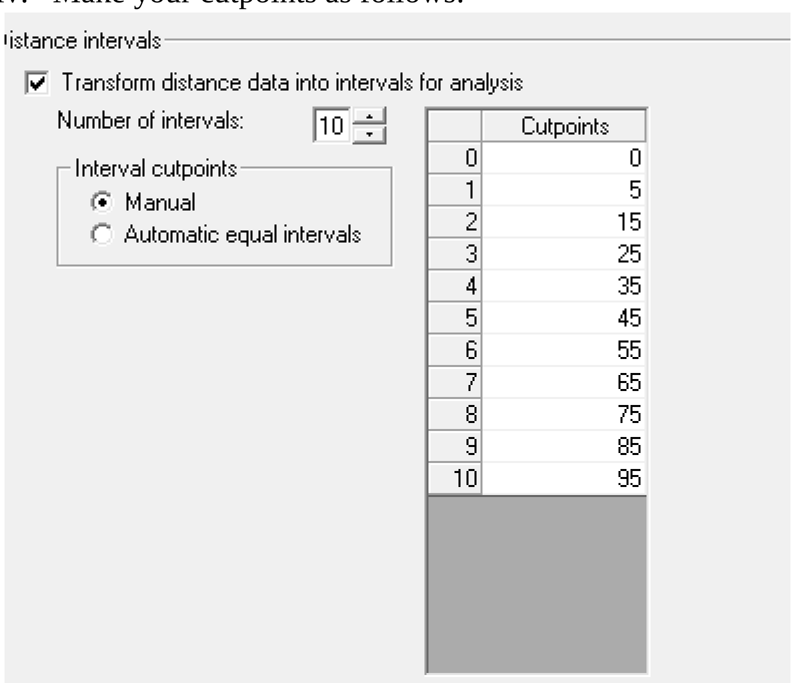
9. When the selection process is complete, hit Next
10. When the "Finished" window of the Data Import Wizard appears, select "Overwrite existing data" and then "Finish."
11. The data import process will take a bit of time, depending on how large your dataset is.

STEP 3: DATA ANALYSIS

It would be of great benefit for you to familiarize yourself with Program Distance. Explore the different options, what your data looks like, how you can edit it, etc. before running any models.

1. Make sure you are in the "Analyses" tab.

2. An undefined model is already in the box for you. You want to edit this model for your data. Double click on the gray bubble of this undefined model.
3. The analysis screen will then appear. Give it an appropriate name.
4. Move down to the “Data Filter” portion and click on the undefined filter.
5. Next click Properties to define that filter.
    a. Under the Data Selection tab, this is where the species of interest will be defined. You should only run models one species at a time.
        i. To create this selection, click the “+” on the right side of the screen.
        ii. Categorize the Layer Type as an Observation
        iii. In the Selection Criteria, type the following formula exactly as it is written here for Deer: Species = ‘D’
            1. For other species, replace the D with the appropriate label (N, C, P, J, etc.)
    b. Under the Intervals tab, the distance bins need to be defined. Make sure the cutpoint of your distance bin falls within the middle of the cutpoints in the program.
        i. Check the box “Transform distance data into intervals for analysis
        ii. Select “10” for the number of intervals
        iii. Select Manual for Interval cutpoints
        iv. Make your cutpoints as follows:



    c. Under the Truncation tab, for right truncation, select “Discard all observations beyond” and then select “95.”
        i. For left truncation, select “Discard all observations within” and then select “0.”
        ii. For the truncation of cluster size, select “Same as that specified above.”

d. Under the Units tab, make the following selections:
   i. Distance: Same as distance data
   ii. Angle: Degrees
   iii. Length: Same as length data
   iv. Area: Same as area data
e. Finally, give your filter a name that explicitly explains the filter. An example would be "Deer_95_Truncate."

6. Next we need to define the model.
   a. Click on the default model and then select Properties.
   b. Select "MRDS-Mark Recapture Distance Sampling" under the analysis engine.
   c. Under the Estimate tab, select:
      i. Stratum definition → No stratification
      ii. Use layer type → Sample
      iii. Check the box for Estimate Density/Abundance
      iv. Detection Function → Estimate detection function
   d. Under the Detection Function tab
      i. `Under the Methods tab
         1. Fitting Method → io-independent observer, point independence
      ii. Under the DS Model tab
         1. Key function → half normal
         2. Model for scale parameter of key function → scale parameter is constant (CDS).
      iii. Under the MR Model tab
         1. Class of Model → Generalized linear model
         2. Link function → logit
         3. Model formula → This is where you will add your numerical covariates. The correct formatting is "x+y", with x and y being your covariates. For an example of distance from the transect line and cluster size as covariates, you would add "distance+size". DISTANCE renames your categories, so you will have to discover what your categories were renamed as (ie. Perpendicular distance to distance, and cluster size to size.)
      iv. Under the Factors tab
         1. This is where you will add your text covariates, such as habitat type or activity
      v. Under the Control tab
         1. Leave this blank
      vi. Under the Diagnostics tab
         1. Check the box next to "Plot distance histograms and detection functions."

2. Check the box next to "Compute goodness-of-fit statistics and qq plot."

vii. Name your model something appropriate that reflects the covariates you included.

viii. Click OK

e. Under the Variance tab

i. Select option #1 for Analytic variance of density estimate

ii. Variance Estimator → R2

f. Under the Misc. tab

i. Select Standard Output

7. Run your model by selecting "Run" in the upper right hand corner.
8. If your model has run successfully, the middle Log tab will turn green and your Results tab will show your results.
    a. If your model has run successfully but the middle Log tab is orange, this simply means the program is issuing warnings. The majority of the time these are acceptable, and you can continue on to your results.
    b. If your model has not run successfully, the middle Log tab will be red. Read the error messages and determine whether the error was in the model, the filter, the data import process, or in the data itself.
9. You can then explore your results and determine the information you are seeking.
10. Run multiple models with different covariates and determine which best explains the data using AIC, Chi-square goodness of fit, etc.

VITA

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