MONITORING VEGETATION AND NORTHERN BOBWHITE DENSITY IN A GRAZING DEMONSTRATION PROJECT IN SOUTH TEXAS

A Dissertation

by

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ABSTRACT

Monitoring Vegetation and Northern Bobwhite Density in a Grazing Demonstration Project in South Texas

(December 2018)

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Cattle grazing can be beneficial or detrimental to wildlife depending upon how the disturbances from grazing influence habitat components such as food, cover, and water needed to support the annual needs of a species. Making this relationship beneficial may be achieved through understanding how cattle in different grazing systems (e.g. continuous vs. rotational) and stocking rates (moderate vs. high) influence vegetation characteristics and wildlife density. The northern bobwhite (*Colinus virginianus;* hereafter bobwhite) is an economically valuable upland game bird commonly found co-occurring on South Texas ranches with cattle and co-utilizing similar resources. Bobwhites in South Texas are often managed in conjunction with cattle operations. Grazing regimes (stocking and system combination) can impact bobwhite habitat in different ways; however, research relating the effects of different grazing regimes on bobwhite density in South Texas is inconclusive or examines grazing regimes that are not common in the region. I used distance sampling to estimate bobwhite density as a part of a long-term project monitoring the flora and fauna on the San Antonio Viejo Ranch of the East Foundation, a 60,298-ha property in South Texas. I examined interactions between cattle operations and bobwhite density by generating pre- and post-grazing estimates of bobwhite density. In 2014, a 7,689 pasture was divided into 4 grazing regimes representing 4 treatment sites. Bobwhite

density and vegetation were measured on 4 grazing treatments and 3 reference sites (total 4,375 ha). The objectives of my study were to: (1) investigate the efficacy of using video cameras to detect missed flushes, assess which covariates affect detection during surveys, and evaluate density at various levels of survey coverage (Chapter II), (2) analyze vegetation and bobwhite density response to 4 different grazing treatments and 3 reference sites, before and after grazing (Chapter III), and (3) assess the differences in precision of sub-strata density estimates obtained through density surface modeling and model the spatial distribution of bobwhite density across all grazing treatments and reference sites (Chapter IV). In addition to these objectives, I provided a review pertaining to distance sampling and its use in monitoring upland game bird populations (Chapter I). My results will inform management decisions on Texas rangelands where cattle production and bobwhite conservation are integrated goals.

DEDICATION

I dedicate this dissertation to my family and friends in New England who supported and cared for me every step of the way throughout my pursuit of a career in wildlife and to my Texas family that gave me a sense of home in a foreign place.

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I would like to thank Dr. Leonard Brennan for giving me the opportunity to work on a project that advanced my skill set and understanding of wildlife and grazing management in South Texas. Hs encouragement, support, and advice throughout this process helped me see new perspectives on topics beyond just the research component of academia and has helped me a great deal professionally. I would like to thank my committee members Dr. Michael Morrison, Dr. Eric Grahmann, and Dr. Andrew Tri for providing their insights and giving me honest and constructive criticisms and pointing me in the right direction. I would like to thank Dr. David Wester for his patience and support on statistical analyses and always willing to answer even the smallest questions. I would especially like to thank Mr. John Edwards for working with me through distance sampling analyses and providing me with guidance when needed. I would like to thank john for always being willing to help and provide me with his knowledge, which can be very rare for a busy graduate student.

I would also like to extend my gratitude to the East Foundation for allowing me access to their properties and for being a wonderful organization to partner with. In terms of providing graduate students with all the tools necessary to accomplish their goals, the East Foundation is exceptional.

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LITERATURE REVIEW

DISTANCE SAMPLING: THEORY AND APPLICATIONS FOR ESTIMATING DENSITY OF LAND BIRD POPULATIONS

BACKGROUND

Count data provide vital information for developing conservation management plans for wildlife (Rosenstock et al. 2002). The most common methods used to estimate a sample population of land birds are indices of abundance, collected over time to analyze trends (e.g., morning covey calls, whistle counts, roadside surveys; Rosenstock et al. 2002, Rusk et al. 2007). A literature review by Rosenstock et al. (2002) found that out of 224 peer reviewed papers, 95% of them relied upon index counts. Indices are particularly efficient for monitoring landscape level abundance changes, long term estimates of relative abundance for multiple species. For example, the breeding bird survey (BBS) has been monitoring trends in abundance for 650 breeding bird species in North America since 1966 (Sauer et al. 2013). One of the major issues with index data are the biases created by assuming constant detection of objects throughout the survey (Diefenbach et al. 2003). Count indices are often biased by observer variability, differences in plant community type, environmental factors, and species characteristics (Anderson 2001, Rosenstock et al. 2002, Thompson 2002, Diefenbach et al. 2003, Rusk et al. 2007). Some of the biases in BBS data are controlled by keeping spatial (placement of transects) and temporal (time of year) factors consistent for every survey. However, difficulty in summarizing and analyzing the data still arises from inconsistent survey effort throughout the large study area (i.e., route

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This dissertation follows the style of the Journal of Wildlife Management number and length). All estimates of abundance and change through BBS and index counts are model-based and require assumptions to be made accounting for detectability (Sauer et al. 2004). Researchers have developed methods to account for variability and analyze index data over space and time using estimating-equations estimators (Link and Sauer 1994), negative binomial models (Link and Sauer 1998), and more recently, hierarchical models (Link and Sauer 2002). It is implied that researchers using these methods understand that there are complications to analyzing their data based on the nature of the index survey design (Link and Sauer 2004). Other options for estimating density include variations of distance sampling (Buckland et al. 2001) and capture-recapture methods (Borchers 2011). Both methods include estimates of detectability within their survey design and are recommended for abundance estimation when feasible (Nichols et al. 2000). Standard distance sampling uses the distances to detected animals from the surveyor to calculate the detection probability (Borchers et al. 2015). In this review, I will focus on estimating density and using distance sampling.

Distance sampling theory is based on a detection function (g (y)): a measure of the probability of detecting an object given that it is at distance y from the observer (Buckland et al. 2001). The distance y refers to the perpendicular distance from the observer on a point, quadrant, or line to the object detected (Buckland et al. 2001). For the purpose of this review, I will focus on distance sampling from line-transects. A detection function is calculated (using perpendicular distances from the transect line to the object) and used to measure the probability of detection (p) using maximum likelihood estimation (Buckland et al. 2001, Marques et al. 2006). The probability of detection (p) is applied to the standard density estimate ($\widehat{D}$) as $\widehat{D}= n\ /a*\hat{p}$; where n is the number of objects counted and a is the area surveyed (Buckland et al. 2001). For a reliable density estimate, 100% of objects at distance zero are assumed detected (i.e., $\hat{g}(0)$ = 1); detection is then expected to decrease as distance from the transect line increases (Buckland et al. 2001). Distance sampling is a reliable approach to estimating wildlife densities given the assumptions are met (Guthery 1988, Anderson 2001, Rosenstock et al. 2002, Thompson 2002, Rusk et al. 2007).

Distance Sampling and Game Birds

Reliable density estimates can be instrumental in game bird management, especially for setting statewide bag limits, setting harvest levels, providing spatial estimates of density (Warren and Baines 2001), and implementing disease control strategies (Newborn and Foster 2002). Line-transect distance sampling has been effectively used to estimate densities for species such as mountain quail (*Oreortyx pictus*; Brennan and Block 1986), where previous methods (strip censes) were deemed inaccurate due to the reclusive nature of the bird. Butler et al. (2007) applied distance sampling techniques to traditional roadside surveys for wild turkeys (*Meleagris gallopavo*). He found that estimates provided sufficient power to detect changes in density over time, and the method could be easily and inexpensively implemented to large-scale monitoring studies. Line-transect distance sampling was also an efficient method to estimate densities of willow ptarmigans (*Lagopus lagopus*) compared to other methods (Pelletier and Krebs 1997).

Line-transect distance sampling also works well to monitor upland game birds such as black grouse (*Tetrao tetrix*), rock ptarmigan (*Lagopus muta*; Franceschi et al. 2014), red grouse (*Lagopus scoticus*; Warren and Baines 2001), and northern bobwhites (*Colinus virginianus*; Shupe et al. 1987, Guthery 1988, DeMaso et al. 1992, Rusk et al. 2007, Murray et al. 2011). Northern bobwhite (hereafter bobwhites) population declines across the species range have been attributed to a number of factors (i.e., climate change, habitat loss, fragmentation, exotic grass invasion, disease; Hernández et al. 2013). Distance sampling can be a useful tool to assist in impact analyses and conservation planning for this species.

When using distance sampling techniques to estimate land bird density over large areas, surveyors commonly traverse line transects because they are thought to be efficient in number of objects counted per unit of effort (Bollinger et al. 1988, Buckland et al. 2001) and do not require as large of a sample size as point count distance sampling (Rosenstock et al 2002). Surveying bobwhites from line transects using distance sampling has been explored with walked-line transects (Guthery 1988) and helicopters (Shupe et al. 1987, Rusk et al. 2007, Schnupp et al. 2013). Guthery (1988) found he was able to estimate density walking line transects using distance sampling with relatively good precision (<20% CV) but had to expend a large amount of effort to achieve a sufficient number of detections. Researchers typically walk line transects at a rate of about 4.7km/hr or 17–23 minutes/km thus making large scale estimates too costly and time consuming (Guthery 1988). Shupe et al. (1987) and Rusk et al. (2007) found that line-transect distance sampling from a helicopter platform produced precise and efficient (cost and time) estimates of bobwhite density compared to other estimation methods (i.e., walked transects, point counts) in South Texas. Shupe et al. (1987) demonstrated that using helicopters for distance sampling costs less ($0.21/ha) than methods to obtain Lincoln Index estimates ($0.39/ha) and required less effort than Lincoln estimates and walk transects. Rusk et al. (2007) found a similar advantage in effort and cost per detection in helicopter surveys (48 km/hr, $13/detection) compared to walked transects (3 km/hr, $12/detection) based on effort needed to obtain the recommended 60 (Buckland et al. 2001) observations. Surveying from helicopters yielded similar density estimates to walked transects but allowed for a greater number of detections and increased precision (Rusk et al. 2007). Furthermore, researchers have optimized the use of technology in making distance estimates more accurate easier to collect in aerial surveys (Rusk 2006, Schnupp et al. 2013). Prior to the use of laser range finders and global position systems, observers visually estimated perpendicular distance (Shupe et al. 1987, Rusk et al. 2007) from the helicopter; however, visually estimating density at altitude can introduce bias. Schnupp et al. (2013) modified an electronic survey system that connected transect number, transect length, covey location, and covey size to their respective perpendicular distance estimate measured by a laser range finder. Measurement error from visual estimates was 4 times greater than the error rate from laser range finders when compared to known distances (Schnupp et al. 2013). The combined use of distance sampling, helicopters, and the electronic data collection system has improved the way researchers estimate bobwhite abundance in terms of precision, effort, and cost, particularly in South Texas. However, the validity of distance sampling estimates is dependent upon the fulfillment of several design and model-based assumptions and surveying from aerial platforms can present new challenges to assumption testing.

DISTANCE SAMPLING ASSUMPTIONS

The reliability of density estimates obtained through distance sampling is determined according to satisfaction of the following model based assumptions (Buckland et al 2001:30−34): "(1) Objects directly on the line or point are always detected (i.e. they are detected with a probability of 1, or $g(0) = 1$); (2) Objects are detected at their initial location, prior to any movement in response to the observer; and (3) Distances (and angles where relevant) are measured accurately (ungrouped data) or objects are correctly counted in the proper distance interval (grouped data)." The one designed based assumption of distance sampling is that animals are distributed randomly of the lines or points (Buckland et al. 2015). Satisfying this assumption is dependent upon placing line transects randomly across a survey area with respect to the species of interest. For example, transect lines should not be placed parallel to roads or fences where one would expect higher bobwhite detections to occur. Transects should also be placed so that they represent the entire study area, this way density can be appropriately scaled up from surveyed area (Buckland et al. 2001). Observers should be mindful of assumptions on the accuracy of cluster (covey) size and double counting, however, these assumptions can have less consequences on precision. For example, the accompanying distance sampling software, program Distance (Thomas et al. 2010), uses a regression estimator where cluster size is dependent on distance assuming that clusters are estimated correctly at $\hat{g}(0)$ only (Buckland et al. 2001). Furthermore, detecting the same objects on more than one line should not create bias if the movement occurred independently of the observer (i.e., movement due to foraging; Buckland et al. 2015).

Meeting Assumptions During Aerial Surveys

For bobwhites, researchers have dedicated efforts to determine if counting bobwhites from an aerial platform (Rusk et al. 2007, Schnupp 2009) and regular walk-transect surveys (Guthery 1988) could be used to satisfy the model-based assumptions of distance sampling as well as attempted to empirically test the first assumption.

Often, if researchers expect the first assumption of distance sampling to be violated (i.e., $g(0) < 1$), double observer or mark-recapture distance sampling is recommended (Nichols et al. 2000, Buckland et al. 2001). These methods mitigate the necessity of satisfying the first assumption because they depend on independent counts from 2 individual observers, which provides a direct measure of objects not detected (Thompson 2002). However, double observer sampling from a helicopter platform with the electronic system is not feasible in this study due to the specifics of the aerial survey (discussed further in the Chapter II). If conventional distance sampling is used, surveys that incorporate empirical estimations of $g(0)$ can include them as a correction factor in their estimates. However, few studies have estimated *g(0)* in the field (Bachler and Liechti 2007). In a literature review by Bachler and Liechti (2007) out of 28 studies utilizing distance sampling to estimate avian densities, none attempted to test *g(0)* =1. Instead, studies relied on the argument that *g(0)* =1 was validated by their study design or made other assumptions without empirical support (Bachler and Liechti 2007). Shupe et al. (1987) anecdotally validated the first assumption based on the bobwhite's instinct to freeze initially in response to an aerial predator and fly or run to a more secure cover only when the predator appears to be making a direct approach (Mueller 1976). Thus, flying at a low altitude and slow speed with the helicopter simulates an approaching aerial threat and should trigger flushing behavior (Shupe et al. 1987). While this reasoning describes why coveys should be detected, it does not explain how observers assess whether all objects on the line are detected. Often missed detections on the line may be the result of visual obstruction below the helicopter fuselage or bobwhite movement prior to detection resulting in underestimates at 0 distance (assumption 2). Empirical measurements of $\hat{g}(0)$ can be achieved by radio marking objects so a known detection rate can be calculated. Rusk et al. (2007) and Schnupp (2009) achieved an empirical $\hat{g}(0)$ estimate of 0.70 and 0.94, respectively, indicating detection on the line can be variable with aerial surveys. Radio marking and flight trials can be a costly and time-consuming method to employ for researchers looking to estimate density. There is potential for the use of digital survey methods to help observers account for detection on the line; I will explore this topic in Chapter II.

According to Buckland et al. (2001), satisfying the second assumption should be tangible so long as object movement (1.5–2.7 km/hr for bobwhites) is slow relative to observer movement (37 km/hr, helicopter). Animal movement after detection (i.e., a covey flush) is not a problem as long as the distance to the original location of the cluster is measured (Buckland et al. 2001). While this is true for bobwhites, the assumption can be violated if bobwhites run undetected prior to flushing or are detected when running and their initial origin cannot be determined. Rusk et al. (2007) noted running in 2 of the 6 coveys not detected by the helicopter observers. Evaluating this assumption is often accomplished through detection of lateral movements in frequency distributions (Guthery 1988, Schnupp 2009) and observer training to detect objects at their initial point of flush. When using walk line transects, Guthery (1988) observed no lateral movement in the frequency distributions in 26 of 29 surveys but noted running over flushing behavior in areas with sparse cover. Schnupp (2009) determined presence of movement through heaping in frequency distribution bins outside of the first bin in 4 out of 8 surveys. While evaluating histograms can allude to lateral movement, it does not empirically test the assumption of responsive movement, this may be better addressed with marked birds or digital aerial survey methods (discussed in Chapter II). The third assumption is most easily met through use of laser rangefinders. Range finders are preferable to visual estimations because measurement estimates are often rounded by observers (Rosenstock et al. 2002, Rusk 2006; Schnupp et al. 2013).

As previously mentioned, counting the same covey on 2 different transect lines is only an issue when the covey movement was caused by the observer. The use of helicopters to count bobwhites can inherently create a flushing response to the observer; whether or not these coveys fly to the next un-surveyed transect is unknown without the aid of marked birds. Increasing transect spacing (> 400 m) has been suggesting mitigating double counting (Shupe et al. 1987, Guthery 1988, Rusk et al. 2007, Schnupp 2009). Average covey flight distance was estimated as 157.4 ± 71.5 m (Perkins et al. 2014) after a flush response to humans and predators (avian and mammalian). Given covey flight distance and that detections from the helicopter are typically made out to 100 m of the transect line, conducting surveys at 400 m would likely reduce double counting, but may also reduce survey effort. The flush distance of coveys and occurrence of double counting has not been evaluated for bobwhites with helicopter surveys. I will explore the differences in bobwhite density estimates and number of detections from surveys conducted at 400 m and 200 m transect spacing in Chapter II.

MONITORING IMPACTS WITH DISTANCE SAMPLING

Bobwhites are valued among sportsmen and conservationists due to the cultural and economic benefits associated with hunting (Hernández and Guthery 2012). The bobwhite's ecological significance is equally as important due to their association with a wide range of grassland bird assemblages (Church et al. 1993, Crosby et al. 2015). Crosby et al. (2015) recently demonstrated that bobwhites are commonly associated with grassland species of concern such as the grasshopper sparrow (*Ammodramus savannarum*) and dicksissel (*Spiza americana*). While bobwhites are often more abundant than other grassland bird species, bobwhite populations throughout the southeastern United States are experiencing similar distribution wide declines mainly due to loss of open and semi-open vegetation communities (Brennan 1991, Sauer et al. 2014, Crosby et al. 2015). Understanding how alterations in the environment affect bobwhite abundance can have implications at a large economic and ecologic scale, and thus accurate estimations of their density (i.e., through distance sampling) are necessary for assessing management success.

Cattle Grazing and Bobwhite

With habitat loss being the ultimate cause of quail decline (Hernández et al. 2013), relatively large areas of suitable habitat, at least 400–2,000 ha in size, are of particular importance to bobwhites (Brennan et al. 2007). Approximately 53 million ha in Texas are devoted to working lands (i.e., farm and ranch) with a great majority of large ranches (>810 ha) occurring in South Texas (Texas Land Trends 2014). South Texas has a long history of cattle grazing driven by market demand for beef and tradition in ranching culture and family legacy (Hanselka et al. 1991, Ortega-S and Bryant 2005). However, the growing human population in South Texas threatens the status of these large contiguous ranches with high rates of fragmentation into smaller ownerships and conversion to urban areas (Texas Land Trends 2014). Large unfragmented blocks of native rangeland across the landscape has been suggested to decrease vulnerability of local extinction for bobwhites as well as increase probability of reformation for small vulnerable coveys (Guthery 2000, Williams et al. 2004). Over the past few decades, a shifting economic climate has prompted many cattle ranchers to diversify their income by incorporating fee lease hunting for bobwhites (Hanselka et 1991, Rowan and White 1994). Supplementing the cost of cattle operations with income from bobwhite hunting is an attractive alternative to fragmenting and selling large ranches and has the added benefit of large-scale conservation given the appropriate management practices are used.

Previous research explaining the interactions between grazing systems and bobwhite population response in Texas have yielded a myriad of results. Changes in vegetation structure caused by grazing and the subsequent response by bobwhites are the most commonly measured variables (Hammerquist et al. 1981, Campbell-Kissock et al. 1984, Schulz and Guthery 1988, Baker and Guthery 1990, Wilkins and Swank 1992).

Continuous grazing systems minimize input from a management standpoint (Holechek 1983) and allow cattle greater access to preferred plants, potentially maximizing performance and economic return (Baker and Guthery 1990; Hernández and Guthery 2012). Baker and Guthery (1990) evaluated vegetation and bobwhite density response to continuous grazing at 2 stocking densities. They concluded their treatments had a depressing or neutral effect on bobwhite density. However, because they did not include pre-grazing densities of bobwhites and vegetation parameters, the effects of treatment were confounded with the speculation that the habitat was of marginal quality to begin with.

Rotational systems are often regarded to be more beneficial to game birds because they provide relief in grazing during nesting (Holechek 1983; Krausman et al. 2009). Short duration grazing (SDG) was evaluated frequently in the 1980's for its potential to accelerate new growth, improve cattle performance, and cease brush encroachment (Savory and Parsons 1980). Researchers in Texas reported SDG as more beneficial for bobwhites than continuous grazing because high stocking rates with fast turnover increase cover of bare ground and forb and decrease cover of dense grass and litter (Hammerquist and Crawford 1981, Campbell-Kissock et al. 1984, Schulz and Guthery 1988, Wilkins and Swank 1992). Schulz and Guthery (1988) and Wilkins and Swank (1992) were able to show improvement of bobwhite densities with SDG with advanced methods of population estimation; however, neither measured densities prior to treatment implementation. Despite the extensive research, managers seldom recommend SDG because an inadequate understanding of the process combined with a lack of involvement by the rancher can cause range deterioration due to heavily stocked paddocks (Savory and Parsons 1980).

Few of the mentioned studies on bobwhites and grazing were able to attain sufficient sample sizes at a geographic scale large enough to assess the effects of different grazing regimes on vegetation or density (Krausman et al. 2009), most likely because they were constricted logistically and financially. Additionally, much of the completed research has been based on population indices (Hammerquist et al. 1981, Campbell-Kissock et al. 1984) or involved walk-line transects on a small spatial scale (Schulz and Guthery 1988, Baker and Guthery 1990). A potential improvement for assessing and monitoring bobwhite response to grazing on a large spatial scale is utilizing distance sampling from an aerial platform such as a helicopter.

Current Research

The goals of my dissertation project were to monitor vegetation metrics and bobwhite density response to a 4-year grazing demonstration project (Fig. 1.1). I used line-transect distance sampling to estimate bobwhite density. My project was conducted on the East Foundation's San Antonio Viejo Ranch in Jim Hogg County, Texas on a 7,689-ha pasture complex called the Coloraditas Grazing Research and Demonstration Area and 3 reference sites (1,200−1,600 ha) for comparison. The project included 2 years (2014, 2015) of bobwhite density surveys and 1 year (2015) of vegetation surveys prior to grazing treatments and 2 years (2016, 2017) of all surveys post grazing treatment. Grazing regimes included continuous and rotational, each divided into high (1 Animal Unit [AU]/20.8 ha) and low (1 AU/14.6 ha) stocking rates applied to 10 sub pastures of the Coloraditas Grazing Research and Demonstration Area. The chapters my dissertation provide (1) an assessment of distance sampling survey techniques and conditions for estimating bobwhite density, (2) a baseline of vegetation and bobwhite density estimates estimated through 4 years of a grazing demonstration project, and (3) an evaluation of the spatial distribution of density through time using density surface models.

Situation: The economy in South Texas is built around the cattle and hunting industry. While many ranches in South Texas are focused on improving bobwhite habitat for hunters, others operate to improve cattle productivity with hunting as a secondary priority. The East Foundation dedicated 7,478 ha to a grazing research and demonstration area on their largest property, the San Antonio Viejo Ranch, in Jim Hogg County, Texas in order to investigate changes to wildlife populations and vegetation structure from before to after grazing. The grazing treatments included a continuous and rotational grazing system each stocked at a high and moderate stocking rate. Additionally, I monitored 3 pastures outside of the demonstration for comparison. This large-scale study also allowed me to implement and develop monitoring recommendations for using distance sampling to estimate northern bobwhite density across grazing treatments and reference site pastures. The use of distance sampling methodology improves upon the precision of density estimates and the efficiency of collecting this information on large areas.

INPUTS	**OUTPUTS**		**OUTCOMES**		
What we invest	**What we do**	**Who we reach**	**Knowledge**	**Actions**	**Conditions**
• University Faculty • Graduate Students • Undergraduate students • Field technicians • Ranch Staff • Land • Time • Money • Materials • Equipment • Technology • Previous research knowledge	• **Monitoring Bobwhite density before and after grazing using distance sampling** • Helicopter surveys for 4 years over 4 grazing treatments and 3 reference sites for annual bobwhite density estimates • Assessing replicate surveys and different levels of transect coverage • Evaluating use of video surveys in distance sampling • **Monitoring vegetation before and after grazing over 4 grazing treatments and 3 reference sites** • Measuring residual forage before grazing and at each rotation • Measuring vegetation structure and composition each fall • Measuring forage inside and and outside grazing exclosures to calculate forage utilization each summer and fall	• Undergraduate student workers • Seasonal field technicians • Graduate students • Professors • Local land owners • Local ranch managers • Local cattlemen • Wildlife biologists • East Foundation partners	• Graduate students learn new skills, methods, and management techniques • Student workers and field technicians learn new skills that lead to future opportunities • Foundation receives information on current grazing practices (systems and stocking rates) • Foundation receives recommendations on bobwhite monitoring • Foundation acquires data to use in economic case studies on stocking and destocking • Add to knowledge on vegetation changes through grazing and drought	• Continue bobwhite monitoring using recommendations • Use forage information to set future stocking rates • Create management plans for stocking in drought • Use large vegetation dataset in future graduate or Foundation projects • Publish and present case studies on vegetation and cattle to lay audiences • Publish case study as wildlife monograph • Publish methods papers (distance sampling) • Use data to restructure grazing demonstration to answer new questions	• Regional knowledge on grazing system and stocking rate through drought and increased precipitation • Knowledge on effects of deferment after historic grazing • Documentation on what happens from an ecological standpoint when ranchers do not destock in a drought • Better information for managers conducting bobwhite surveys using distance sampling

Figure 1.1. Logic Model for the project: Monitoring Changes in Northern Bobwhite Density and Vegetation in a Grazing Demonstration Project in South Texas.

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CHAPTER II.

EVALUATION OF DISTANCE SAMPLING SURVEY EFFORT AND METHODS TO IMPROVE DENSITY ESTIMATES FOR NORTHERN BOBWHITES

ABSTRACT

Estimating density and abundance is central to wildlife conservation for planning and decision-making. Development of model-based techniques, such as distance sampling, allows researchers to estimate density based on detection probabilities. However, the reliability of estimates obtained through this method is dependent upon the satisfaction of underlying assumptions, the most critical being that observers detect objects on the line with 100% certainty. Over the past 20 years, the use of conventional distance sampling, where observers traverse line transects from an aerial platform, has proven to be a method that is reliable, efficient, and commonly used to estimate northern bobwhite (*Colinus virginianus*; hereafter bobwhite) density over large areas of rangeland vegetation. However, aerial surveys can complicate the ability to meet the assumption of detecting 100% of the target objects on the transect line. Testing this assumption can be time-consuming and challenging to implement for each annual survey replication. Furthermore, anecdotal evidence suggests flying aerial surveys at different times of day and under different weather conditions can affect detectability, which can lead to biased density estimates if not adequately addressed. I attempted to improve upon the precision of density estimates derived from aerial surveys for bobwhites by (1) evaluating the efficacy of digital methods to address missed detections of birds flushing behind the helicopter and (2) evaluating covariates that were potentially affecting the detection function. Assessing these two points provides a basis to make survey recommendations based on weather conditions, time of day, and level of observer experience. Additionally, I evaluated changes in the precision of bobwhite density at various

levels of survey coverage, the number of transects surveyed is directly related to variance estimation as well as survey cost. From December 2014 to 2017, I flew 2,641 km of line transects and detected 2,333 coveys across 12,054 ha of rangeland in on the San Antonio Viejo Ranch in Jim Hogg County, Texas. I detected 1 pair of bobwhites that flushed on video footage unnoticed by observers. These results indicated that when coveys flushed (1) they rarely flushed behind the helicopter and (2) the helicopter flew at the proper speed and altitude to detect late flushes. Observer experience was the top covariate in explaining detection probability where detection on the line was < 1.0 for observers with low (<10 days) experience. Detection probability was ~60% higher for observers with high experience compared to low experience. Cloud condition did not affect detection at 0 distance, but observers detected coveys at further distances ($\bar{x}$ = 4 m) on clear (0% cloud cover) compared to overcast days (100% cloud cover). Based on the results of simulated surveys at < 100% coverage and empirical surveys conducted at 100 and 50% coverage, I do not recommend surveying for bobwhites with less than 50% coverage in South Texas. On small pastures and during years of low expected density, I recommend replicating surveys at 50% or surveying at 100% coverage. Satisfying the first assumption of distance sampling from an aerial platform is difficult and seldom empirically estimated; digital survey methods may provide a pathway to reducing observer sampling error without sacrificing exact measured distances. These recommendations are based on surveys conducted at the juncture of the Coastal Sand Sheet and Tamaulipan Thorn Scrub ecoregions in South Texas and need to be tested and evaluated in other arid and semi-arid rangeland systems.

INTRODUCTION

Monitoring and manipulative studies of animal populations depend on accurate and precise density and abundance estimates to detect changes in estimated abundance over time. Distance sampling techniques are used in these studies because they account for objects unseen by the observer and provide average density estimates along with associated measures of variability for a survey. Line transect distance-sampling uses the observed perpendicular distances from the detections (x) to the transect (0) to estimate detection probability (Laake et al 2008). There are 3 fundamental assumptions that determine the reliability of density estimates and associated variance measurements obtained through distance sampling (Buckland et al. 2001). These assumptions, summarized from Buckland et al. (2001) are: (1) objects directly on the line or point are directed with 100% certainty, or a probability of 1, where $g(0) = 1$; (2) objects are detected at their initial location and do not move in response to the observer; and (3) distances are measured accurately. In addition to meeting the assumptions of the survey procedure, consideration in survey design is also paramount to deriving reliable statistical inference from these estimates (e.g., random placement of lines or points with respect to the distribution of the objects and environmental gradients). Additionally, Buckland et al. (2001:232) recommended that surveys contain a minimum of 10–20 lines/stratum for adequate variance estimation of the encounter rate and the number of degrees of freedom to calculate confidence intervals. While detection functions can be adequately fit to most line transect data, a minimum of 60–80 detections are recommended to estimate density reliably (Buckland et al. 2001).

Failure to satisfy the first assumption leads to difficulties when modeling the detection and density estimates that are biased low (Buckland et al. 2001; Bachler and Liechti. 2007). Several studies have evaluated the use of line transect distance sampling with northern bobwhites (*Colinus* *virginianus*; hereafter bobwhite). Often these studies tested the feasibility of satisfying the 3 key assumptions (Guthery 1988, Rusk et al. 2007, Schnupp 2009) as well as obtaining the minimum amount of detections from various platforms (e.g., helicopter, vehicle, walking). Of these studies, Rusk et al. (2007) and Schnupp (2009) used methods that allowed the direct estimation of the detection function ($g(x)$) at 0 distance ($g(0)$). Estimating $g(0)$ must be evaluated through addressing both perception bias (when observers fail to detect animals at 0 distance even though animals are present) and availability bias (when animals are unavailable for detection; Marsh and Sinclair 1989). Perception bias occurs when observers miss visible animals because of environmental conditions, fatigue and-or distance (Laake et al. 2008). Availability bias, while much more difficult to address, can be estimated through radiomarked birds as the marked samples indicates presence when visibility is obstructed (i.e., diving marine mammals and seabirds or songbirds in dense canopy; Buckland et al. 2015). Both Rusk et al. (2007) and Schnupp (2009) estimated the detection probability at $\hat{g}(0)$ by surveying with radiomarked birds over several trials from a helicopter platform. Rusk et al. (2007) estimated $\hat{g}(0)$ = 70% and Schnupp (2009) determined that observers were correctly able to detect a covey at $\hat{g}(0)$ 94% of the time out of 92 trails.

Subsequent aerial surveys used to estimate bobwhite density have assumed assumption 1 is met in their analyses based on the results of Rusk et al. (2007) and Schnupp (2009). However, adverse weather, thick brush, or an inexperienced observer may alter the results expected under ideal conditions. When observers are unsure or unable to satisfy the first assumption, Buckland et al. (2001) recommend Mark-recapture distance sampling (Laake and Borchers, 2004; Borchers et al. 2006), which allows relaxation of this assumption. Surveys analyzed through mark-recapture distance sampling can be conducted in a trial-observer or independent-observer configuration

(Buckland et al. 2015). In an independent-observer configuration, the detections made by one observer (or group of observers) are entirely independent of a separate observer. As observers make no permanent marks during distance sampling, the resulting analysis must be able to identify duplicate detections that qualify as “marks” by one observer as “recaptures” by another and model independent detection functions for each observer (i.e., full-independence models, Buckland et al. 2015).

The development of the electronic system (Schnupp et al. 2013) coupled with a helicopter platform has provided a solution to counting bobwhites over large areas of rangeland vegetation with accurate distance and location measurement. However, the helicopter must hover to measure perpendicular distances with rangefinders accurately. Hovering removes any independence between the groups of observers necessary in the independent-observer configuration for mark-recapture distance sampling. Independence requires constant movement by the helicopter and, as a result, for observers to visually estimate distances. Visually estimating distance can introduce measurement error in estimates of exact locations or incorrect groupings in distance intervals (Schnupp 2009). The second option for mark-recapture distance sampling surveys is a trial-observer configuration. Here, the detections made by one observer set up trials for the second observer, but the second observer does not know the detections made by the first observer. Because conventional distance sampling only requires 100% detection at 0 distance, this configuration only requires the observer to set up trials for detection on the line (Laake and Borchers 2004).

Video Surveys

A current proposed solution to the potential visibility biases in aerial surveys is the inclusion of high-resolution cameras mounted on aerial platforms (Buckland et al. 2015). Digital surveys using cameras to collect detection data with photographs and-or video have been employed to improve detection and reduce disturbance (i.e., response to observers) of water birds, offshore, over large tracts of open water (Burt et al. 2009, Hexter, 2009). Current methods include using a series of video cameras to survey large strips and estimating density via plot sampling (i.e., where observers can make a complete count in the swath). In applying this technique to bobwhites, an altitude higher than 10 m would be necessary to count birds within a reasonable swath width (50 m); however, previous research has suggested the low altitude (<10 m) of the helicopter is necessary to elicit a covey flush (Shupe et al. 1987). Prior research has not tested the feasibility of counting bobwhites using cameras without observers in a strip transect. However, there is potential to combine digital surveys with trial-observer mark-recapture distance sampling by using the camera to set up trials for detection at $g(0)$ (E. Rexstad and L. Thomas, personal communications). This method would relax the assumption of 100% detection at $g(0)$ and still allow observers to measure exact distances and estimate covey size. The use of a video camera may also help address availability and perception bias at $g(0)$ given the resolution of the camera is sufficient enough to detect unflushed birds. Being that un-modeled heterogeneity is a more significant issue with mark-recapture distance sampling compared to conventional distance sampling (Buckland 1992), covariates other than distance must be included in the detection function (Laake et al. 2008). However, Laake (1999) introduced point independence models for mark-recapture distance sampling where independence at the line or point only needs to be assumed. In theory, point independence models are less sensitive to un-modeled heterogeneity, but will not produce reliable estimates with responsive movement (Laake and Borchers 2004).

Covariates Affecting Detection

Conventional distance sampling models the probability of detection as a function of distance alone and, under most circumstances, is not affected by un-modeled heterogeneity (Burnham et al. 2004; Buckland et al. 2015). This property is called pooling robustness and holds true if researchers can meet assumptions of conventional distance sampling and heterogeneity is not extreme (Buckland et al. 2015). However, there are situations where factors other than distance may affect the detection function and estimation of $g(0)$. For example, pooling robustness does not hold in cases of extreme heterogeneity (i.e., dense forest where calling behavior varies by sex), when using a pooled detection function to estimate stratum-specific density estimates, or when using mark-recapture distance sampling. As an alternative, Multiple-covariate distance sampling (Marques and Buckland, 2003) can be used to model detectability as a function of distance and covariates relating to individual objects, the environment, or the observer.

There are several recommended survey conditions to be aware of when counting bobwhites from a helicopter to maximize detectability. For example, researchers recommended surveys be conducted in early December during the first 3 hours after sunrise and the last 3 hours before sunset (DeMaso et al. 2010). DeMaso et al. (2010) also recommended conducting surveys during clear, cold (<26 °C) days with winds less than 6.7 meters/second (m/s). Surveying large areas (8,000 ha) at 100% coverage at the recommended survey speed and altitude (37 kilometers/hour [kph] at 10 m; Schnupp 2009) can take up to 10 hours of survey time including stops for fuel. With limited pilot availability and weather delaying full day or multiday surveys, it can be unrealistic to limit surveys to 6 hours. Additionally, cloud-free days can be infrequent or short-lived in December. Aside from time and weather conditions, detectability may differ most appreciably between or among observers (Marques et al. 2007). Experienced observers may be particularly important for low altitude helicopter surveys where an accurate location and covey count must be made in a short hover time (5–10 seconds) before the helicopter loses power and altitude. A nervous or inexperienced observer may be more inclined to rush detections leading to inaccurate counts or a misidentification of the initial detection location. Finally, landscapes in South Texas range in brush cover from closed and dense canopies in the Tamaulipan thorn scrub to open and patchy canopies on the Coastal sand sheet. Closed canopy brush interspersed with open areas may introduce heterogeneity in the detection function (Buckland et al. 2015) if bobwhites are difficult to detect where vegetation reduces visibility. Multiple-covariate distance sampling can be used to empirically assess the effect these covariates have on the detection function and validate recommendations and conditions for surveying bobwhites using distance sampling from a helicopter.

In addition to defining survey conditions for optimal detection, Schnupp (2009) determined that early December be the optimal time for aerial surveys. Depending upon the timing and extent of precipitation during the breeding season from April through September, surveys conducted in October or November may include juvenile birds from late hatches that may be difficult to detect (Brennan 2007, Schnupp 2009). Based on this recommendation, researchers and managers typically conduct a single survey on any available date in December (date differs according to pilot availability; personal observation). Average daily home range and movement for a post-fledging bobwhite brood in South Texas averaged 1.4 ha and 589 m (Taylor et al. 1994), and home range for coveys on an un-baited ranch from November to December averaged 13.03 ha (Haines et al. 2004). Given these small-scale movements, I would not expect changes in temporal variance between 2 samples taken within the same period (Underwood 2009). However, variation in survey conditions or an extreme weather event (above or below average temperature), may influence detection probability or even bobwhite density from day to day. Typically, researchers may replicate surveys within a single period to help achieve the recommended amount of detections and increase precision (Buckland et al. 2015). Data from these replicate surveys are not considered independent and are therefore pooled due to correlation in space (Buckland et al. 2001). As an alternative, including the survey number as a covariate in a multiple covariate distance sampling analysis and comparing it with a fully stratified and pooled detection function would allow for the determination if a difference in survey period affected detection (Akaike's Information Criterion [AIC]; E. Rexstad, personal communication). Additionally, a (Z-test) for independent samples tests the differences in density between estimates when there are enough detections to fit separate detection function to each survey.

Survey Coverage

An underlying assumption nested in the design of a distance sampling survey is that there is sufficient survey effort (at least 10–20 lines) to detect the minimum amount of detections (60–80; Buckland et al. 2001). Buckland et al. (2001; 2015) recommended conducting a pilot survey to determine the amount of effort needed to obtain a target coefficient of variation (CV <20% for bobwhites; Guthery 1988), and a higher amount of survey effort translates to a higher survey cost. Aerial surveys for both research and management objectives that use distance sampling to estimate bobwhite density are often flown at a transect spacing of 400 m between lines to reduce the chance of double counting and to keep survey costs low (DeMaso et al. 1992, Shupe et al. 1987, Rusk et al. 2007). General wildlife surveys often neglect the minimum amount of detections needed and target precision desired by assuming this level of effort is sufficient across all areas.

Survey coverage is expressed as a percentage of the total area covered in a survey and defined as the distance between adjacent transects. For example, 50% coverage translates to 400 m transect spacing (200 m strip on either side of the centerline) and observers typically survey out to 100 m. Surveys designed at higher coverage (100%) cover more area (200 m spacing) and thus cost more to conduct; however, this may be at the cost of reliability and precision.

Increasing strip width (decreasing survey coverage) can potentially translate into fewer transects and decrease the potential to obtain a sufficient sample size. Surveys conducted at 50% coverage can be flown multiple times to acquire the number of detections needed. However, for the same amount of effort, more transects can be flown resulting in an increased spatial coverage, improved estimates of encounter rate variance, and better conformation to the assumption of a uniform animal distribution with respect to the line placement. Additionally, for birds in clusters (such as bobwhites in coveys), wider spaced transects increase the difficulty to accurately count individuals at further distances (Diefenbach et al. 2003). Complete survey coverage (100%) may be necessary to reach these minimums in years when populations are lows, or in areas with poor visibility, and in small areas. Scant empirical information exists on how survey effort choice affects estimates and variation.

During my study, I estimated bobwhite density with line-transect distance sampling from a helicopter as a part of a long-term study on grazing and monitoring wildlife populations. The objectives of this chapter include:

1. Using video cameras to evaluate missed detections (a) behind the helicopter, and (b) on the line (flushing bobwhites only);
2. Using 4 years of survey effort to evaluate covariates affecting the detection function;
3. Evaluating the precision (standard error (SE), coefficient of variation (CV) and 95% confidence intervals (CI)) of bobwhite density estimates at (a) randomly simulated survey coverage between 90% and 10% for 2014 and 2015, (b) at surveys of 50% and 25% manipulated from a surveys at 100% for 2014 and 2015, and (c) from actual surveys flown at 50% compared to combined estimates at 100% for 2016 and 2017, and

4. evaluating the repeatability of estimates and effect of coverage on 2 single surveys at 100% in 2015, and 2 single surveys at 50% coverage in 2016 and 2017 on a) pooled and b) stratum-specific density estimates (i.e., treatments and pastures from the long-term grazing study).

For the first objective, I hypothesized that bobwhite coveys would not flush behind the helicopter indicating the altitude and speed of the survey is sufficient to elicit a covey flush upon approach. Additionally, I hypothesized that all bobwhites recorded flushing on the line would be detected by observers. For the second objective, I hypothesized that weather, time of day, and brush covariates would not influence detection (i.e., pooling robustness holds); however, detection on the line will be <1 for inexperienced observers (<10 days' experience). For the third objective, I hypothesized that density estimates below the simulated 50% coverage would be less precise due to lack of sufficient detections, but density and precision estimates would be similar between 100 and 50% simulated surveys pooled over sub strata (2014 and 2015) and similar between 100 and 50% flown surveys pooled over sub strata (2016 and 2017). For the fourth objective, I hypothesized there would be no significant difference in detection and density between replicated surveys within a year pooled across sub strata; however, density and detectability would change between 2 surveys on individual stratum where < 60 detections were made. This research provided the basis for density estimates used in monitoring changes by treatment and year in a long-term grazing demonstration project (Chapter III).

STUDY AREA

My study was conducted in 2 areas on the East Foundation, San Antonio Viejo Ranch (SAV; 60,298 ha) in Jim Hogg County, Texas: (1) Coloraditas Grazing Research and Demonstration Area (7,689 ha treatment pasture), and (2) 3 pastures ranging in size from 1,200 to 1,600 ha south of the Coloraditas Grazing Research and Demonstration Area (reference sites) (Fig. 2.1). The Coloraditas Grazing Research and Demonstration Area was divided into 4 grazing treatments beginning in December 2015: continuous system at moderate stocking rate (1 Animal Unit [AU]/20 ha), continuous high (1 AU/14 ha), rotational moderate, and rotational high; Fig. 2.1). The San Antonio Viejo ranch is located 32 km South of Hebbronville, Texas and is part of the collection of properties that make up the East Foundation. The property was previously a family-owned ranch with a history of intense grazing and ranching activity dating back to the early 1900s. This ranch lies within the South Texas Plains Ecoregion (Gould 1960). The 30-year average annual precipitation on the ranch is 53.6 cm (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 April 2018). Based on 30-year normal, average temperatures are between 12 and 13 °C in January and 27–30 °C in July (PRISM 2018). Elevation ranges from 52 m on the eastern edge to 64 m on the western edge of the ranch. The Coloraditas Grazing Research and Demonstration Area and reference sites lie within the Coastal Sand Plain and Texas-Tamaulipan Thorn scrub ecoregions (Omernik 1987). There are 6 different ecological sites on the Coloraditas Grazing Research and Demonstration Area of which 3 (Sandy PE 25-44, Loamy Sand PE 19-31, Red Sand Loam PE 19-31) make up 95% of the area. The same 3 range sites comprise 83% of the reference sites. Woody plant communities on the study areas are dominated by honey mesquite (*Prosopis glandulosa*), huisache (*Acacia farnesiana*), brasil (*Condalia hookeri*), granjeno (*Celtis pallida*), and prickly pear (*Opuntia* spp.). Seacoast bluestem (*Schizachyrium scoparium var. littorale*), purple threeawn (*Aristida purpurea*), Lehman lovegrass (*Eragrostis lehmanniana*), spotted beebalm (*Monarda fruticulosa*), and woolly croton (*Croton capitatus*) dominate the herbaceous plant community. Tanglehead (*Heteropogon contortus*) was only present on <3% of the total area in 2014.

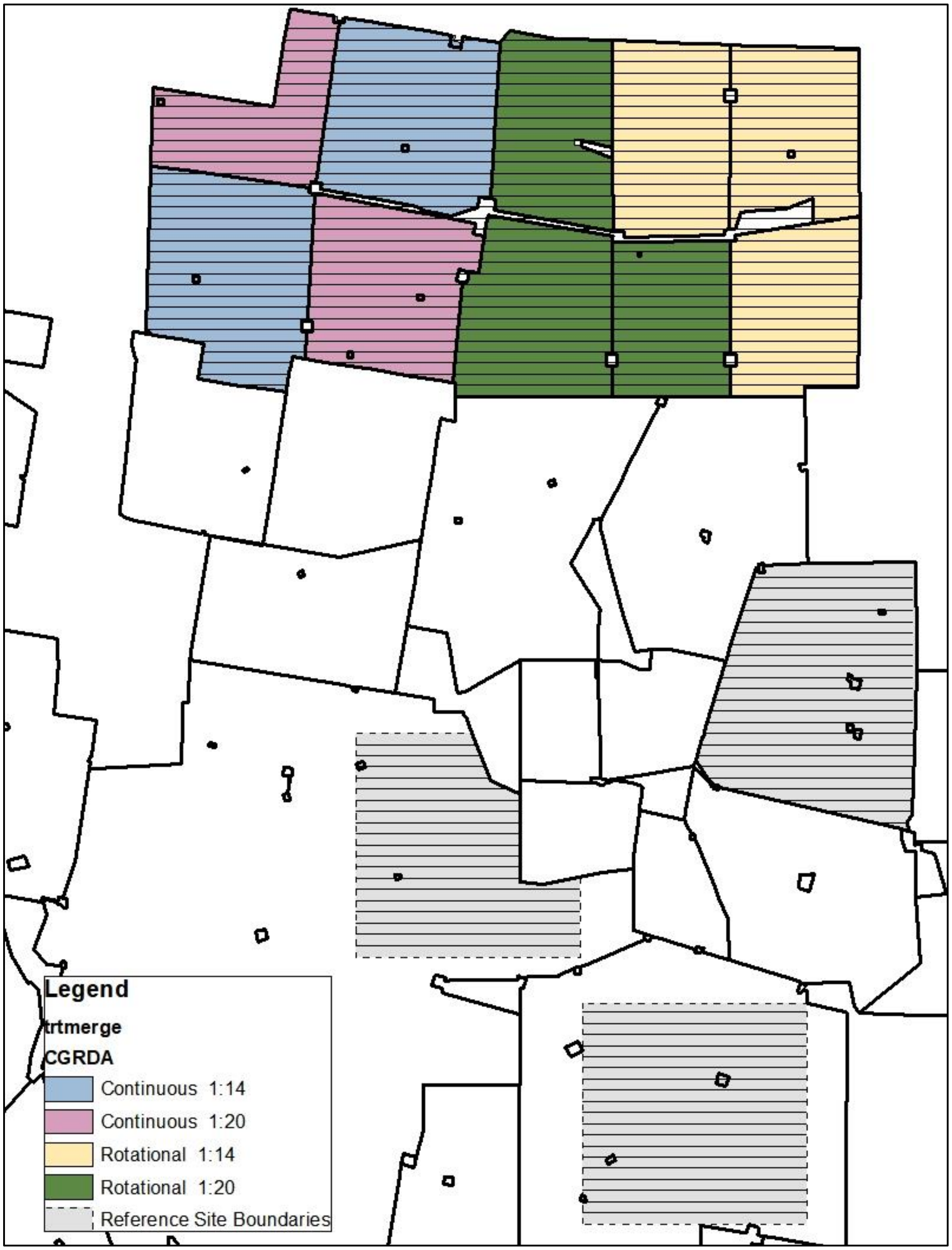

Figure 2.1. Map of the Coloraditas Grazing Research and Demonstration Area and 3 reference site boundaries and line transects on the San Antonio Viejo Ranch in Jim Hogg County, Texas, USA, 2014–2017. The grazing treatments for the long-term study on the Coloraditas Grazing Research and Demonstration Area are shown in color.

Defining the bobwhite population.—The South Texas region is approximately 8,080,000 ha where more than 4,7000,000 ha of rangeland has been classified as habitat that will support a wild bobwhite population (Brennan 2014). I define the bobwhite population in this study as the sample population of bobwhites in South Texas within the Coloraditas Grazing Research and Demonstration Area and reference site pasture boundaries on the San Antonio Viejo Ranch from 2014 to 2017.

METHODS

Transect Design

Distance sampling assumes that animals are distributed uniformly with respect to the transect placement. Therefore, I used a systematic set of parallel lines placed randomly (i.e., randomly across habitat gradients and roads) across the both the Coloraditas Grazing Research and Demonstration Area and 3 reference sites. Using the fishnet tool in ArcMap 10.4.1 (Environmental Systems Research Institute [ESRI], Redlands, CA), I spaced transects 200 m apart oriented East–West (Fig. 2.1). I evaluated the design using aerial imagery to ensure transects were not running with gradients (i.e., following brush lines, roads, fence lines). Prior to flight, I electronically numbered transects and uploaded them on a Garmin Nuvi 52 LM (Garmin Corp, Lenexa, KS) using Mapwel 11.0 (BALARAD, Slovak Republic, EU) to ensure accuracy of coverage by the helicopter pilot.

Aerial Surveys

Survey execution was consistent for each of the surveys flown during December (2014 to 2017). I conducted a single survey of all transects 3–5 December 2014 at 100% coverage; however, I replicated 2 surveys at 100% coverage in 6–19 December 2015, 1 survey at 100% in 7–17 December 2016 and 5–14 December 2017 where even numbered transects were flown for survey

1 (50%) and odd numbered transects for survey 2 (50%) so that 1 complete survey was flown over 2 time periods. No more than 10 days elapsed between any 2 survey events. Three observers (including myself) and the pilot traversed transects at a height of 7–10 m and a velocity of 37 kilometers/hour [km/hr] (as recommended by: Rusk et al. 2007, Schnupp 2009, Schnupp et al. 2013) using an R-44 helicopter (Rio Grande helicopters, Laredo, TX) in sequential order with a random start point. I followed the search and survey protocol developed by Schnupp Consulting LLC (Distance workshop, Kingsville, TX) where one front seat observer scanned the area directly in front of the helicopter to the door frame of the back seat and the 2 back seat observers scanned the area from the door frame to the tail rotor. The pilot also made detections when he was able to but was not considered an observer.

When a covey was detected, the helicopter moved into a hover perpendicular to the transect line, the back-seat observers took a reading of range, azimuth, and inclination with a laser rangefinder (Trimble Laser Ace 1000, Trimble Navigation Ltd, Sunnyvale, CA) at the initial point of detection. The laser rangefinder was linked to a Juno handheld unit (Trimble Juno 5 series handheld, Trimble Navigation Ltd, Sunnyvale, CA) via Bluetooth. The Juno recorded and stored the following information: observer positions and names, date, time of detection, survey region, transect number, transect length, covey location (x, y), covey size, and the range, azimuth, and inclination of each detection via the CKWRI Wildlife Survey Database application (Schnupp Consulting, LLC, Kingsville, Texas). I mounted a Trimble Enhanced Patch Antenna (Ram Mounts, Seattle, WA) to the frame of the helicopter door to ensure continuous global positioning system (GPS) signal for the Juno handheld unit. Upon survey completion, I uploaded the data stored in the Juno into CyberTracker (CyberTracker Conservation NPC, Cape Town, South Africa). At data import, each covey location was stored at the helicopter's position at the time of detection. CyberTracker uses the information collected by the laser range finder (range, azimuth, and inclination) to calculate the location of the covey.

Due to lack of observer availability in 2014, I had 3 pairs of different observers who collected data in the back seats of the helicopter. From 2015 to 2017, I held the back-seat observers constant between each survey period within a year. Backseat observers were consistent between 2015 and 2016 but changed between 2016 and 2017. Prior to each survey season, I trained observers and familiarized them with the equipment. Observers were prompted to locate the initial point where coveys flush from and focus search effort so that 100% of coveys at 0 distance are detected. Due to our use of laser range finders, I did not need to train observers in accurate distance estimation.

I collected covariate data post hoc to use in a multiple covariate distance sampling analysis. From the data stored in CyberTracker, I converted the timestamp for each detection into a 24-hr continuous covariate corresponding to time of day. To determine observer experience for each detection, I calculated the cumulative number of days a pair of back seat observers had conducting distance sampling aerial surveys for bobwhites. I coded observers with no experienced as 0 and added days of experience with the completion of a full survey day. Experience days accumulated over each year for observers who worked multiple year surveys. I also used the date and time stamp from each detection to match weather conditions to each detection through the historical data explorer on weather underground (https://www.wunderground.com/). This database collects weather measurements in 20 min intervals throughout the day from a weather station located 26 km from the Coloraditas Grazing Research and Demonstration Area. These variables included temperature (°C), wind speed (m/s), and could cover as a factor (clear, scattered clouds, mostly cloudy, overcast, fog). I determined the percent of brush cover at each covey location (x, y) by extracting the values of percent cover from a percentage of landscape (PLAND) raster for brush using the values to points tool in ArcMap 10.4.1

Video surveys. — In 2015, I mounted 2 GoPro (Model Hero3+, San Mateo, CA) cameras angled at the tail rotor on either side of the helicopter door frames to observe whether coveys were flushing after the helicopter passed. I attached the cameras using 2 pilot-approved mounts (GoPro Roll Bar mounts, San Mateo, CA). I tested the battery life of the GoPros at varying levels of resolution and frame speeds by mounting cameras to a Polaris Ranger for the duration of unrelated field work. I recorded footage at and 60 frames/second (fps), so I could review footage at half speed. I faced cameras backwards with the objective that this information would indicate a visibility bias in my survey methods. If coveys waited to flush after a helicopter passed, I wanted to know if observers could still detect late flushes. I also wanted to test if the GoPros could detect bobwhites that both did not flush and were not detected by observers. Following the survey, I matched count data collected by observers inside the helicopter against video footage by converting the video start and end time into real time (GoPros are not enabled with a timestamp on screen). I indicated positive detections in the video when the helicopter turned 90° into a hover. I reviewed all footage using a monitor connected to the laptop. Any coveys in the footage that were passed by the helicopter, not detected (no hover or pause in the video), and not matched with a detected time stamp were considered a missed detection.

I could not record a complete survey in 2015 because the GoPros were severely limited by a 4-hour battery life. For each GoPro, I used a GoPro battery with back up BacPac© for 4 hours and then switched out the system with a single spare battery for a remaining 3 hours. However, failure to turn off cameras at fuel stops and off transect periods drained battery life and made matching detections time to video time more difficult. Alternatively, when observers turned cameras off, failure to turn them back on in unison made review and matching from each side difficult, particularly because there was no timestamp in the video.

In 2016, I purchased a FlightCam 360 (Flight Flix LLC, Maple Grove, MN) camera with an 8-hour streaming capability a single battery. I mounted the camera, facing forward, to the tow ball helicopter with a pilot approved R-44 Clamp with Vibration control (Vibex Ball Mount; Flight Flix LLC, Maple Grove, MN). I recorded footage at a resolution of 960 p to increase battery life and 60 fps for review at half speed. Because the FlightCam was enabled with an onscreen timestamp, I was able to match exact covey detection times from inside the helicopter to the video footage. The FlightCam also had a wider field of view than the GoPro and was advertised with better resolution. I used the methods described above to determine if a covey was detected or missed by observers during post survey reviews.

During this survey, the bolt that connected the camera to the tow-ball mount broke and had to be secured to the helicopter using bailing wire. As a result, I could not properly adjust the camera angle. The camera angle from this video made the calculation of survey area and distance to coveys impossible to calculate. Therefore, I could not determine detections on the line because I could not determine where the centerline was located. I also did not include a scale needed to convert pixel distance in the video to actual distance (see discussion). The battery was advertised to last for 10 hours at the settings I used; however, the battery died after <5 hours. For safety reasons, I did not collect any video during the second survey. I did not collect any video in 2017.

Analyses

All analyses focused on distance sampling and video survey data collected during aerial surveys each December (Fig. 2.2). Distance sampling data were evaluated with multiple

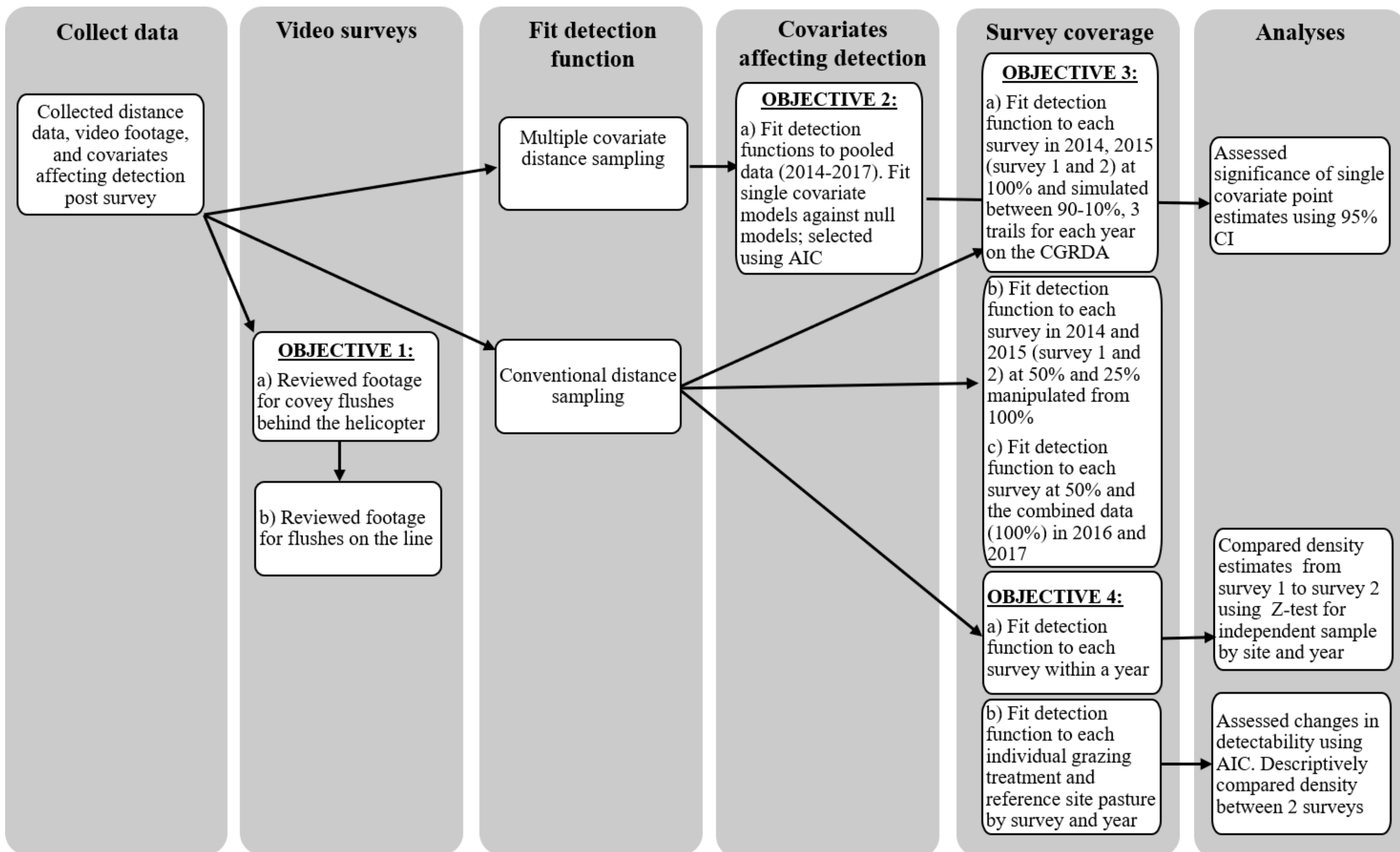

Figure 2.2 Analytic pathway for analyses involving northern bobwhite distance data related to research objectives involving (1) video surveys, (2) covariates affecting detection, and (3) survey coverage. CGRDA = Coloraditas Grazing Research and Demonstration Area.

covariate distance sampling to assess covariates affected detectability and conventional distance sampling to assess survey coverage. I pooled data from the Coloraditas Research and Demonstration Area and the reference sites in order to assess covariates affecting detection as covariate response, rather than site, to detection was the target. I separated the Coloraditas Grazing Research and Demonstration Area and reference sites to assess survey coverage because sites were separated spatially and contained a different number of transects.

Density estimation. —I used line transect data collected during aerial surveys to estimate bobwhite density on the Coloraditas Grazing Research and Demonstration Area (pooled across grazing treatments and by individual grazing treatment), and reference sites, (pooled across pastures and by individual pasture). To obtain a baseline estimate of bobwhite density at 100% coverage, I conducted analyses on each area by survey and year following conventional distance sampling methodology for line transects as outlined in Buckland et al. (2001) using Program Distance version 7.0, Release 1 (Thomas et al. 2010). Conventional distance sampling uses total transect length, number of detections (coveys), cluster size (covey size), and perpendicular distances (distance from transect to covey) to estimate density; abundance can be estimated if a survey area was included in the analysis. Detection probability (P_a) or the proportion of animals detected in the covered region (a), was estimated by fitting a detection function $\hat{g}(x)$ to the observed data and was modeled using the recorded distances (x) of detected animals from the line (Buckland et al. 2015). Where the curve was $g(x)$, detection probability was represented by the proportion of the area under the curve ($\mu = \int_0^w g(x)dx$) to the area of a rectangle (w; 1.0), where w is the truncation point and μ is the effective strip half-width (see Buckland et al. 2015:11). To empirically estimate $g(x)$, a probability density function ($f(x)$) was used where the area under the curve is 1.0, so that,

$$\hat{P}a = \frac{1}{[w.\hat{f}(0)]}$$

Conventional line-transect distance sampling estimates density for objects in clusters as,

$$\widehat{D} = \frac{n\hat{f}(0)}{2L} \times \hat{E}(s)$$

Where $\widehat{D}$ is estimated density, n is the number of coveys detected, $\hat{f}(0)$ is the estimated probability density function of observed distances at x = 0 distance, L is the total length of transects, and $\hat{E}(s)$ is the estimated mean cluster size.

I estimated bobwhite population density for all surveys using a 2-stage process. First, I examined histograms of the entire dataset partitioned into 10–20 groups to determine an appropriate truncation distance using R (Ver. 3.3.2, R Foundation for Statistical Computing, Vienna, Austria). I examined the resulting goodness-of-fit tests from different truncation distances and removed large gaps in distances where no detections were made. During this stage, I also evaluated histograms for indications of potential evasive movement, or bobwhites running away from the line and then flushing, indicated by spikes or large amounts of detections in the distance bins further from the line (i.e. when the curve is not strictly monotonically decreasing). As a rule, Buckland et al. (2001) recommends truncation where $\hat{g}(x)$ = 0.15 and Williams and Thomas (2006) recommends truncation where $\hat{g}(x)$ = 0.1 for line transects. Detections at large distances are generally not informative in modeling the detection function and can be difficult to model (Buckland et al. 2001).

Next, using the chosen truncation distance, I assessed data fit to several detection function models. I fit the following models recommended by Thomas et al. (2010): uniform key with cosine adjustments; half-normal key, individually, and with cosine and Hermite polynomial adjustments, respectively; and a hazard-rate key, individually and with simple polynomial adjustments. I selected the best fit models based on AIC where ΔAIC values were <2.00. Within these models, I chose a final model based on 3 goodness-of-fit tests (Kolmogorov–Smirnov [K-S], Cramer VonMises [CvM unif], and Cramer VonMises [CvM cos]) where $P > 0.05$. The K-S and CvM tests determine model fit based on $H_0 = 0$. Models where the difference between the estimated cumulative distribution and empirical distribution function is zero (Buckland et al. 2015) are indicated by $P = 1.00$. I reported all density estimates as density ($\hat{D}$) ± standard error (SE).

Covariates affecting detection. — I analyzed detections pooled across 2014–2017 and pooled across the Coloraditas Grazing Research and Demonstration Area and reference sites using the conventional distance sampling and multiple covariate distance sampling engine in Program Distance. The multiple covariate distance sampling engine extends conventional distance sampling to include both distance and one or more covariates (z) so that detection probability is estimated as

$$\hat{P}a(z_i) = \frac{1}{w}\int_0^w \hat{g}(x, z_i)dx)$$

And density is estimated as,

$$\hat{D} = \frac{1}{a}\sum_{i=1}^{n}\frac{1}{\hat{P}a(z_i)}$$

Where $\hat{P}a(z_i)$ is the estimated probability of detecting the *i*th object given that it is within w of the line and has the covariate values z_i (Marques et al. 2007).

I explored the relationship between distance data and 6 covariates (observer experience[experience], percent brush cover [PLAND], cloud cover [condition], temperature, wind speed, and time of day [hour]) using R. I selected a truncation distance using the same methods described in the previous section. For the null model, I ran a conventional distance sampling model (no covariates) with the following key functions and adjustments: Uniform with cosine adjustments, half-normal with no adjustments, and hazard-rate with no adjustments. Based on exploratory analyses, I included the following continuous covariates as factors in the analysis: experience, temperature, and hour. Observer experience as a factor had 3 levels: low (0–10 days), moderate (11–20 days), and high (> 20 days). Temperature as a factor had 4 levels: low (0–9 °C), moderate (10–19 °C), moderate-high (19–29 °C), and high (> 29 °C). Hour as factor had 3 levels: first (first 3 hours of daylight), last (last 3 hours of daylight), and midday (hours between the first and last). Additionally, I included condition (a factor covariate) as a continuous covariate where I coded clear with 1, scattered clouds with 2, mostly cloudy with 3, and overcast with 4. I ran each factor as a single factor analysis in the multiple covariate distance sampling engine each with a half-normal model with cosine adjustment and hazard rate key function and no adjustments. I used AIC to rank models and considered covariates that significantly improved AIC above the best fitting null model (conventional distance sampling) to affect detectability. I tested the point estimate of the top model of each continuous covariate for significance at $P \leq 0.1$, $P \leq 0.05$, and $P \leq 0.001$ by constructing 95%, 99% and 99.9% confidence limits around the point estimate.

Survey coverage. — For the 2014 and 2, 2015 surveys conducted at 100%, I used 2 methods to simulate lower levels of survey coverage. Because of the number of transects, covey detections, and continuity of the study site, I only used the Coloraditas Grazing Research and Demonstration Area for these methods. For the first method, I removed transects from the completed survey (100% coverage, 33 transects) at random in 10% accumulating intervals. I used a random number generator (www.random.org) to randomly arrange transect numbers and removed transects from the data in the sequential order generated from the random number output. I assessed detection probability ($\hat{p}$), Density ($\hat{D}$) ± SE, CV of Density (CV($\hat{D}$)), 95% CI, goodness of fit tests (CvM (cos), CvM (unif), and K-S) from 90% to 10% coverage in decreasing increments of 10%. For example, at 90% coverage, I removed 10% (n ~ 3) of transects (10% of 33) and analyze density from 30 transects, at 80% I removed 20% (n ~7) of the transects. I repeated this until only 10% of the original transects remained. I analyzed each level of survey coverage as an individual survey in that: (1) I used a truncation distance appropriate for that individual survey; and (2) I used AIC to select the appropriate model (detection function + key adjustment) for that individual survey. This entire process was repeated at random for 3 trials resulting in 18 individual surveys, 3 surveys at each of the 9 levels of coverage from 90 to 10%. For the second method, I created transects spaced at 50 and 25% coverage in ArcMap and re-analyzed the data using all the detections from the completed survey. At each 50 and 25% transect spacing, I used a spatial-join to match the detected coveys from the completed survey to new transects. This matched the new transect ID and length to the detection and recalculated a perpendicular distance (specifying nearest distance from point to line) in ArcMap. Like the first method, I analyzed each survey as an individual. This resulted in 8 individual surveys, 2 new surveys for each year at 100% (2014, 2015 (survey 1, survey 2, and the combined effort from survey 1 and 2). For the combined effort survey, I combined the 2 surveys from 2015 into a single analysis and doubled the survey effort (line length) for each transect (Buckland et al. 2001).

Since 2 survey periods each were conducted in December 2015, 2016, and 2017, I analyzed each survey within a year as a separate survey to obtain an independent $\hat{f}(0)$ for each survey year. This resulted in 6 surveys for each the Coloraditas Grazing Research and Demonstration Area (pooled across grazing treatments) and reference sites (pooled across pastures): 2 surveys at 100% in 2015, 2 surveys at 50% in 2016, and 2 surveys at 50% in 2017. I used a Z-test for independent samples (Buckland et al. 2001:85 eqn. 3.102) to test the hypothesis H_0: $\hat{D}_1 = \hat{D}_2$ or that the density from survey 1 was equal to the density from survey 2 within each year for the Coloraditas Grazing Research and Demonstration Area and reference sites, respectively. I tested for differences in the detection function using AIC in Program Distance by modeling each survey (1 or 2) as a separate stratum within a single analysis (site by year). A similar detection function was indicated by a pooled $\hat{f}(0)$ as the top model and a difference in detection function was indicated by a fully stratified $\hat{f}(0)$ for each survey as the top model. Additionally, within each year, I analyzed the 4 grazing treatments and 3 reference pastures as 7 individual analyses (Fig. 2.1). Within a single analysis I descriptively compared changes in density from survey 1 to survey 2 and used AIC to compare changes in detection function from survey 1 to survey 2 (e.g., 2015, continuous high survey 1 vs. 2015, continuous high survey 2) as described above.

RESULTS

Video Cameras

For 2015, I reviewed 12.56 hours of footage at half speed from both the left and right-side cameras from survey 1 and 8.13 hours of footage from survey 2. I identified one pair of bobwhites on camera missed by observers; this pair flushed 30 seconds after a separate detection was made. I suspect resolution of the GoPros were not sufficient enough to detect coveys that did not flush but could not document this empirically because either (1) no unflushed coveys were recorded or (2) all coveys flushed.

For 2016, I reviewed 4.78 hours of footage at half speed from the first survey at 50% coverage. The timestamp on this video made detection matching more reliable. On 5 occasions, I observed singles or pairs flushing shortly after a covey was detected (<5 seconds). On one occasion, I observed a miscount of the covey size recorded. I was able to correct the count using the video; however, it was rare that I was able to confirm counts in the video as individuals disappeared when the video was paused, or part of the covey flushed out of frame. There were no obvious flushes of large coveys missed by observers during the recorded survey. On 6 occasions, a single bird flushed outside of recorded covey detections (>60 seconds), but I could not make a positive ID on the species of bird either because of the poor resolution or because it flew out of the frame too quickly.

Covariates Affecting Detection

I detected 2,333 coveys from 2014 to 2017 pooled across all surveys and areas. All models satisfied goodness-of-fit tests (Fig. 2.3). An exploratory analysis of covariates revealed that covariates may influence detectability (specifically experience, cloud cover, and temperature; Fig. 2.4–2.8). The top model included distance and observer experience as a continuous covariate and was fit with a half-normal model with no adjustments (Table 2.1). The proportion of the variance in the density estimate from the detection function dropped from 33% in the best fitting null model (conventional distance sampling) to 13% in the top model that included experience as a covariate and to 11% in the model that included condition as a covariate. The next 3 best models included observer experience and observer experience as a factor. Other covariates above the null model included: condition (continuous and factor), temperature (continuous and factor), hour (continuous and factor), and wind; however, these models had a much higher (>40) ΔAIC than models including experience. Temperature (continuous and factor), hour (continuous and factor), and wind did not considerably improve ΔAIC above the null model. Percent brush cover (PLAND) did not improve detectability above the best fitting

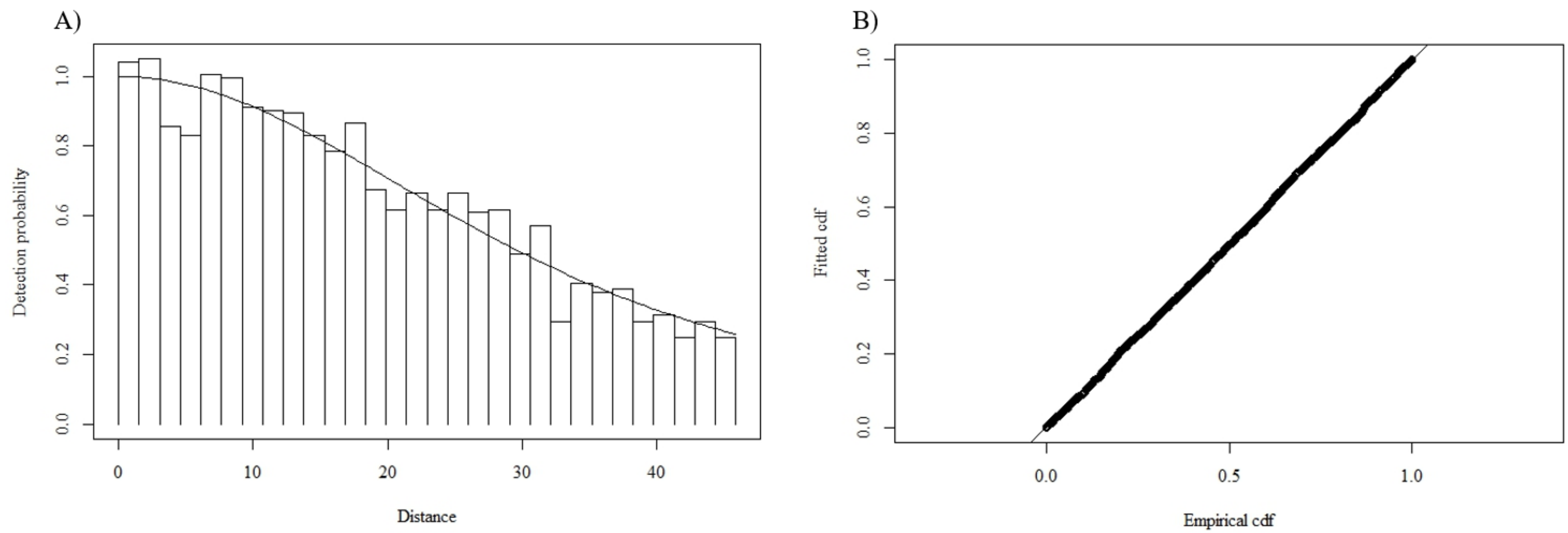

Figure 2.3. The estimated multiple covariate distance sampling detection function (A) and q-q plot (B), based on the best model and averaged over the observed covariate values for experience for 2,333 northern bobwhite covey detections made on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017.

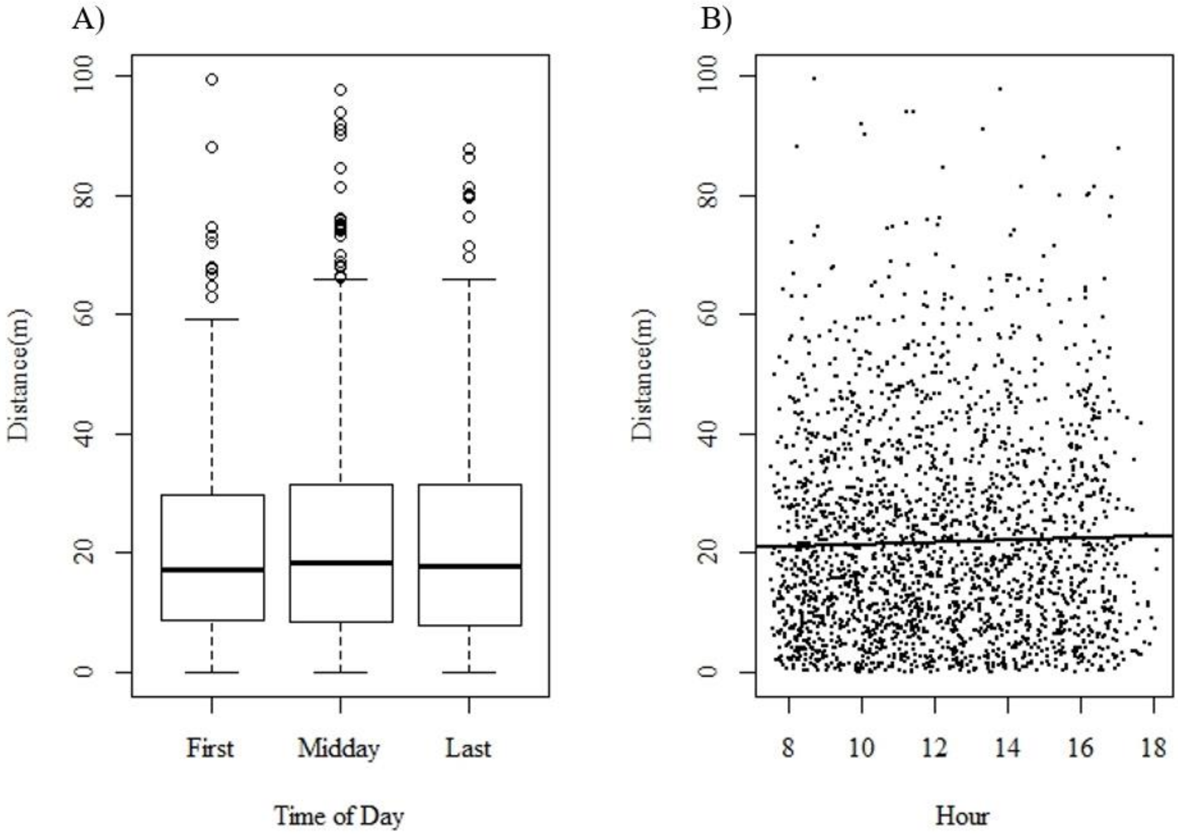

Fig 2.4. Exploratory analysis of the effects of time of day on distances for 2,333 northern bobwhite covey detections on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017. (A) boxplots of distances by hour (24-hour time scale) as a factor covariate (Hour F). (B) Scatterplot of distances as a function of hour (24-hour time scale) as a continuous covariate (Hour).

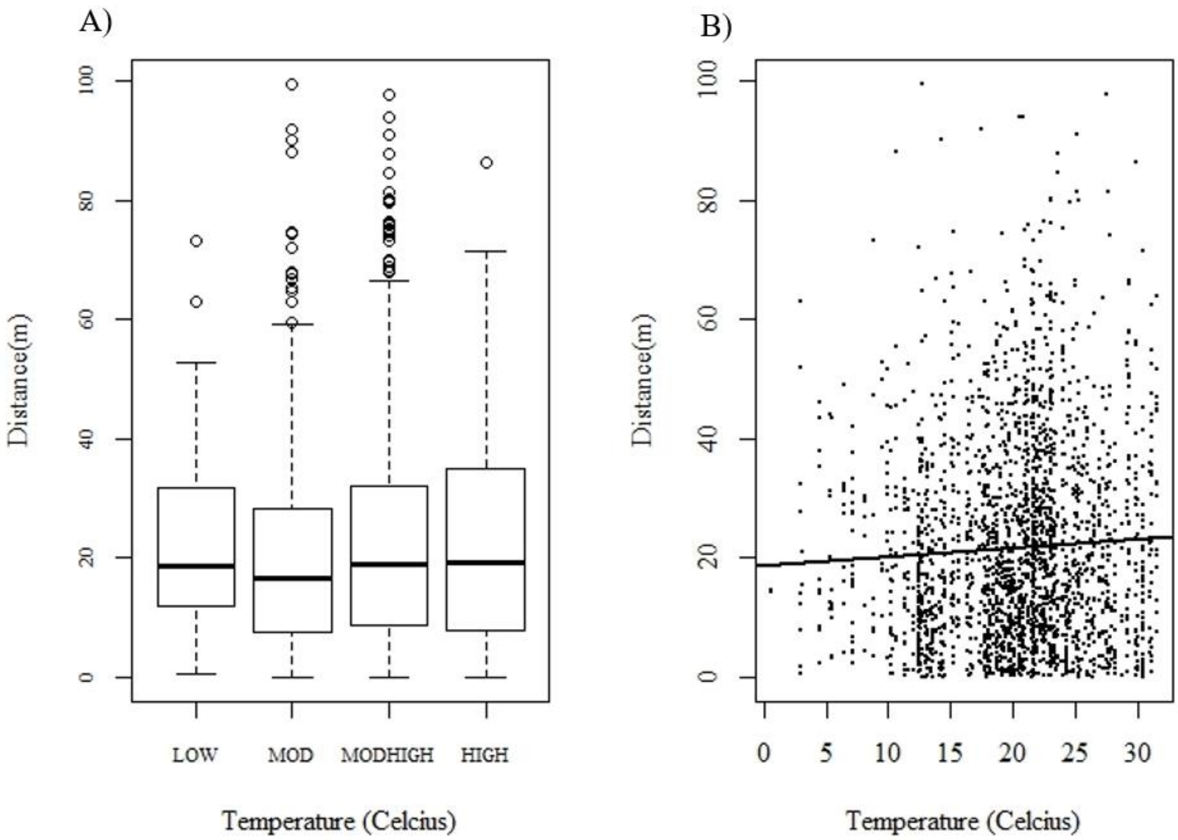

Figure 2.5. Exploratory analysis of the effects of temperature on distances for 2,333 northern bobwhite covey detections on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017. (A) boxplots of distances by temperature as a factor covariate (Temperature F). (B) Scatterplot of distances as a function of temperature as a continuous covariate (Temperature).

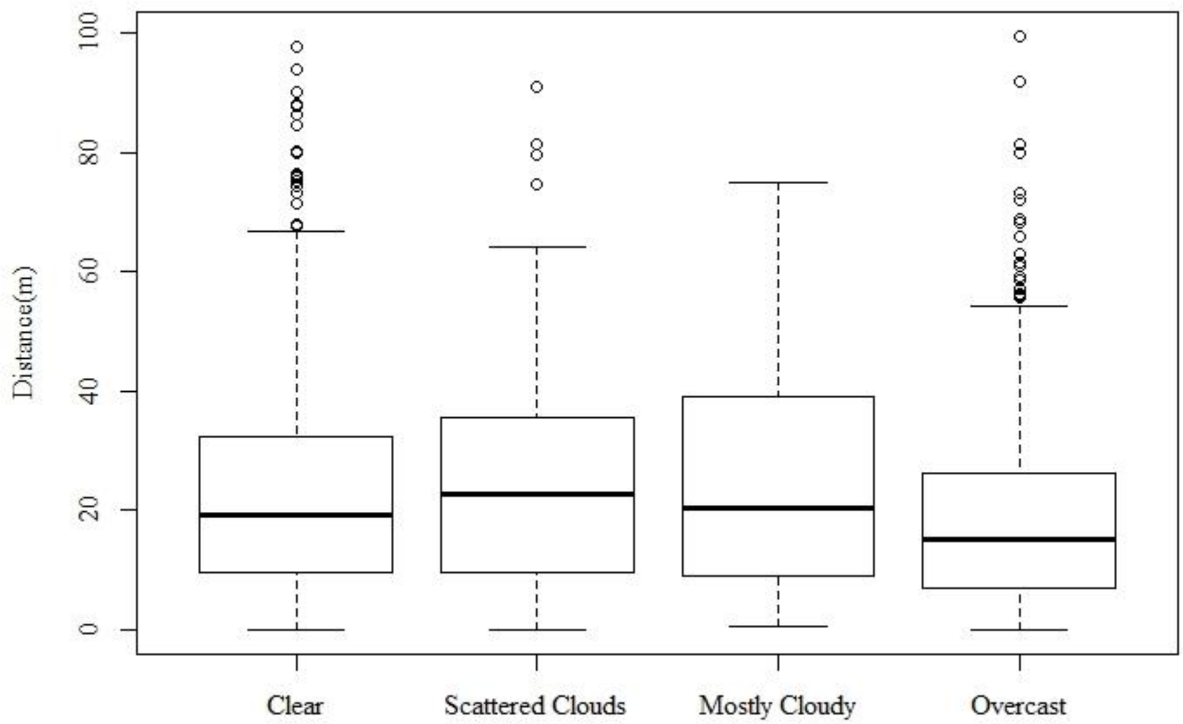

Figure 2.6. Exploratory analysis of the effects of temperature on distances for 2,333 northern bobwhite covey detections on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017. Boxplots of distances by cloud cover as a factor covariate (Condition F).

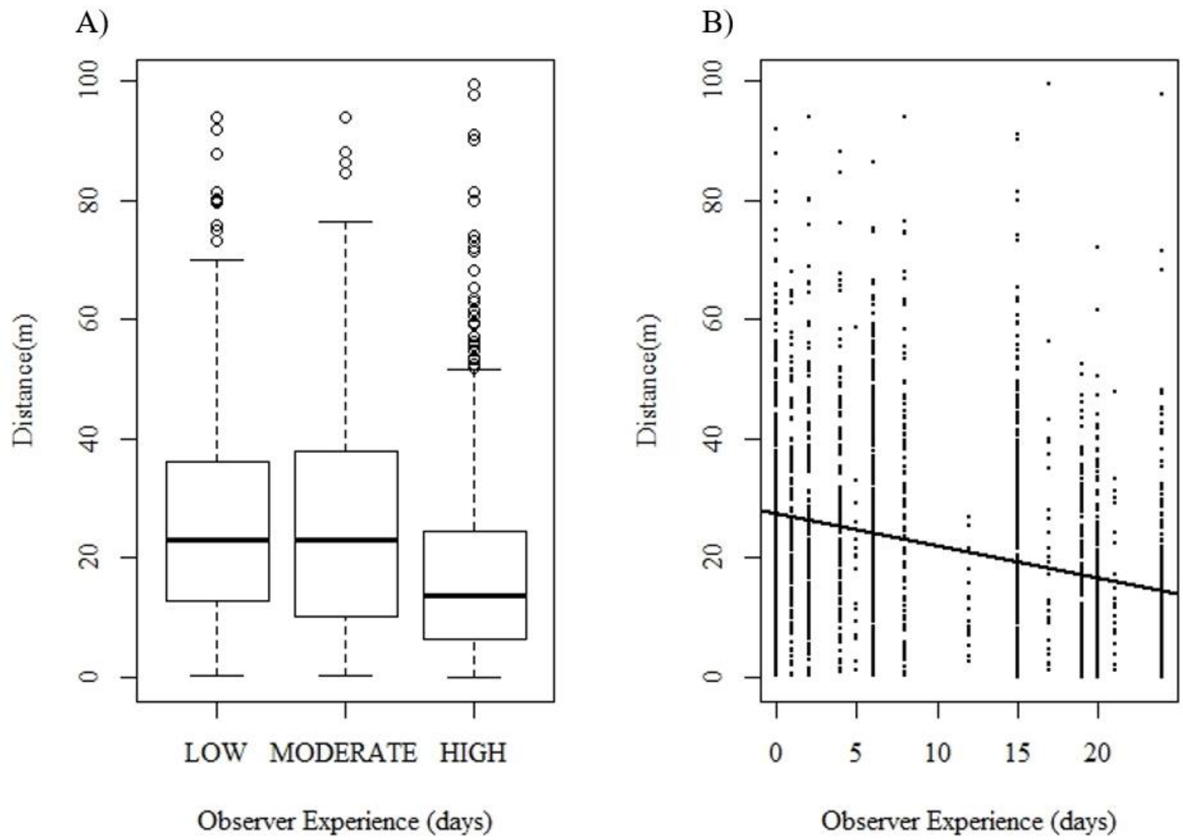

Figure 2.7. Exploratory analysis of the effects of observer experience on distances for 2,333 northern bobwhite covey detections on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017. (A) boxplots of distances by days of experience as a factor covariate (Experience F). (B) Scatterplot of distances as a function of days of experience as a continuous covariate (Experience).

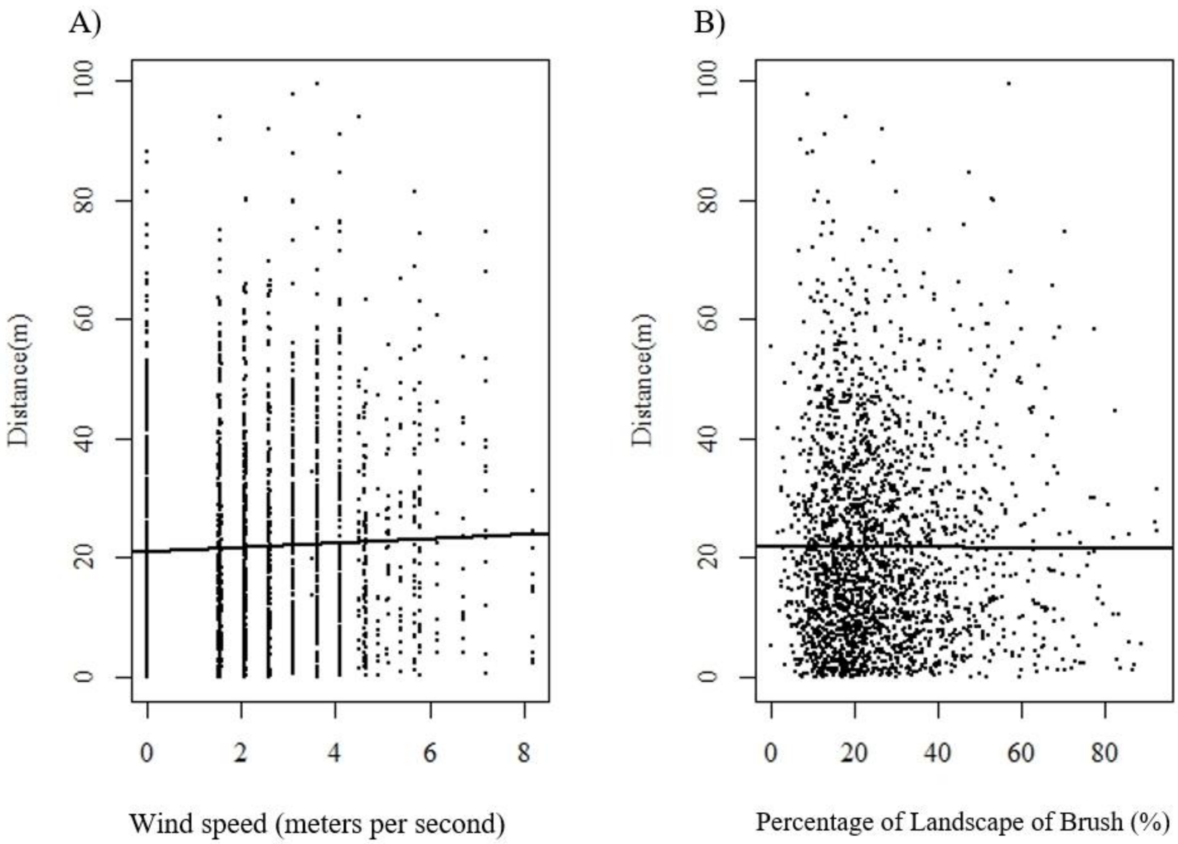

Figure 2.8. Exploratory analysis of the effects of wind and percentage of landscape of brush cover on distances for northern bobwhite 2,333 covey detections on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017. (A) Scatterplot of distances as a function of days of wind speed (m/s) as a continuous covariate (Wind). (B) Scatterplot of distances as a function of percentage of landscape of brush as a continuous covariate (PLAND).

Table 2.1. Model selection for factors affecting the detection of 2,333 northern bobwhite coveys on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017. Detections were modeled as a function of distance alone through conventional distance sampling and as a function of 6 individual covariates (4 as a continuous and factor covariate, denoted by F) through multiple covariate distance sample. Models are sorted by differences in Akaike's Information Criterion (ΔAIC). Also shown for each model is effective strip width (ESW), and 3 goodness of fit (GOF) tests: Kolmogorov–Smirnov (K-S), Cramer VonMises uniform (CvM [unif]), and Cramer VonMises cosine (CvM [cos]).

Analysis[a]	Covariate[b]	Key function[c]	No. of Parameters	ΔAIC	AIC	ESW	CvM (cos)	CvM (unif)	K-S
MCDS	Experience	HN	2	0	15611.07	29.58	0.7	0.6	0.35
MCDS	Experience	HR	3	4.96	15616.03	29.41	0.6	0.3	0.22
MCDS	Experience F	HR	4	40.09	15651.16	30.2	0.7	0.7	0.58
MCDS	Experience F	HN	3	46.15	15657.22	29.82	1	0.9	0.72
MCDS	Condition F	HN	4	107.56	15718.63	30.24	1	1	0.98
MCDS	Condition	HN	2	117.82	15728.89	30.35	1	1	0.99
MCDS	Condition F	HR	5	119.06	15730.13	30.44	0.9	0.6	0.42
MCDS	Temperature F	HN	4	123.13	15734.2	30.27	1	1	0.94
MCDS	Hour F	HN	4	126.1	15737.17	30.37	1	1	0.96
MCDS	Condition	HR	3	127.19	15738.26	30.68	0.8	0.5	0.25
MCDS	Wind	HN	2	127.61	15738.68	30.41	1	1	0.98
MCDS	Temperature	HN	2	128.37	15739.44	30.41	1	1	0.98

Table 2.1 continued

Analysis[a]	Covariate[b]	Key function[c]	No. of Parameters	ΔAIC	AIC	ESW	CvM (cos)	CvM (unif)	K-S
MCDS	Hour	HN	2	129.42	15740.49	30.42	1	1	0.98
CDS	-	HN	1	129.98	15741.05	30.44	1	1	0.99
MCDS	PLAND	HN	2	130	15741.07	30.43	1	1	0.99
CDS	-	Uni	1	130.65	15741.72	29.51	0.8	0.8	0.82
CDS	-	HR	2	134.28	15745.35	31.31	0.9	0.9	0.87
MCDS	Temp	HR	3	137.77	15748.84	30.28	0.8	0.7	0.45
MCDS	PLAND	HR	3	137.98	15749.05	30.18	0.7	0.6	0.61
MCDS	Hour	HR	3	138.05	15749.12	30.19	0.7	0.6	0.51
MCDS	Wind	HR	3	138.44	15749.51	30.35	0.9	0.6	0.37
MCDS	Temperature F	HR	5	138.59	15749.66	30.59	0.7	0.4	0.11
MCDS	Hour F	HR	4	139.67	15750.74	30.29	0.6	0.35	0.11

[a]Analysis: CDS = Conventional Distance Sampling; MCDS =Multiple Covariate Distance Sampling

[b]Covariate: PLAND = Percentage of Landscape (brush)

[c]Key functions: HN = Half-normal; HZ = Hazard-rate; Unif = uniform. Adjustment terms: cos = cosine, sp = simple polynomial.

null model. However, detections at further distances were made when brush cover was <40%, with few detections made at brush cover greater than 60% (Fig. 2.8B).

Observer experience and condition were both significant continuous covariates ($P \leq 0.001$; Table 2.2). No other continuous factors in this analysis were significant. Observer experience modeled as a continuous covariate indicated that detection distance within 0–40 m increased with days of experience. When looking at the difference between high and low experience as a factor, the detection function modeled for high experience levels indicated observers make 100% of the detections for 0–10 m (Fig. 2.9A) while observers with low experience levels miss ~30% of detections within 0–10 m (Fig. 2.9B). The observers with high experience exhibited a steep drop in detections after 20 m while observers with moderate and low experience fell off more gradually (Fig. 2.9C). Cloud condition did not affect detection at 0 distance (Fig. 2.10A), but observers detected coveys at further distances ($\bar{x}$ = 4 m) on clear (0% cloud cover) compared to overcast days (100% cloud cover; Fig. 2.10B and C). The fitted detection function for cloudy conditions (represented by both scattered and mostly cloudy skies), was similar to the detection function in clear conditions.

Survey Coverage

In 2014 and 2015, 95% CI of bobwhite density increased when more than 50% of the transects were removed in all 3 trials (Fig. 2.11 and 2.12). Similarly, CV($\hat{D}$) began to increase past 20% when 50% or of the transects where removed (Fig. 2.11D and Fig. 2.12D). At 50% coverage, CV($\hat{D}$) varied between trials, with at least one trial >20%.

Detection probability was similar between 100% and 50% coverage for 2014 and 2015 survey 2 and combined (Table 2.3) but increased by more than 10% in 2015 survey 1 (Table 2.3). Detection probability ($\hat{p}$) increased close to 1.0 at 25% coverage in 2015 survey 1 and 2

Table 2.2. Point estimates (± SE) for each covariate from models with 99.9, 99, and 95% lower and upper confidence limits (LCL, UCL) affecting detection. Significance is denoted by *** at $P \leq 0.0001$, ** at $P \leq 0.01$, and * for $P \leq 0.05$. Data is from 2,333 northern bobwhite covey detections from surveys across the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017.

Models[a]	ΔAIC	Point	SE	LCL	UCL	Sig (99.9%)	LCL	UCL	Sig (99%)	LCL	UCL	Sig (95%)
Experience HN	0.00	-0.04	0.004	-0.06	-0.03	***	-0.05	-0.03	**	-0.05	-0.04	*
ExperienceF HR	40.09	-	-	-	-	-	-	-	-	-	-	-
ConditionF HN	107.56	-	-	-	-	-	-	-	-	-	-	-
Condition HN	117.82	-0.08	0.02	-0.15	-0.008	***	-0.14	-0.02	**	-0.12	-0.04	*
TemperatureF HN	123.13	-	-	-	-	-	-	-	-	-	-	-
HourF HN	126.10	-	-	-	-	-	-	-	-	-	-	-
Wind HN	127.61	0.02	0.01	-0.03	0.08	NS	-0.02	0.07	NS	-0.006	0.06	NS
Temperature HN	128.37	0.007	0.005	-0.009	0.02	NS	-0.006	0.02	NS	-0.003	0.01	NS
Hour HN	129.42	0.01	0.01	-0.03	0.04	NS	-0.03	0.04	NS	-0.01	0.03	NS
Null HN	129.98	-	-	-	-	-	-	-	-	-	-	-
PLAND HN	130.00	-0.001	0.002	-0.008	0.005	NS	-0.006	0.004	NS	-0.005	0.003	NS
Null Uni	130.65	-	-	-	-	-	-	-	-	-	-	-
Null HR	134.28	-	-	-	-	-	-	-	-	-	-	-

[a]Models: PLAND: = Percentage of Landscape (brush). Key functions: HN = Half-normal; HZ = Hazard-rate; Unif = uniform. Null models were not modeled with covariates other than distance.

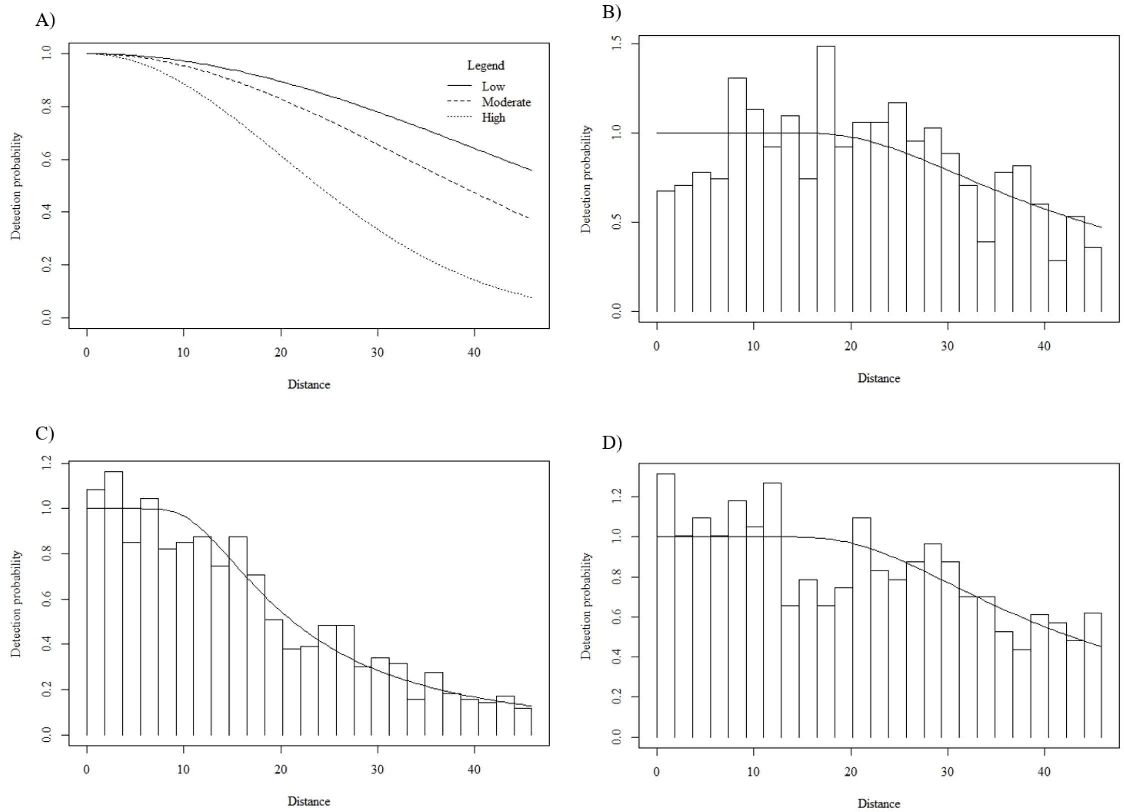

Figure 2.9. Marginal detection functions for northern bobwhites plotted for different values of (A) observer experience as a continuous covariate at high, moderate and, low observer experience. When modeled as a factor covariate (B) detection function pooled over observers with low experience, (C) detection function pooled over observers with moderate experience, and (D) detection function pooled over observers with high experience on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017.

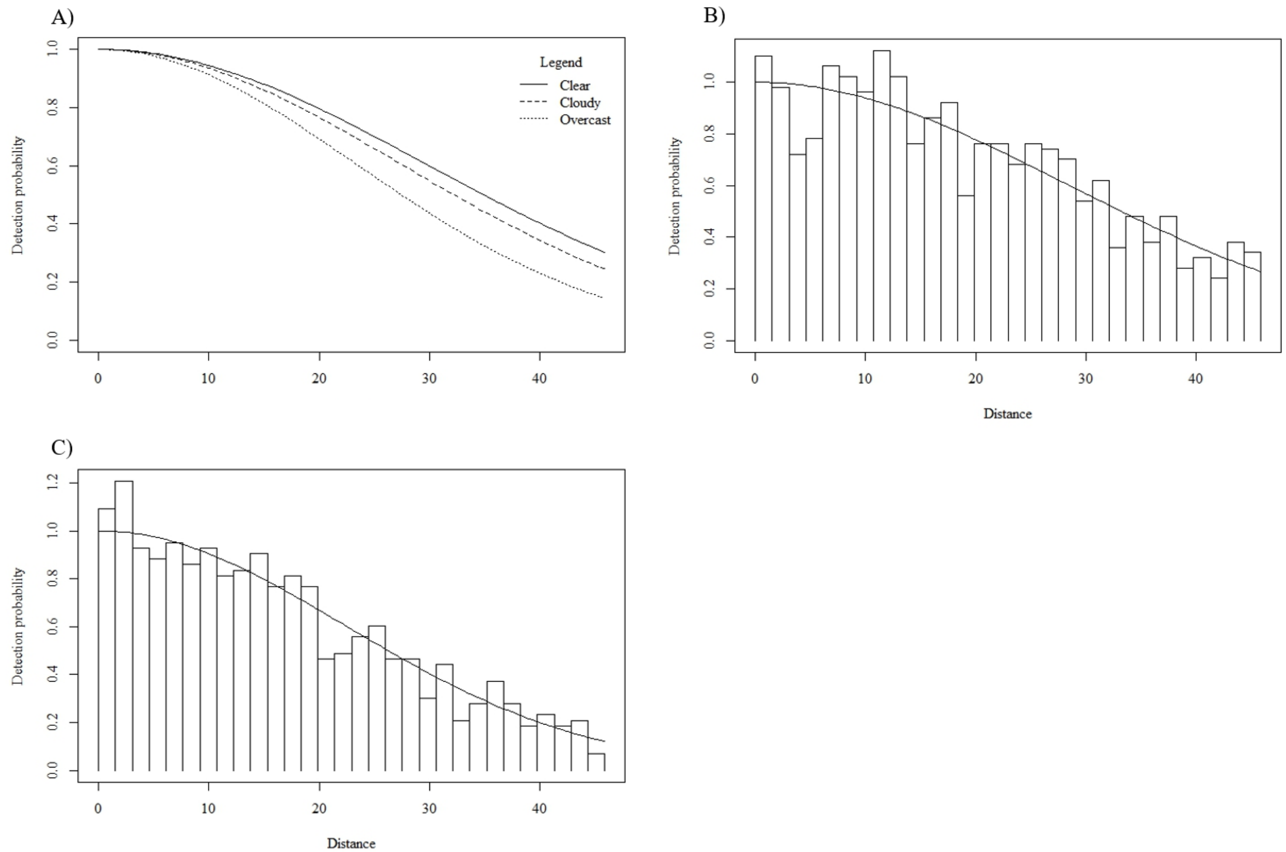

Figure 2.10. Marginal detection functions for northern bobwhites plotted for different values of (A) cloud cover as a continuous covariate at clear, cloudy and, overcast conditions. When modeled as a factor covariate (B) detection function pooled over clear conditions and (C) detection function pooled over overcast conditions on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017.

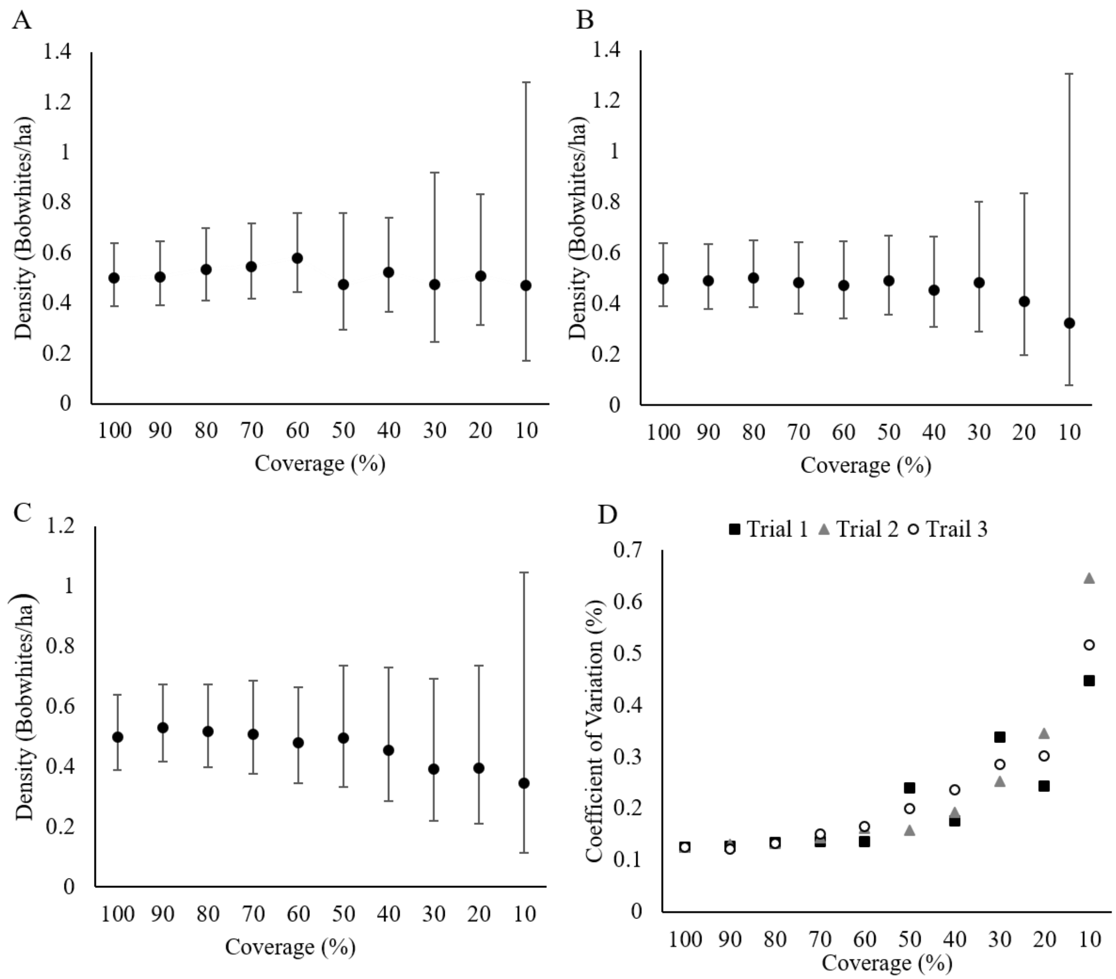

Figure 2.11. Relationship between northern bobwhite density estimates (bobwhites/ha; gray circles) and 95% confidence intervals for decreasing survey coverage: (A) trial 1; (B) trail 2; (C) trail 3; and (D) their respective coefficient of variation (%CV[$\hat{D}$]) from the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2014.

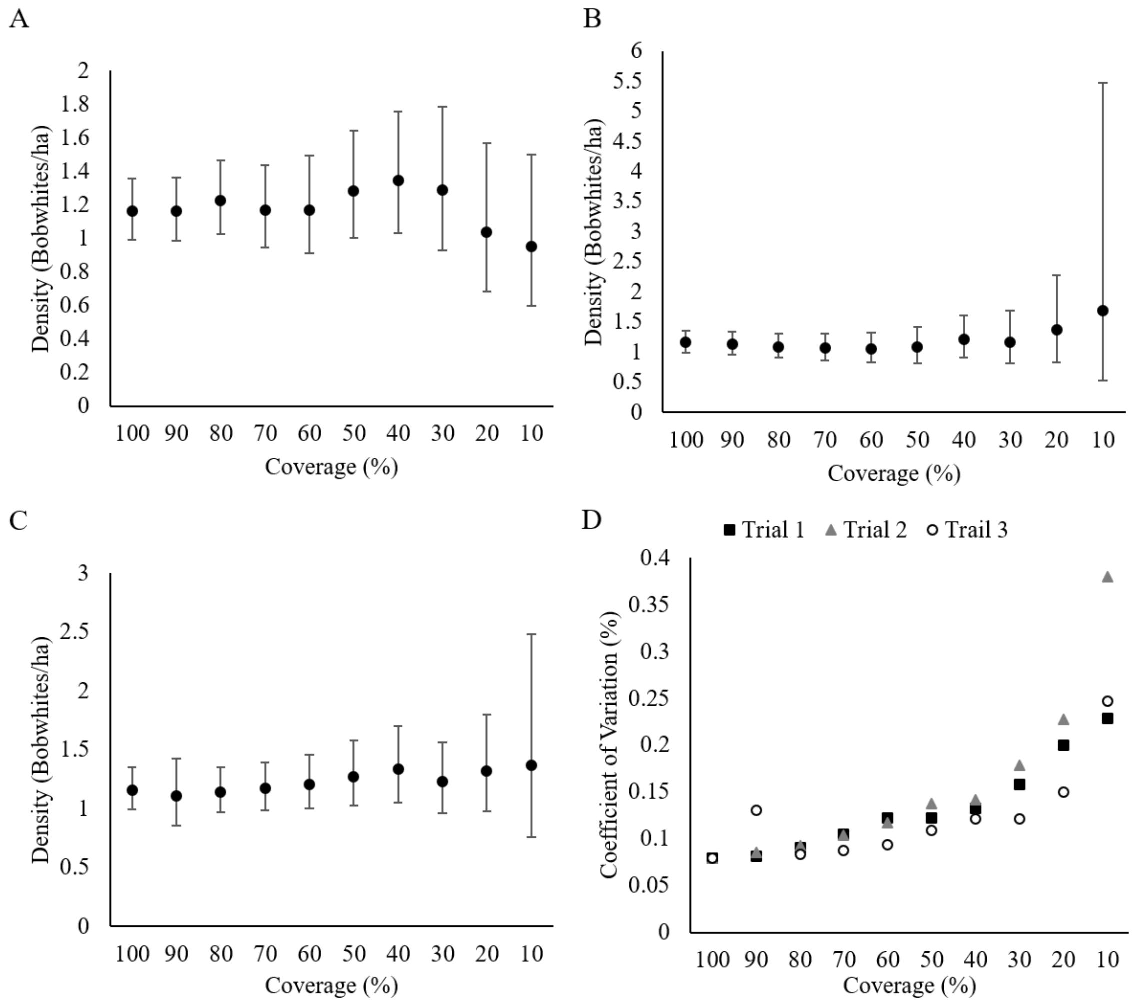

Figure 2.12. Relationship between northern bobwhite density estimates (bobwhites/ha) and 95% confidence intervals for and decreasing survey coverage: (A) trial 1; (B) trail 2; (C) trail 3; and (D) their respective coefficient of variation (%CV[$\hat{D}$]) from pooled detections on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2015.

Table 2.3. Number of transects (*k*), total transect length, (*L*), number of northern bobwhite covey detections (*n*), detection probability (*p*), coefficient of variation (%CV[*p*]), density (bobwhites/ha [$\widehat{D}$ ± SE]), coefficient of variation (%CV[$\widehat{D}$]), 95% confidence intervals (95%CI [$\widehat{D}$]), from a survey at 100% survey coverage and manipulated surveys (25 and 50%). Surveys are from pooled detections 2014–2017 on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA. Also shown for each model are the results (*P*-value) from 3 goodness of fit (GOF) tests: Kolmogorov–Smirnov (K-S), Cramer VonMises uniform (CvM [unif]), and Cramer VonMises cosine (CvM [cos]).

							$\hat{D}$			Goodness of Fit (GOF)		
Survey	Coverage (%)	k	L (m)	n	$\hat{p}$	% CV ($\hat{p}$)	$\hat{D}$ ± SE	% CV ($\hat{D}$)	95% CI	CvM (cos)	CvM (unif)	K-S
2014	100	33	380317	131	0.58	7.52	0.48 ± 0.06	12.93	(0.37–0.63)	0.90	1.00	0.97
	50	16	187445	69	0.58	7.24	0.50 ± 0.08	15.42	(0.37–0.68)	0.60	0.70	0.77
	25	8	90854	31	0.53	13.64	0.64 ± 0.18	27.79	(0.36–1.13)	0.60	0.70	0.73
2015 survey 1	100	33	380317	484	0.71	3.87	1.26 ± 0.09	6.93	(1.1–1.44)	0.01	0.03	0.00
	50	16	187445	196	0.88	6.69	1.08 ± 0.13	11.76	(0.86–1.38)	0.05	0.10	0.02
	25	8	90854	96	0.91	5.96	0.79 ± 0.13	17.05	(0.55–1.13)	0.30	0.40	0.09
2015 survey 2	100	33	380317	405	0.68	4.52	1.28 ± 0.09	7.35	(1.11–1.48)	1.00	1.00	0.95
	50	16	187445	188	0.63	5.61	1.55 ± 0.19	12.26	(1.21–1.99)	0.90	1.00	0.89
	25	8	90854	96	0.76	9.8	1.56 ± 0.38	24.71	(0.91–2.65)	1.00	1.00	0.99
2015 combined	100	33	760635	905	0.68	0.02	1.19 ± 0.06	5.07	(1.08–1.32)	0.15	0.30	0.08

Table 2.3 continued

Survey	Coverage (%)	k	L (m)	n	$\hat{p}$	% CV ($\hat{p}$)	$\hat{D}$			Goodness of Fit (GOF)		
							$\hat{D} \pm SE$	% CV ($\hat{D}$)	95% CI	CvM (cos)	CvM (unif)	K-S
	50	16	374890	383	0.75	0.04	1.34 ± 0.11	8.49	(1.13–1.59)	0.50	0.60	0.24
	25	8	181709	182	0.89	7.99	1.19 ± 0.23	19.41	(0.78–1.82)	0.60	0.70	0.31
2016	100	33	380317	346	0.57	4.43	2.00±0.16	8.21	(1.71–2.36)	0.70	0.80	0.73
	50_odd	17	192872	178	0.42	8.89	1.72±0.21	12.41	(1.34–2.20)	1.00	1.00	1.00
	50_even	16	187445	199	0.35	6.94	2.43±0.27	11.1	(1.95–3.03)	0.60	0.80	0.74
2017	100	33	380317	271	0.61	5.27	0.76±0.06	9.15	(0.64–0.94)	0.80	0.90	0.71
	50_odd	17	192872	143	0.67	7.69	0.73±0.11	14.67	(0.54–0.98)	0.90	1.00	0.83
	50_even	16	187445	130	0.55	4.4	0.77±0.08	11.3	(0.62–0.97)	0.60	0.60	0.48

combined. The CV ($\hat{p}$) in 2014 and 2015 survey 2, was stable between 100 and 50% coverage, but doubled at 25% coverage. The CV ($\hat{p}$) in the combined survey was stable between 100 and 50% coverage and increased by 100% at 25% coverage.

Density estimates were similar between 100% and 50% coverage for 2014 (z = -1.00, P = 0.317), 2015 survey 1 (z = 1.14, P = 0.258), 2015 survey 2 (z =-1.28, P = 0.200), and 2015 combined (z = -1.19, P = 0.234; Table 2.3). Density estimates were similar between 100% and 25% coverage for 2014 (z = -0.84, P = 0.401), 2015 survey 2 (z = -0.71, P = 0.473), and 2015 combined (z =0, P = 1.00), but differed between 100% and 25% for 2015 survey 1 (z =2.970, P = 0.0029; Table 2.3). As coverage decreased from 100 to 25%, CV($\hat{D}$) and 95% CI increased in all surveys (Table 2.3).

In 2014, goodness of fit tests decreased from 100 to 50% coverage (Table 2.3). In 2015 survey 2, decreasing survey coverage had no effect on goodness of fit tests (Table 2.3). Goodness of fit tests for 2015 survey 1, and the combined survey were poor at 100% coverage and artificially increased from 50 to 25% (Table 2.3). All estimates probability in surveys with good model fit (i.e., 2014 and 2015 survey 2) were less effected by decreasing coverage from 100 to 50% coverage (Table 2.3).

In 2016, the detection probability ($\hat{p}$) for surveys flown at 50% were >10% lower than the combined survey at 100% (Table 2.3). In 2017, detection probability did not differ by >6% between surveys flown at 50% coverage and the combined survey at 100% (Table 2.3). I was able to detect >60 coveys for each individual survey at 50% for 2016 and 2017. The CV($\hat{D}$) decreased below 10% when 50% surveys were combined into 100% coverage (Table 2.3). Estimates from each of the two surveys flown at 50% coverage did not differ from the combined estimates at 100% coverage in 2016 (z = 1.33, P = 0. 184, z = -1.11, P = 0.267) and 2017 (z = -

0.200, P = 0.841, z = 0.198, P = 0.843; Table 2.3). In 2016 and 2017, goodness of fit tests from surveys flown at 50% coverage were similar to combined estimates at 100% coverage (Table 2.3).

Comparisons between surveys within years. —In 2015, I flew 760 km of transects over 7,689 ha (including the center cattle lane) on the Coloraditas Grazing Research and Demonstration Area and 486 km of transect over 4,375 ha on the reference areas for both surveys combined. For the Coloraditas Grazing Research and Demonstration Area, density estimates from survey 1 ($\hat{D}$: 1.55 bobwhites/ha, 1.26−1.79 95% CI, 12% CV) and survey 2 ($\hat{D}$: 1.26 bobwhites/ha, 1.01−1.58 95% CI, 12% CV) were similar (Table 2.4). However, detectability on the line in survey 2 was higher than in survey 1 (Fig. 2.13). For the reference sites, density estimates from survey 1 ($\hat{D}$: 0.74 bobwhites/ha, 0.54−0.98 95% CI, 16% CV) and survey 2 ($\hat{D}$: 1.08 bobwhites/ha, 0.56−1.75 95% CI, 29% CV) were also similar (Table 2.4). Detections on the line in survey 1 on the reference areas appear to have the same issues as in survey 1 on the Coloraditas Grazing Research and Demonstration Area (Fig. 2.14). On the reference sites, CV($\hat{D}$) in survey 2 was high indicating that precision in covey locations may have been affected by significant wind.

Between surveys within grazing treatments in 2015, the probability of detection was similar except for the rotational high grazing treatment (Table 2.5). Density varied the most between survey 1 and survey 2 of the rotational high grazing treatment and the continuous moderate grazing treatment, but 95% CI overlapped. The number of detections slightly decreased from survey 1 to survey 2 for each grazing treatment.

For the reference sites each complete survey was run as a separate analysis. I was not

Table 2.4. Summary statistics for annual differences in northern bobwhite densities between 2 surveys on the Coloraditas Grazing Research and Demonstration Area (CGRDA) and reference sites in 2015 (100% vs. 100%), 2016 (50% vs. 50%), and 2017 (50% vs. 50%) in Jim Hogg County, Texas, USA. Difference = CGRDA − REF; SE for the diff. = √SE2CGRDA+SE2REF; z-score = difference/SE for the diff.

	2015		2016		2017	
	CGRDA Survey 1 vs 2	Reference sites Survey EW vs. NS[a]	CGRDA Survey 1 vs 2	Reference sites Survey 1 vs 2	CGRDA Survey 1 vs 2	Reference sites Survey 1 vs 2
Difference	0.094	0.049	-0.711	0.292	0.082	0.241
SE for the diff.	0.127	0.157	0.290	0.394	0.147	0.185
z-score	0.739	0.315	-2.450	0.740	0.561	1.303
P-value two tailed	0.459	0.370	0.014	0.183	0.575	0.183

[a]In 2015, on the reference sites, transects were flown East to West (EW) during the first survey, however, transects were flown North to South (NS) during the second survey due to high winds.

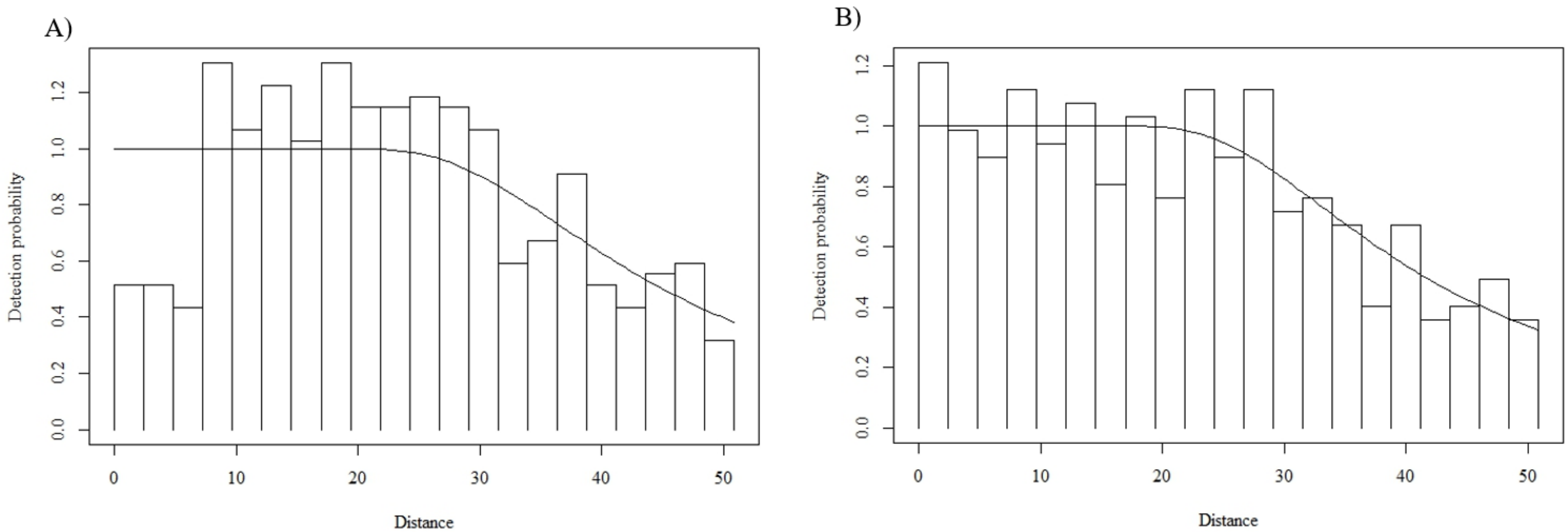

Figure 2.13. The estimated conventional distance sampling detection function for (A) survey 1 and (B) survey 2 at 100% coverage from coveys pooled across treatments on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2015.

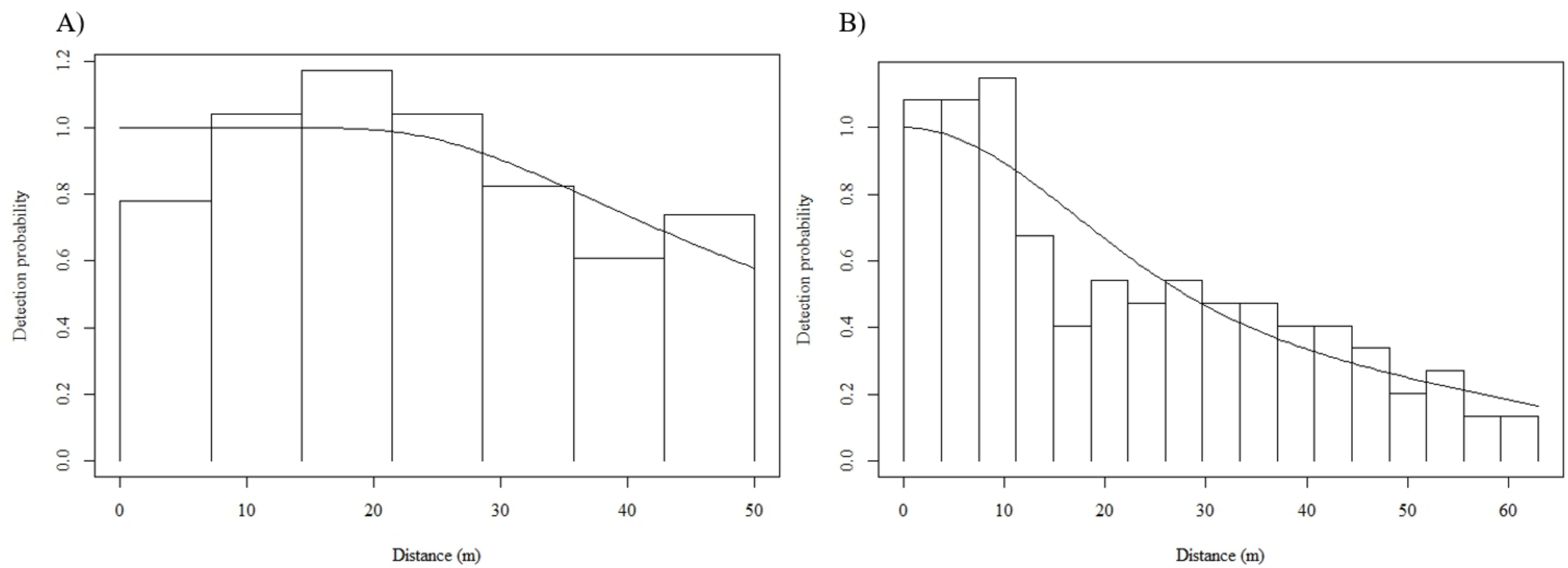

Figure 2.14. The estimated conventional distance sampling detection function for (A) survey 1 flow in the East–West direction and (B) survey 2 flown in the North–South direction at 100% coverage from coveys pooled across pastures on the reference sites in in Jim Hogg County, Texas, USA, 2015.

Table 2.5. Number of transects (k), total transect length, (L), number of northern bobwhite covey detections (n), detection probability ($\hat{p}$), density (bobwhites/ha [$\hat{D}$ ± SE]), coefficient of variation (CV[$\hat{D}$]), 95% confidence intervals (95%CI[$\hat{D}$]), from 2015 surveys each at 100% coverage (1 and 2) and combined (doubled) by treatment site on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2015. Also shown for each model is effective strip width (ESW), and 3 goodness of fit (GOF) tests: Kolmogorov–Smirnov (K-S), Cramer VonMises uniform (CvM [unif]), and Cramer VonMises cosine (CvM [cos]).

Treatment[a]	k	L (m)	n	$\hat{p}$	$\hat{D}$			Goodness of Fit (GOF)		
					$\hat{D}$ ± SE	% CV ($\hat{D}$)	95% CI	CvM (cos)	CvM (unif)	K-S
CH survey1	33	192169.8	98	1.0	1.03 ± 0.16	15.1	(0.76–1.4)	0.3	0.3	0.3
CH survey 2	33	192169.8	70	0.8	0.92 ± 0.16	17.8	(0.65–1.3)	1.0	1.0	1.0
CH doubled	33	192169.8	168	0.9	1.12 ± 0.13	11.8	(0.89–1.4)	0.5	0.5	0.4
CM survey 1	30	137130.0	77	0.9	1.38 ± 0.20	14.3	(1.04–1.8)	0.2	0.3	0.1
CM survey 2	30	137130.0	63	0.9	1.31 ± 0.22	17.0	(0.93–1.8)	0.7	0.7	0.7
CM doubled	30	137130.0	140	0.9	1.35 ± 0.15	10.8	(1.08–1.7)	0.2	0.3	0.3
RH survey 1[b]	31	214572.0	115	1.0	1.30 ± 0.18	13.7	(0.98–1.7)	0.3	0.4	0.2
RH survey 2[b]	31	214572.0	109	0.8	1.70 ± 0.25	14.7	(1.27–2.3)	0.9	1.0	0.9
RH doubled	31	214572.0	224	0.9	1.58 ± 0.17	11.0	(1.26–2.0)	0.8	0.9	0.8
RM survey 1	32	200740.0	110	0.8	1.04 ± 0.17	16.6	(0.74–1.4)	0.1	0.1	0.1
RM survey 2	32	200740.0	98	0.8	1.16 ± 0.18	15.7	(0.86–1.6)	0.7	0.8	0.9
RM doubled	32	200740.0	208	0.8	1.09 ± 0.13	11.6	(0.87–1.4)	0.2	0.2	0.2

[a]Treatment: CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate.

[b]Detection probability differed between surveys, doubled estimate includes survey number as a covariate

able to fly the second survey in the regular transect direction from East to West due to high winds that would make hovering in a direction unsafe, therefore, the pilot would only fly a second survey if transects were flown North to South. I did not directly compare these in a single analysis. The top model for survey 1 East to West, was a global detection function (pooled $\hat{f}(0)$ indicating there was no difference in the detection function between the 3 reference site pastures (Table 2.6). The top model for survey 2 was a full geographic stratification indicating the data were best fit by a separate $\hat{f}(0)$ for each pasture (Table 2.6). Density varied the most between the East to West and North to South surveys on Atole and Agua Dulce pastures, but 95% CI overlapped. Density was similar between the East to West and NS surveys on the Pinto pasture. The CV($\hat{D}$) increased from the East to West to North to South surveys on the Pinto and Agua Dulce pastures, but remained stable on the Agua Dulce pasture. The pooled density and CV($\hat{D}$) also increased from the East to West to North to South surveys, but model fit was better on the North to South survey.

Although there was no difference in density between the East to West and North to South surveys on the reference sites, the probability of detection decreased from 0.86 in the East to West surveys to 0.42 in the North to South surveys and the CV and 95% CI increased from the East to West to the North to South surveys. This may indicate that the East to West survey design is better suited for the reference sites than the North to South design.

In 2016, I flew 380 km (192.8 for survey 1 and 187.4 for survey 2) of transects over 7,689 ha on the Coloraditas Grazing Research and Demonstration Area and 197 km (100.4 for survey 1 and 96.6 for survey 2) of transect over 4,375 ha on the reference areas. For the Coloraditas Grazing Research and Demonstration Area, density estimates from survey 1 (1.65 bobwhites/ha, 1.30−2.02 95% CI, 11% CV) and survey 2 (2.40 bobwhites/ha, 1.83−3.11 95% CI,

Table 2.6. Number of transects (k), total transect length, (m, L), number of northern bobwhite covey detections (n), detection probability ($\hat{p}$), density (bobwhites/ha [$\hat{D}$ ± SE]), coefficient of variation (CV[$\hat{D}$]), 95% confidence intervals (95%CI [$\hat{D}$]), from 2015 surveys each at 100% coverage (1 and 2 by pasture) and total average density pooled over the reference sites in Jim Hogg County, Texas, USA, 2015. Also shown for each model is effective strip width (ESW), and 3 goodness of fit (GOF) tests: Kolmogorov–Smirnov (K-S), Cramer VonMises uniform (CvM [unif]), and Cramer VonMises cosine (CvM [cos]).

Pasture[b]	k	L	n	$\hat{p}$	$\hat{D}$			Goodness of Fit (GOF)		
					$\hat{D}$ ± SE	% CV ($\hat{D}$)	95% CI	CvM (cos)	CvM (unif)	K-S
Atole survey1	23	45530	52	-	0.73 ± 0.15	20.32	(0.49–1.09)	-	-	-
Pinto survey 1	19	36990	35	-	0.69 ± 0.14	20.77	(0.45–1.04)	-	-	-
Agua Dulce survey 1	19	47540	56	-	0.76 ± 0.15	19.44	(0.52–1.13)	-	-	-
Total survey 1	61	130070	143	0.86	0.73	13.74	(0.55–0.95)	0.4	0.5	0.39
Atole survey 2	20	47210	51	0.80	0.55 ± 0.12	20.95	(0.36–0.85)	0.9	0.9	0.94
Pinto survey 2	20	38150	36	0.70	0.73 ± 0.20	27.12	(0.43–1.26)	0.3	0.5	0.25
Agua Dulce survey 2	20	49140	40	0.35	1.36 ± 0.39	28.27	(0.78–2.38)	1	1	0.99
Total survey 2	60	134500	130	0.42	0.99	19.64	(0.67–1.46)	0.9	0.9	0.95

[a]Detection functions differ, combined estimate includes survey number as a covariate

[b]Each complete survey analyzed with proper detection function. Survey 1 was flown from East to West and analyzed with a pooled $\hat{f}(0)$. Survey 2 was flown from North to South and analyzed with a fully stratified $\hat{f}(0)$.

13.6% CV) were different (Table 2.4). Probability of detection was similar between survey 1 and survey 2 (Fig. 2.15). For the reference sites, density estimates from survey 1 (1.18 bobwhites/ha, 0.77−1.85 95% CI, 22.4% CV) and survey 2 (1.48 bobwhites/ha, 1.06−2.10 95% CI, 17.2% CV) were similar (Table 2.4). The detection probability between the 2 surveys was similar (Fig. 2.16).

Between surveys within grazing treatments in 2016, the probability of detection was similar except for the continuous moderate treatment (Table 2.7). Model fit in the continuous moderate grazing treatment decreased between survey 1 and survey 2. Density doubled between survey 1 and survey 2 on all grazing treatments except for the rotational high treatment. The rotational high grazing treatment was the only area where the recommended amount of detections was achieved in each 50% survey. Between surveys within reference site pastures, the probability of detection did not change between survey 1 and survey 2 for any pasture (Table 2.8). Density varied the most between survey 1 and survey 2 on the Agua Dulce pasture, but 95% CI overlapped. The recommended number of detections was not achieved in any individual survey or combined survey for all pastures.

I flew the same distance and area in 2017 as I did in 2016. Density between survey 1 ($\hat{D}$: 0.69 bobwhites/ha, 0.49−0.98 95% CI, 15% CV) and survey 2 (D: 0.76 bobwhites/ha, 0.59−0.98 95% CI, 13% CV) were similar (Table 2.4). Probability of detection differed for each survey across the Coloraditas Grazing Research and Demonstration Area (Fig. 2.17). Across the pooled reference sites, density on survey 1 ($\hat{D}$: 0.52 bobwhites/ha, 0.34−0.76 95% CI, 19% CV) and survey 2 ($\hat{D}$: 0.76 bobwhites/ha, 0.52 −1.08 95% CI, 20% CV), were similar (Table 2.4). Probability of detection did not change between survey 1 and survey 2 across the pooled reference sites (Fig. 2.18).

Between surveys within grazing treatments in 2017, the probability of detection was

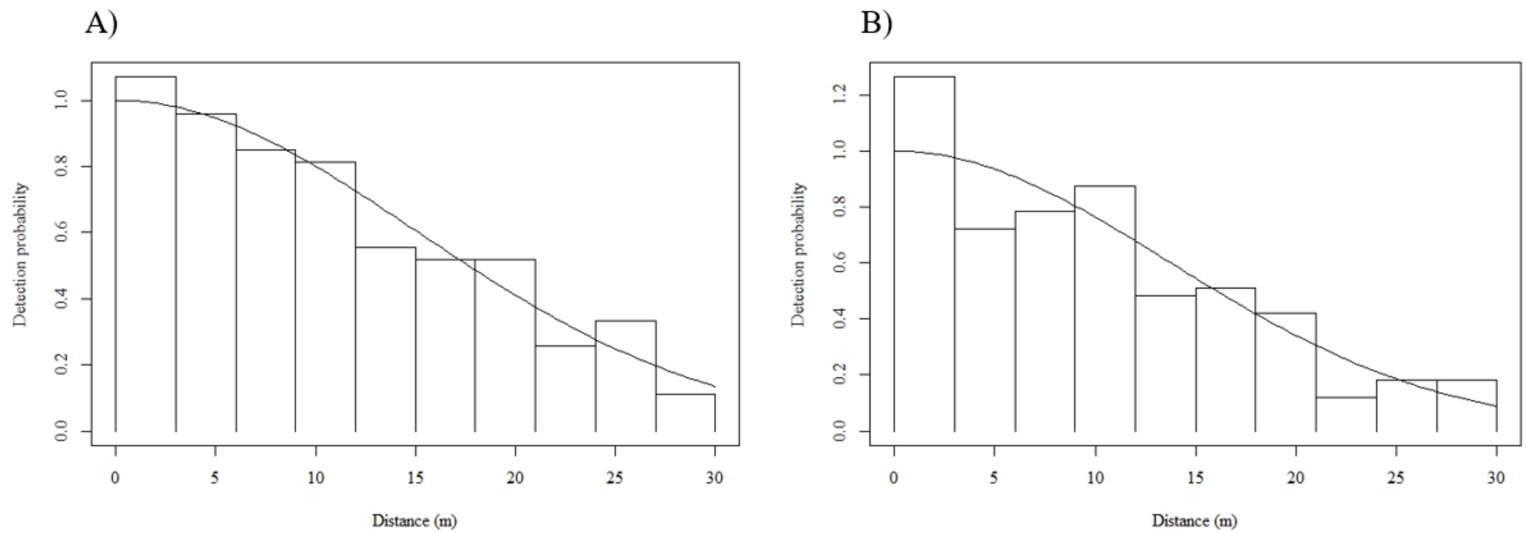

Figure 2.15. The estimated conventional distance sampling detection function for (A) survey 1 and (B) survey 2 at 50% coverage from coveys pooled across treatments on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2016.

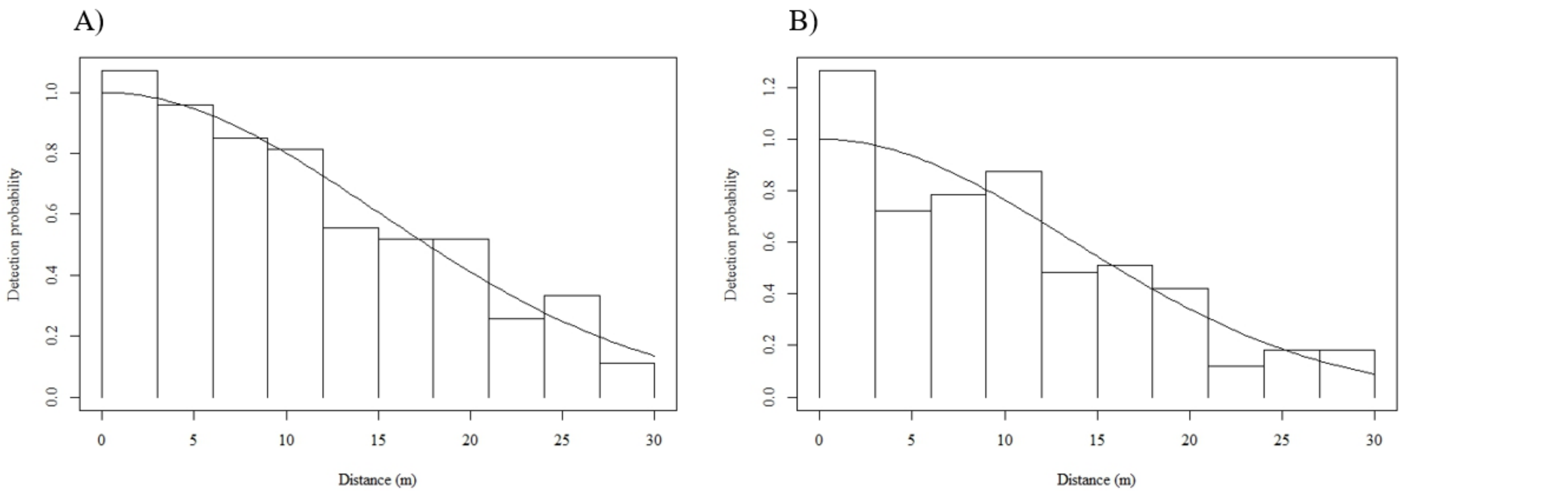

Figure 2.16. The estimated conventional distance sampling detection function for (A) survey 1 and (B) survey 2 at 50% coverage from coveys pooled across pastures on the reference sites in Jim Hogg County, Texas, USA, 2016.

Table 2.7. Number of transects (k), total transect length, (L), number of northern bobwhite covey detections (n), detection probability ($\hat{p}$), density (bobwhites/ha [$\hat{D}$ ± SE]), coefficient of variation (CV[$\hat{D}$]), 95% confidence intervals (95%CI [$\hat{D}$]), from 2016 surveys each at 50% coverage (1 and 2) and combined (100%) by treatment site on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA.

Treatment[a]	k	L (m)	n	$\hat{p}$	$\hat{D}$			Goodness of Fit (GOF)		
					$\hat{D}$ ± SE	% CV ($\hat{D}$)	95% CI	CvM (cos)	CvM (unif)	K-S
CH survey 1	17	48238.88	34	0.52	1.17 ± 0.28	23.6	(0.73–1.86)	0.80	0.90	0.82
CH survey 2	16	47846.02	45	0.46	2.54 ± 0.53	20.7	(1.68–3.83)	1.00	1.00	0.99
CH combined	33	96084.9	79	0.49	1.81± 0.28	15.4	(1.33–2.45)	0.90	0.90	0.96
CM survey 1[b]	15	34214.67	44	0.62	1.55 ± 0.29	18.42	(1.08–2.24)	0.80	0.90	0.89
CM survey 2[b]	15	34351	41	0.40	3.16 ± 0.71	22.31	(2.03–4.93)	0.40	0.40	0.41
CM combined	30	68565	85	0.49	2.19 ± 0.30	13.71	(1.67–2.87)	0.70	0.80	0.59
RH survey 1	16	55748	64	0.58	2.49 ± 0.41	16.23	(1.81–3.45)	0.70	0.80	0.71
RH survey 2	15	51538	60	0.51	2.80 ± 0.57	20.17	(1.88–4.17)	0.80	0.90	0.80
RH combined	31	107286	124	0.51	2.79 ± 0.39	14.06	(2.12–3.69)	0.80	0.90	0.84
RM survey 1	16	51611	26	0.53	1.22 ± 0.28	22.56	(0.78–1.93)	0.70	0.70	0.72
RM survey 2	16	48759	40	0.58	2.19 ± 0.40	18.3	(1.52–3.17)	0.10	0.15	0.09
RM combined	32	100370	66	0.57	1.68 ± 0.24	14.01	(1.27–2.22)	0.30	0.40	0.61

[a]Treatment: CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate.

[b]Detection probability differed between surveys, combined estimate includes survey number as a covariate

Table 2.8. Number of transects (k), total transect length, (L), number of northern bobwhite covey detections (n), detection probability ($\hat{p}$), density (bobwhites/ha [$\hat{D}$ ± SE]), coefficient of variation (CV[$\hat{D}$]), 95% confidence intervals (95%CI [$\hat{D}$]), from 2016 surveys each at 50% coverage (1 and 2) and combined (100%) by pasture site on the reference sites in Jim Hogg County, Texas, USA. Also shown for each model is effective strip width (ESW), and 3 goodness of fit (GOF) tests: Kolmogorov–Smirnov (K-S), Cramer VonMises uniform (CvM [unif]), and Cramer VonMises cosine (CvM [cos]).

Reference	k	L (m)	n	$\hat{p}$	$\hat{D}$			Goodness of Fit (GOF)		
					$\hat{D}$ ± SE	% CV ($\hat{D}$)	95% CI	CvM (cos)	CvM (unif)	K-S
Atole survey 1	12	37351	21	0.62	1.30 ± 0.45	34.96	(0.65–2.58)	0.70	0.70	0.58
Atole survey 2	11	35938	32	0.81	1.69 ± 0.45	26.85	(0.98–2.90)	0.60	0.70	0.73
Atole combined	23	73289	53	0.69	1.56 ± 0.32	20.42	(1.05–2.35)	0.80	0.90	0.90
Pinto survey 1	10	31066	19	0.54	1.60 ± 0.66	41.34	(0.70–3.67)	1.00	1.00	0.99
Pinto survey 2	9	28480	16	0.52	1.60 ± 0.51	31.97	(0.85–3.05)	0.70	0.80	0.81
Pinto combined	19	59546	35	0.53	1.58 ± 0.43	27.07	(0.93–2.71)	0.90	0.90	0.93
Agua Dulce survey 1[a]	8	32224	10	0.46	0.72 ± 0.33	46.46	(0.28–1.80)	1.00	1.00	1.00
Agua Dulce survey 2[a]	8	32224	15	0.39	1.60 ± 0.73	45.79	(0.65–3.95)	1.00	0.90	0.86
Agua Dulce combined	16	64448	25	0.42	1.08 ± 0.34	31.68	(0.58–2.02)	1.00	1.00	0.95

[a]Detection functions differ, combined estimate includes survey number as a covariate

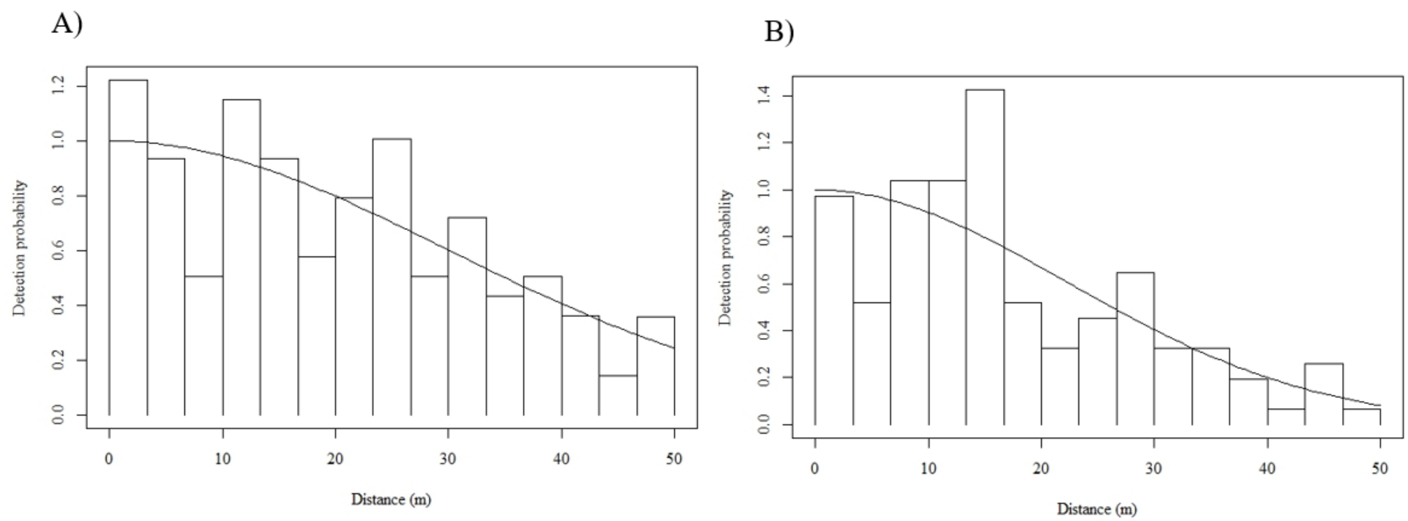

Figure 2.17. The estimated conventional distance sampling detection function for (A) survey 1 and (B) survey 2 at 50% coverage from coveys pooled across treatments on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2017.

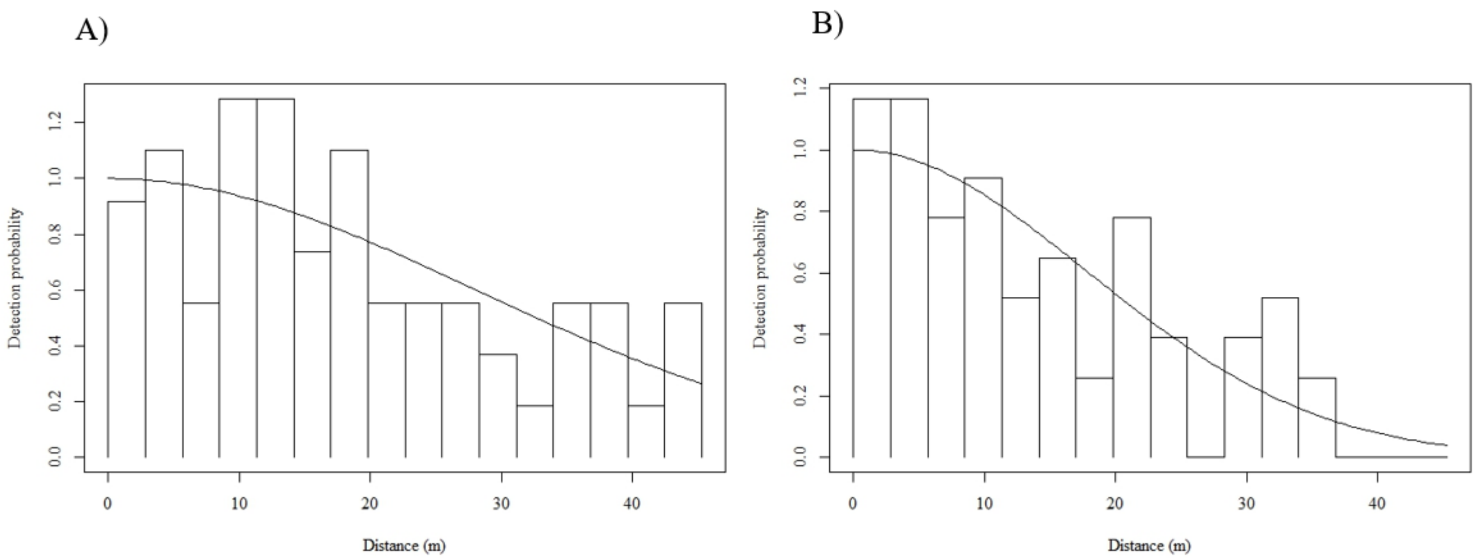

Figure 2.18. The estimated conventional distance sampling detection function for (A) survey 1 and (B) survey 2 at 50% coverage from coveys pooled across pastures on the reference sites in Jim Hogg County, Texas, USA, 2017.

similar between survey 1 to survey 2 for the continuous moderate and rotational high grazing treatments, but different between survey 1 and survey 2 for the continuous high and rotational moderate grazing treatments (Table 2.9). Detectability and density varied the most between survey 1 and 2 for the continuous high and rotational moderate grazing treatments. The CV($\hat{D}$) for each survey within treatments was above the recommended 20% but did not differ by more than 10% between each survey except for the continuous high grazing treatment. Within a 50% survey on an individual pasture, I did not achieve the recommended amount of detections for any treatment site.

Between surveys, within reference sites, probability of detection did not change between survey 1 and survey 2 for the Pinto and Agua Dulce pastures (Table 2.10). On all pastures, density increased by 25–30% from survey 1 to survey 2. Within a 50% survey on an individual pasture, I did not achieve the recommended minimum number of detections for any pasture.

Target Coefficient of Variation.—In 2014, I flew a total of 380 km (1 complete survey at 100%), detected 143 coveys with a CV of 11.5%. Based on 2014 surveys, the total line length necessary to achieve a target CV of 20% is 120 km with 47 detections expected, 215 km for 15% CV and 83 detections expected, and 484 km for 10% CV with 188 detections expected. Surveys of the Coloraditas Grazing Research and Demonstration Area conducted at 50% cover approximately 190 km/survey. If I were restricted to 50% coverage in 2014 this would yield a CV of 18% (Buckland et al. 2001: 243, eqn. 7.6), which is below the recommended target (20%), but higher than what I achieved with actual surveys flown at 100% coverage.

DISCUSSION

Video Surveys

Hypothesis 1. —The video footage from these surveys supported the hypothesis that

Table 2.9. Number of transects (k), total transect length, (m, L), number of northern bobwhite covey detections (n), detection probability ($\hat{p}$), density (bobwhites/ha [$\hat{D}$ ± SE]), coefficient of variation (CV[$\hat{D}$]), 95% confidence intervals (95%CI [$\hat{D}$]), from 2017 surveys each at 50% coverage (1 and 2) and combined (100%) by treatment site on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA. Also shown for each model is effective strip width (ESW), and 3 goodness of fit (GOF) tests: Kolmogorov–Smirnov (K-S), Cramer VonMises uniform (CvM [unif]), and Cramer VonMises cosine (CvM [cos]).

Treatment[a]	k	L	n	$\hat{p}$	$\hat{D}$			Goodness of Fit (GOF)		
					$\hat{D}$ ± SE	% CV ($\hat{D}$)	95% CI	CvM (cos)	CvM (unif)	K-S
CH survey 1[b]	17	48238.88	25	1.00	0.40 ± 0.14	34.61	(0.20–0.79)	0.80	0.70	0.83
CH survey 2[b]	16	47846.02	32	0.63	0.89 ± 0.20	22.40	(0.57–1.38)	0.40	0.50	0.40
CH combined	33	96084.9	57	0.81	0.60 ±0.11	17.45	(0.43–0.85)	0.80	0.90	0.90
CM survey 1	15	34214.67	18	0.50	0.60 ± 0.23	30.53	(0.32–1.11)	0.30	0.30	0.18
CM survey 2	15	34351	19	0.59	0.74 ± 0.27	37.80	(0.35–1.58)	0.80	0.90	0.92
CM combined	30	68565	37	0.53	0.67 ± 0.16	25.47	0.40–1.11)	0.40	0.50	0.57
RH survey 1	16	55748	46	0.79	0.79 ± 0.21	25.51	(0.47–1.33)	0.80	0.80	0.55
RH survey 2	15	51538	31	0.74	0.62 ± 0.16	21.6	(0.40–0.94)	0.30	0.40	0.21
RH combined	31	107286	77	0.77	0.72 ± 0.20	18.71	(0.49–1.04)	0.30	0.40	0.15
RM survey 1[b]	16	51611	46	0.74	0.72 ± 0.17	22.55	(0.47–1.15)	0.80	0.90	0.86
RM survey 2[b]	16	48759	42	0.51	1.11 ± 0.28	24.91	(0.67–1.80)	1.00	1.00	0.93
RM combined	32	100370	88	0.62	0.90 ± 0.14	15.22	(0.66–1.21)	0.90	1.00	0.98

[a]Treatments: CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate

[b]Detection functions differ, combined estimate includes survey number as a covariate

Table 2.10. Number of transects (k), total transect length, (m, L), number of northern bobwhite covey detections (n), detection probability ($\hat{p}$), density (bobwhites/ha [$\widehat{D}$ ± SE]), coefficient of variation (CV[$\hat{D}$]), 95% confidence intervals (95%CI [$\hat{D}$]), from 2017 surveys each at 50% coverage (1 and 2) and combined (100%) by pasture in the reference sites in Jim Hogg County, Texas, USA, 2017. Also shown for each model is effective strip width (ESW), and 3 goodness of fit (GOF) tests: Kolmogorov–Smirnov (K-S), Cramer VonMises uniform (CvM [unif]), and Cramer VonMises cosine (CvM [cos]).

Reference	k	L	n	$\hat{p}$	$\hat{D}$			Goodness of Fit (GOF)		
2017					$\hat{D}$ ± SE	% CV ($\hat{D}$)	95% CI	CvM (cos)	CvM (unif)	K-S
Atole survey 1[a]	12	37351	23	0.90	0.60±0.19	31.13	(0.32–1.11)	0.7	0.7	0.65
Atole survey 2[a]	11	35938	25	0.61	0.94±0.25	26.59	(0.55–1.59)	0.9	0.9	0.93
Atole combined[a]	23	73289	48	0.72	0.72±0.12	17.24	(0.51–1.02)	0.8	0.9	0.91
Pinto survey 1	10	31066	12	0.49	0.52±0.16	31.57	(0.27–0.98)	0.6	0.5	0.60
Pinto survey 2	9	28480	12	0.55	0.78±0.29	37.94	(0.37–1.66)	0.6	0.7	0.46
Pinto combined	19	59546	24	0.45	0.67±0.27	34.13	(0.41–1.55)	0.7	0.8	0.72
Agua Dulce survey 1	10	40280	20	0.76	0.38±0.12	31.57	(0.21–0.72)	1	1	1.00
Agua Dulce survey 2	9	36252	21	0.56	0.64±0.25	38.68	(0.29–1.43)	0.8	0.9	0.94
Agua Dulce combined	19	76532	41	0.64	0.50±0.12	23.96	(0.31–0.81)	1	1	0.99

[a]Detection functions differ, combined estimate includes survey number as a covariate

coveys rarely flush behind the helicopter. The single undetected covey flush behind the helicopter reinforces the supposition that the helicopter survey speed and altitude are sufficient to flush coveys upon approach. The vantage points of the camera in 2015 allowed me to view the observer and in some instances, a covey flush in the same frame. Where I could see both, I was able to confirm instances were observers were not recording distances from the initial point of covey flush. Incorrectly identifying the initial flush point was indicated by an observer angling the rangefinder toward a different location than where the observed flush occurred. I can correct this in future surveys by using trained observers, and evidence of an assumption violation enforces the need for observer training days where observers can practice detecting coveys with rangefinders with less pressure. Scheduling and weather conflicts forced the cancellation of 2 scheduled training days in 2016 and 2017. In those instances, I trained observers with equipment on the ground. The shortcomings of facing the cameras toward the tail rotor are that the footage did not address perception bias at $g(0)$ as I could not directly survey the line or availability bias in that I likely could not see un-flushed coveys in the video. Conventional distance sampling methods account for and expect missed detections at distances where the cameras were recording.

Given that pairs of bobwhites are typically rare in December, the missed flush may be the result of (1) part of the larger detected covey flushing for the second time or, (2) part of a larger detected covey that did not flush initially. If a rangefinder experiences a malfunction or does not register a reading on the first hit, the hover becomes prolonged while observers resolve technical difficulties. During an extended hover, coveys may settle and partially flush again once the survey is resumed. Observers in the helicopter communicate to avoid double counting a flushed covey; however, I was not able to determine this from the video alone. The only way to remedy this is to make a note on which coveys partially flush or flush twice in the helicopter and mark them with the timestamp on the Juno.

For the forward-facing camera, I was able to obtain the view necessary to survey directly below the helicopter. This camera also had a timestamp, which made matching the observations on video to the data more efficient. I observed 5 occasions where singles and pairs of bobwhites flushed near (<5 seconds) to other detections. These were likely part of a detected covey that did not flush together. As described above, I often observed delayed flushing in the helicopter and typically made the call to include these as part of the detected covey; however, I could not confirm this through the footage. There were 6 separate occasions where single birds flushed, but the resolution was too low to identify these birds as bobwhites positively. These flushes occurred > 60 seconds outside of recorded detections. Because of the restricted view, I had less time to observe the flight pattern of these undetected flushes, which can help in identification, mainly when birds are not in coveys.

The video survey in 2016 served as a trial run for the use of a digital observer in trial-observer mark-recapture distance sampling. The camera must be able to determine the covey size and perpendicular distance for any detections marked by the camera but not recaptured by the observers in the footage. There are 2 realizations for the survey and distance data provided by the inclusion of the camera. The camera can be used to (1) survey a strip where the swath width of the recorded area corresponds to a distance bin; here all detections made by observers in the helicopter would also be analyzed in distance bins (i.e., 0–5, 6–10, 11–15) rather than exact distance data. Rangefinders would still be necessary to time stamp coveys and corroborate duplicates with the camera time stamp; however, the data would be binned in analyses. The camera can also be used (2) as a second observer measuring exact distances. To measure distances, the camera must be set at a known angle, and an object with a known length and height must be recorded at the survey altitude to set a scale for the video. Future studies should calculate perpendicular distances using a known swath width. The easiest way to digitally measure distances would be to set the camera angle at Nadir or 0°. Swath width would be calculated using the following formula,

$$Width = \frac{\text{Altitude}}{\cos(\propto)} \times 2\tan\frac{FOV}{2}$$

Where FOV corresponds to the camera field of view. Once the width was known, I could (1) use the swath as distance bin or from 0 to x distance on either side of the center line, or (2) determine the centerline of the video (0 distance) and measure distance to covey by equating the number of pixels to a meter from the scale.

There may be value in refining digital survey methods with the use of drones and infra-red cameras. The resolution at ground level was poor in both the GoPro and FlightCam, even at 1080p making it difficult for observers to positively identify missed detections as bobwhites unless the shape and covey formation was clear. Drones with infrared cameras may be able to survey at a higher altitude where a broader swath of area could be surveyed. This would allow the data to be analyzed as a strip transect which would eliminate issues with 3 of the critical assumptions of distance sampling (Buckland et al. 2015).

Covariates Affecting Detection

Hypothesis 2. —The covariates selected in the top model supported my hypothesis that observers with low experience would affect the probability of detection on the line. These results also supported my hypothesis that time of day and brush cover would not affect detectability, but I did not expect cloud condition to be a significant covariate. Observers were able to detect coveys further out on clear days compared to overcast days; however, cloud condition was less influential on detection compared to experience.

The effect of observer experience could be the result of experienced observers guarding the track line (0 distance) to avoid missing detections at small distances and missing a larger proportion of detections at further distances. Guarding the track line could result in a $g(0) > 1$, which would positively bias density estimates (Buckland et al. 2001;2015). I addressed guarding the track line with training and review of proper on search and survey protocol each year, however, it still may occur in some situations. This should be done despite the observer's experience level. These results could also be the result of the way I calculated experience for detection (i.e., pooling over 2 back seat observers). Observer differences have been documented to improve the detection function beyond models with distance alone by Diefenbach et al. (2003), Norvell et al. (2003), and Marques et al. (2007). These studies included individual observer as the covariate rather than observer experience, as in this case. I did not record the individual making the detection because the front seat observer and pilot make many of the sight detections and the back-seat observers locate the detection with the rangefinder. However, future analyses may benefit from modeling the individual back seat observer that recorded the detection as well as their level of experience. For long-term studies, observer differences could increase sampling variance and reduce the statistical power needed to detect trends over time (Diefenbach et al. 2003) and therefore, care in using experienced observers with knowledge of distance sampling procedures should be a priority moving forward.

Cloud cover did not alter an observer's ability to make detections on the line, but detections decreased with increasing differences on overcast days compared to clear days. The detection function for cloudy days (i.e., scattered or mostly cloudy conditions) was similar to the detection function for clear days. Detection of coveys during overcast conditions was anecdotally expected to affect bobwhite flushing behavior in that coveys would be less likely to flush under cloudy skies. During helicopter surveys for starlings and blackbirds, flushing did not occur on 6 flights where cloud cover was >95% (Mott 1983). Wellendorf et al. (2004) determined that calling rate of bobwhite coveys decreased as cloud cover increased. However, I was unable to find any literature that correlated flushing behavior with cloud cover for bobwhites. Based on these results, I would not suspend surveys based on cloud cover but would recommend increasing search effort at midranges (20–40 m) on overcast days and include cloud cover as a covariate in detection models.

While other covariates improved model fit from a distance alone, they did not significantly vary significantly with distance. DeMaso et al. (2010) recommended conducting surveys during the first 3 and last 3 hours of the day based on covey foraging activity patterns. Bobwhite activity decreases during the midday hours after foraging, particularly during high midday temperatures when bobwhites seek refuge from heat underbrush. Detection rate during helicopter surveys did not taper with the time of day despite the expected decreases in activity. Much of the daily activity patterns of bobwhites are dependent upon temperature and wind speed with activity expected to increase on cool days with light wind (Sisson 2005). Despite an expected decrease in activity, I recorded 348 detections (15% of total) when temperatures exceeded 26 °C and 27 detections (1% of total) when wind speed exceeded 6.7 m/s. I recorded detections in temperatures up to 31.6 °C. While temperature did not significantly influence detection over distance alone, flushing bobwhites during high temperatures likely induced stress and detection distance slightly increased as temperature increased toward 30 °C likely from observer fatigue. The wind was likely not a significant covariate in detection because pilots would postpone or suspend surveys when wind speeds became dangerous. The pilots never surveyed at wind speeds over 8.2 m/s.

Survey Coverage

Hypothesis 3. — The data supported my hypothesis that density and precision estimates simulated below 50% coverage were more variable and less precise in all scenarios and that there were few differences between surveys simulated at 50% and actual surveys at 100% (2014 and 2015) as well as actual surveys flown at 50% and combined estimates at 100% (2016 and 2017). In all simulations from 2014 and 2015, a drop in survey coverage below 50% resulted in wider 95% CI for density and detection probability, as well as CV($\hat{D}$) >17% and a CV ($\hat{p}$) >5%. Based on simulations, transects for distance sampling surveys on the Coloraditas Grazing Research and Demonstration Area and reference areas should not be spaced further than 400 m (<50%).

When comparing replicate surveys on the Coloraditas Grazing Research and Demonstration Area from 2015, despite the poor model fit in survey 1, detection probability and density were similar to survey 2. However, as the number of transects and detections were reduced with survey coverage at 50 and 25%, model fit and density start to deviate from survey 1 at 100%, while the model fit and density for survey 2 remain stable regardless of coverage. Without the validity of the $g(0)$ assumption at survey 2, estimates from survey 1 alone would be difficult to substantiate at any level of coverage.

Detection at $g(0)$ was < 1 for the 2015 survey 1; this was likely due to observers with no experience (0 days) in the back seat. Days of experience for the back-seat observers increased from 0 to 10 days (combined experience) from survey 1 to survey 2. I attempted to prevent low detections on the line in 2016 by conducting observer training before surveys and by using the same back seat observers with similar experience levels for each survey. The consistency between the 2 surveys at 100% coverage in 2015 reinforced the prediction that distance sampling will produce similar estimates over a short time frame given a stable population in expected (Buckland et al. 2001).

Completing a survey at 100% coverage on both the Coloraditas Grazing Research and Demonstration Area and reference sites required 3 consecutive days of the survey. Conducting 2 separate surveys at 50% coverage in 2016 and 2017 was beneficial in that I could conduct surveys of a whole pasture in a single day rather than over 2–3 days with fluctuations daily weather conditions without sacrificing a decrease in survey coverage below 100%. This method allowed me to assess differences in survey coverage (100% vs. 50%) and survey date at half of the cost of the replicate 100% surveys in 2015. Flying surveys at 50% reinforced the results of the simulated estimates that density did not differ between surveys flown at 50% and 100%.

Hypothesis 4. — Contrary my hypothesis, there was a significant increase in density from survey 1 to survey 2 in 2016 on the Coloraditas Grazing Research and Demonstration Area, but all other surveys were statistically similar within years and study sites for 2015 and 2017. The repeatability of estimates within years was consistent between surveys 2 at 100% in 2015 and 2 surveys at 50% in 2017. In 2016, there was an increase in both mean covey size and encounter rate between the 2 Coloraditas Grazing Research and Demonstration Area surveys, but I can only speculate on why this increase occurred. There may have been a difference in the spatial distribution of bobwhites between the 2 sets of transects; however, I did not observe a difference in density in 2017. The detection function between the 2 surveys at 50% on the Coloraditas Grazing Research and Demonstration Area were similar in 2016 but differed in 2017 despite consistency in observers between the 2 surveys within each year. Potential covariates associated with differences in detection probability between the 2 surveys were highly correlated with survey number and revealed little about why the differences occurred. If future surveys continued to be conducted at 100% but staggered at 50% coverage, I recommend modeling the data with a multiple covariate distance sampling analysis with survey number as a covariate to help explain variations in the detection function. I also recommend these surveys be flown closer in time to reduce the chance of temporal variation that occurred in 2016.

The data did not support my hypothesis that there would be no change in detection and density between replicated surveys within a year on individual stratum (grazing treatments and reference site pastures). Detection probability differed between individual surveys within a treatment on 4 occasions from 2015–2017. Density increased by 50% on grazing treatments between surveys on where detection probability differed; except for the rotational high survey in 2015 where observers made >100 detections in each survey. Based on survey comparisons within substrata for 2016 and 2017, I do not recommend surveying any of the grazing treatments or pastures at 50% coverage due to a low number of detections (<60) over few transects. These surveys exhibited high variance (CV ($\hat{D}$) >20%) and wide 95% CI. Had I only conducted surveys at 50% in 2016 and 2017, treatment level density estimates would be unreliable. Any survey at 50% would need to be replicated to achieve the proper number of detections or modeled with a global detection function, which may not reflect any differences in detectability by treatment. Individual treatment densities are best modeled using a multiple covariate distance sampling analysis with stratum (or treatment) as a covariate, but the increased number of transects at 100% helped improve the encounter rate on the smaller strata. Surveys at 50% coverage are more appropriate when (1) high population densities are expected, (2) independent estimates for individual strata are not necessary, and (3) areas are sufficiently large enough to survey 10–20 transects. I do not recommend any survey designed with <25% survey coverage.

The appropriate survey effort to meet sample size requirements can also be determined by estimating the total line length needed to achieve a targeted CV (Buckland et al. 2001;2015). In this case, a small-scale pilot survey or information from previous literature is necessary to estimate effort at target CV (Buckland et al. 2001:242, eqn. 7.1). Alternatively, researchers can conduct a more extensive pilot survey and define a targeted CV based off empirical estimates from the survey rather than from the literature (Buckland et al. 2001: 243, eqn. 7.5). This approach is useful when refining a second year of a study.

A better solution for researchers to estimate the optimal amount of survey effort may be to carry out simulations of surveys with different design options using the R package DSsim (Marshall 2014) in Program Distance. In this program, the user defines the survey area and estimates the population distribution and the package generates transect design realizations and fits a detection function to the distance data based on each design (Buckland et al. 2015). The bias associated with the density estimates as well as the total effort associated with each design can be helpful in designing line-transect distance sampling surveys (Buckland et al. 2015).

Conclusions

Each December, many ranches across South Texas conduct aerial surveys to estimate northern bobwhite density. Researchers and biologists employ distance sampling methods and managers typically adjust their counts using an estimator derived from distance sampling surveys. While there is considerable research dedicated to testing the feasibility of satisfying the assumptions of distance sampling and refining the survey technique (Guthery 1988, Shupe et al. 1987, Rusk et al. 2007; Schnupp 2009), assuming that the results from these studies are applicable to all studies result in biased estimates. Understanding the amount of effort needed to meet the minimum requirements of distance sampling as well as the covariates or survey conditions that most affect detection should be considered with each survey, whether it be for management or research purposes.

*Survey Recommendations***.** — Based on these tests on the performance of density estimates under the current recommended conditions for line-transect distance sampling for estimating bobwhite population densities in rangelands, I do not recommend conducting any survey below 50% coverage, but 50% is likely acceptable for large pastures. When smaller stratum (or pasture) specific density estimates are needed, I recommend surveying at 100% coverage and then use the formulas provided by Buckland et al. (2001) to adjust in future. The survey date in December should not affect density estimate, but I recommend conducting replicate surveys at either 50% or 100% to improve precision. As has been confirmed in the past, use of trained observers is the most critical factor to consider when conducting any survey to estimate populations. For the methods used in this study, observers greatly benefit from in-flight training with rangefinders, regardless of their experience level. I did not find weather, time of day, or brush cover to influence detection probability, but I recommend recording these covariates with detections mainly where extreme conditions (i.e., dense brush, high wind, high temperature) occur.

There should be a continued focus on the use of technology and mark-recapture distance sampling for relaxing the assumptions of distance sampling with bobwhites. Strip transects using infrared technology and drones may be an alternative to distance sampling for estimating bobwhite population density in rangeland environments, but much more work is needed.

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CHAPTER III.

MONITORING VEGETATION AND NORTHERN BOBWHITE DENSITY DURING FOUR YEARS IN A SOUTH TEXAS CATTLE GRAZING DEMONSTRATION AREA

ABSTRACT

The northern bobwhite (*Colinus virginianus*) is an economically valuable upland game bird commonly found co-occurring on South Texas ranches with cattle and co-utilizing similar resources. Cattle grazing is one of the dominant land-uses in South Texas and often is geared toward increasing cattle herd performance and productivity (i.e., weaning weight, breed up), rather than increasing heterogeneity of habitat conditions for bobwhites. The goals of this study were to monitor vegetation, and bobwhite density among 4 grazing treatments over 7,689 ha on the Coloraditas Grazing Research and Demonstration Area, San Antonio Viejo Ranch in Jim Hogg County, Texas from 2014–2017. Grazing systems and stocking rates were selected to mimic regional grazing management practices in the coastal sand sheet of Texas rather than tailor grazing management toward bobwhites. The Coloraditas Grazing Research and Demonstration Area was previously subjected to a long history of intense grazing and was deferred from March 2014 to December 2015. Grazing was initiated in 4 treatments in December 2015; continuous year-long grazing at a high (1 Animal Unit [AU]/14 ha) and moderate (1 AU/20 ha) and rotational (3 pasture 1 herd) grazing at a high and moderate stocking rate. I also monitored 3 reference sites on the San Antonio Viejo Ranch outside the grazing demonstration, where grazing had not been deferred, and stocking rates were variable as a baseline for comparison to the grazing treatments. I monitored the following response variables: (1) forage standing crop at the end of each growing season and at each cattle rotation from June 2014–December 2017; (2) forage standing crop inside and outside of grazing exclosures and forage

utilization at each growing season from November 2015–December 2017; (3) vegetation structure and composition at transects each October 2015¬2017; and (4) bobwhite density using line transect distance sampling each December 2014¬2017. Within the deferred period, forage standing crop increased from June 2014 to December 2015 by >100% on all treatments. After grazing was implemented, forage standing crop decreased with each year of the study from 2015¬2017. Percent grass, visual obstruction, and bunchgrass density decreased with each year of the study regardless of grazing system or stocking rate, while bare ground increased with each year. Forb cover was higher on the reference sites compared to Coloraditas Grazing Research and Demonstration Area grazing treatments and species richness varied between years within grazing treatments. There were no differences in bobwhite density on the Coloraditas Grazing Research and Demonstration Area between grazing system or stocking rate, but bobwhite density differed between each year in the before (2014 vs. 2015), after (2016 vs. 2017), and before vs. after periods of low (2014 vs. 2017) and high precipitation (2015 vs. 2016). Breeding season precipitation explained 59% of the annual variation in bobwhite density on the Coloraditas Grazing Research and Demonstration Area. Pooled across treatments, Bobwhite density differed on the Coloraditas Grazing Research and Demonstration Area compared to the reference sites in 2015 (1.33 ± 0.09 vs. 0.70 ±0.09) and 2016 (2.05 ± 0.15 vs. 1.34 ± 0.19) during years of above average breeding season precipitation. Timing and duration of precipitation overwhelmed the impacts of grazing system with respect to bobwhite density and vegetation structure in the semi-arid environment used for this study.

INTRODUCTION

Common grazing management practices in semiarid rangelands often neglect the use of cattle to increase the spatial heterogeneity of vegetation (Fuhlendorf and Engle 2001), thus creating conflicts between grassland conservation and cattle production goals (Derner et al. 2009). Despite the wealth of knowledge on cattle as management tools for conservation in mesic areas (Fulendorf and Engle 2001), the appropriate grazing regime (i.e., system and stocking rate) to benefit grassland conservation in semi-arid rangelands are poorly understood (Derner et al. 2009).

The northern bobwhite (*Colinus virginianus*; hereafter bobwhite) occurs throughout South Texas rangelands where cattle grazing is widespread. According to the Texas Land Trends (2018) database, 78% of the land in the South Texas Brush Country is used for grazing. During the past two to three decades, many landowners and ranch managers in South Texas have diversified income streams through lease-fee hunting, and a vital component these hunting activities have been focused on bobwhites. Like many grasslands and grassland-shrubland birds in North America, bobwhites are sensitive to overgrazing, drought, and invasions by woody shrubs and exotic plants (Brennan and Kuvlesky 2005), complicating the co-production of cattle and bobwhites due to shared resources. Bobwhite habitat is characterized as having a range of vegetation configurations for nesting, screening, loafing, and foraging cover in addition to heterogeneity in vegetation structure (Guthery 1997, Kopp et al. 1998, Arredondo et al. 2007). Where precipitation is limited, improperly managed cattle grazing can negatively impact heterogeneity; and thus, food abundance, nesting substrate, and escape cover for bobwhites (Ortega-S and Bryant 2005). These realities have left some bobwhite hunters willing to incur the extra costs of adding grazing fees to their hunting lease costs to control factors that may affect their hunting opportunities (Hernández et al. 2013).

While grazing dominates regional land use in South Texas, the market value per acre of land used to manage wildlife has increased by 96% from 1997 to 2012 (Texas Land Trends 2018). Bobwhite lease hunters in South Texas spent $35 million on hunting operations in 2006 (Dodd et al. 2013). The industry created by hunting is beneficial to rural communities by boosting small businesses and providing jobs (Burger et al. 1999, Cooper et al. 2002). Bobwhite populations have been declining since the 1800’s (Hernández et al. 2013), the rate of these declines have been estimated to be approximately >4%per year from 1966 to 2012, range-wide (Sauer et al. 2014). Much of the decline in the eastern portions of the bobwhite's range have been attributed to broad-scale changes in land use (i.e., modern agriculture practices, timber, and development; Roseberry et al. 1979, Brennan 1991). Although wildlife managers may seek to limit grazing to benefit bobwhites, the large contiguous tracts of rangeland historically established for grazing in South Texas play an essential role in the relative stability of the bobwhite populations that inhabit them (Hernández et al. 2013). When Spanish explorers arrived in southern Texas in the 17th and 18th centuries, they established large acreage settlements from Spanish land grants (Fulbright et al. 1990). With the land being poorly suited for row crop agriculture, but adequate for raising large herds of livestock, grazing provided the economic foundation for the small populations of Europeans who settled there. The necessity of vast grazing lands created inaccessibility that, coupled with the isolation of South Texas, has contributed to the intact nature of the rangelands on the landscape today and as a result, one of the largest areas of remaining contiguous bobwhite habitat in the United States (Brennan and Kuvlesky 2005).

Given the relative importance of cattle grazing and bobwhites in South Texas, previous research projects have attempted to identify combinations and variation of grazing system and stocking rate that would best suit bobwhite productivity. However, the demonstrated effects of grazing have lacked consensus due to confounding factors, including variation in range site productivity and precipitation over short-term studies (i.e., <2 years; Briske et al. 2008). Furthermore, the management implications of these studies have been limited due to use of grazing systems seldom practiced. There have been 6 studies focused on grazing and bobwhites in South Texas since 1978, 5 of which included focus on short duration grazing (SDG) or high-intensity low frequency grazing systems (Hammerquist-Wilson and Crawford 1978, Campbell-Kissock et al. 1984, Bareiss et al. 1986, Schulz and Guthery 1988, and Wilkins and Swank 1992). Two additional studies were conducted on the impacts of SDG on ground-nesting birds (Koerth et al. 1984, Jensen et al. 1990) by simulating nest trampling. The focus on SDG came after Allan Savory developed a holistic grazing method with cattle in Africa and published successful results of range improvements with increased stocking rates in semi-arid environments (Holechek et al. 2011). Despite the success by Savory (Savory and Parsons 1980, Savory 1983; 1988) the implementation of Savory's method in the United States did not improve range condition and cattle productivity beyond traditional systems (Heitschmidt et al. 1990, Manely et al. 1997). While Schulz and Guthery (1988) and Wilkins and Swank (1992) concluded the SDG created vegetation and bare ground structure beneficial to bobwhites, the costs of infrastructure and labor associated with SDG generally discourage use of this grazing system by cattle ranchers in South Texas.

Operations, where cattle are used solely to improve bobwhite habitat (i.e., ranches used for hunting recreation only), are the exception rather than the rule in South Texas. Greater flexibility in grazing practices may characterize these operations because the land was purchased solely for recreation and landowners do not rely solely on income from cattle. Many of the operations in the region may partially sustain themselves on the income from wildlife, but wildlife is secondary to their primary goals of cattle production. Grazing systems in these operations typically fall into a continuous or rotational (deferred rotation). Stocking rates on native rangelands are variable and ranchers may not set according to annual forage production depending upon the scale and investment of the operation.

To improve knowledge on grazing and wildlife responses, the East Foundation implemented a large-scale grazing demonstration project called the Coloraditas Grazing Research and Demonstration Area to test the regional grazing paradigms of a high (Animal Unit [AU]/14 ha) and moderate (AU/20 ha) stocking rate within commonly used grazing systems. While fixed stocking rates are generally deemed unsuitable in variable, stochastic environments (Westoby et al. 1989), cattle operations may subscribe to maintaining stocking rates with supplemental feed when vegetation conditions decline (Toulmin 1994). The decision to hold stocking densities constant represents scenarios where ranchers in drought susceptible environments must either suffer the financial loss of selling herds to a flooded cattle market or holding on to stock and incurring the costs of supplemental feed and increased rangeland degradation (Shrum et al. 2017). Furthermore, traditional paradigms that rangeland degradation is the consequence of excessive stocking rates alone, and that low fixed stocking rates are appropriate through time persist (Müller et al. 2007).

The goals of the Coloraditas Grazing Research and Demonstration Area were to monitor the long-term effects of these grazing systems and stocking rates on the wildlife and vegetation. The demonstration sought to mimic real-world scenarios by holding constant multiyear stocking rates but allowing flexibility in management decisions such as time of rotation, workings, and the decision to provide supplemental feed. In this way, the demonstration would provide insight on the benefits or consequences of an inflexible stocking rate at a high and moderate (conservative) level between a continuous and rotational grazing system at an operational scale.

The objectives of this chapter are to assess the magnitude of difference in (1) forage standing crop, forage utilization, and vegetation structure and composition, and (2) bobwhite density response among 4 grazing treatments, before and after grazing treatments were applied from 2014–2017.

The following research hypotheses were related to my objectives:

Forage Standing Crop and Utilization

Hypothesis 1.A —If forage production in this study follows the same results found in 87% of grazing studies (Briske et al. 2008), there would be no statistical difference in forage standing crop (inside or outside exclosures) between rotational and continuous grazing systems on the Coloraditas Grazing Research and Demonstration Area after grazing implementation.

Hypothesis 2.A — The grazing optimization hypothesis states that plant productivity will increase with grazing intensity up to some optimal grazing intensity (McNaughton 1979), but then decreases. After implementation of cattle grazing, forage standing crop (inside or outside exclosures) on treatments with a moderate stocking rate would be greater than forage standing crop on pastures grazed at high stocking rates.

Hypothesis 3.A — I expected forage utilization rates on grazing treatments with a moderate stocking rate to be lower compared pastures grazed at high stocking rates. I expected utilization rates averaged across in pastures grazed in a continuous system to be higher compared to pastures grazed in a rotational system.

Hypothesis 4.A — Because there were few differences in stocking rates between the grazing treatments on the Coloraditas Grazing Research and Demonstration Area and reference sites, forage standing crop and utilization would be similar between the 2 study areas after grazing implementation on the Coloraditas Grazing Research and Demonstration Area.

Vegetation Structure and Composition

Hypothesis 1.B —Cattle grazing has been hypothesized to increase forb growth when moderate grazing occurs in late successional rangelands (Holechek et al. 2011). After grazing implementation on the Coloraditas Grazing Research and Demonstration Area, I expected bare ground, forb cover, and species richness in treatments grazed in the continuous system to be higher than in rotational system and I expected grass cover and litter cover to be higher in the rotational system than the continuous. I expected the higher utilization in continuous grazing systems to remove residual standing grass crop and cover and increase bare ground, forb cover, and species diversity, and reduce grass cover and litter after building up during the deferment period.

Hypothesis 2.B — After grazing implementation on the Coloraditas Grazing Research and Demonstration Area, I expect grass cover, litter, bunchgrass density, and percent visual obstruction, and litter cover to be lower in treatments grazed at higher stocking rates compared to moderate stocking rates.

Hypothesis 3.B—After grazing implementation on the Coloraditas Grazing Research and Demonstration Area, I expected bunchgrass density and percent of visual obstruction in rotational systems to be higher than pastures grazed in continuous systems. I expected the periodic deferment in rotational grazing systems to leave higher and more grass cover and allow bunchgrass clumps to grow to a size necessary for bobwhite nest sites.

Hypothesis 4.B —I expected forb cover and bare ground to be higher (and thus, grass and litter cover to be lower) on the reference sites compared to the Coloraditas Grazing Research and Demonstration Area throughout the study where no deferment period occurred. I expected bunchgrass density and visual obstruction averaged over the reference sites to be lower than on the Coloraditas Grazing Research and Demonstration Area due to lack of deferment.

Hypothesis 5.B—Due to the short time period of this study, woody cover would not change from before to after grazing, or between grazing systems, or stocking rates. I do not expect woody cover to differ between the Coloraditas Grazing Research and Demonstration Area and reference sites.

Bobwhite Density

Hypothesis 1.C — In the absence of grazing treatments on the Coloraditas Grazing Research and Demonstration Area, I do not expect bobwhite density between 2014 and 2015 to change unless cumulative April–August precipitation increases between the years. Given increased precipitation, I also expect density on the reference sites to increase between 2014 and 2015. I expect bobwhite density on the Coloraditas Grazing Research and Demonstration Area to be similar to the reference sites in 2014 but be higher than the reference sites in 2015.

Hypothesis 2.C —Northern bobwhite density would be highest averaged across pastures within the rotational grazing system stocked at a high rate. I expected the higher stocking rate to increase bare ground and forb cover with periodic deferment providing areas with higher visual obstruction and more nest sites.

Hypothesis 3.C —After cattle grazing implementation, there would be no difference in average bobwhite density between the Coloraditas Grazing Research and Demonstration Area pastures and reference site pastures.

Hypothesis 4.C —Alternatively, variation in annual and breeding season precipitation will have an influence on both average vegetation conditions and bobwhite density and will overwhelm the influence of grazing regimes and stocking rates.

STUDY AREA

I conducted this study on 2 study sites on San Antonio Viejo ranch (60,298 ha) in Jim Hogg County, Texas: (1) Coloraditas Grazing Research and Demonstration Area (7,689 ha treatment area), and (2) 3 pastures ranging in size from 1,200 to 1,600 ha south of the Coloraditas Grazing Research and Demonstration Area (reference sites) (Fig. 3.1). The San Antonio Viejo ranch is located 32 km South of Hebbronville, Texas and is part of the collection of properties that make up the East Foundation. The property was previously a privately-owned ranch with a history of intense grazing and ranching activity dating back to the early 1900s. This ranch lies within the South Texas Plains Ecoregion (Gould 1960). Based on 30-year normal, average temperatures are between 12–13 °C in January and 27–30 °C in July (PRISM 2018). The 30-year average annual precipitation on the Coloraditas Grazing Research and Demonstration Area is 56.3 cm and was highly variable over the 4 years of this research (PRISM 2018; Fig. 3.2). A 3-year drought in the area lasting from 2011–2013 preceded this study. The mean monthly Palmers Drought Severity Index did not rise above a mild drought for any month, and severe to extreme drought persisted in 28 of the 36 months from 2011–2013 (Palmer Drought Severity Index 2018). Elevation ranges from 52 m on the eastern edge to 64 m on the western edge of the San Antonio Viejo Ranch.

The Coloraditas Grazing Research and Demonstration Area and reference sites are within the Coastal Sand Plain and Tamaulipan thorn scrub ecoregions (Omernik1987). The dominant soil series on the Coloraditas Grazing Research and Demonstration Area are the Nueces-Sarita association (40% of total area), Delmita loamy fine sand (30%), Delmita fine sandy loam (17%),

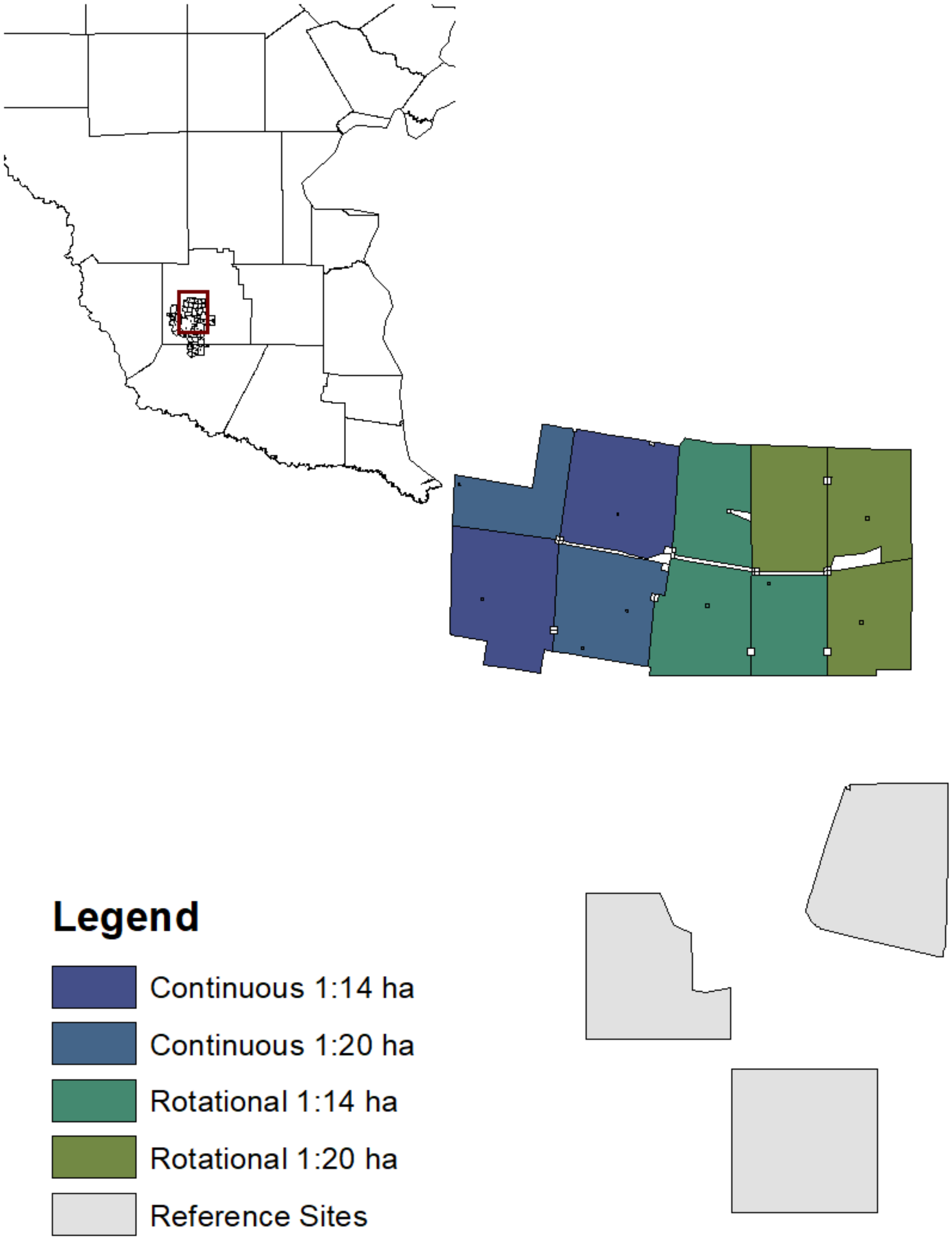

Figure 3.1. Treatments on the Coloraditas Grazing Research and Demonstration Area shown in color and 3 reference sites shown in gray located on the San Antonio Viejo Ranch in Jim Hogg County, Texas, 2014–2017.

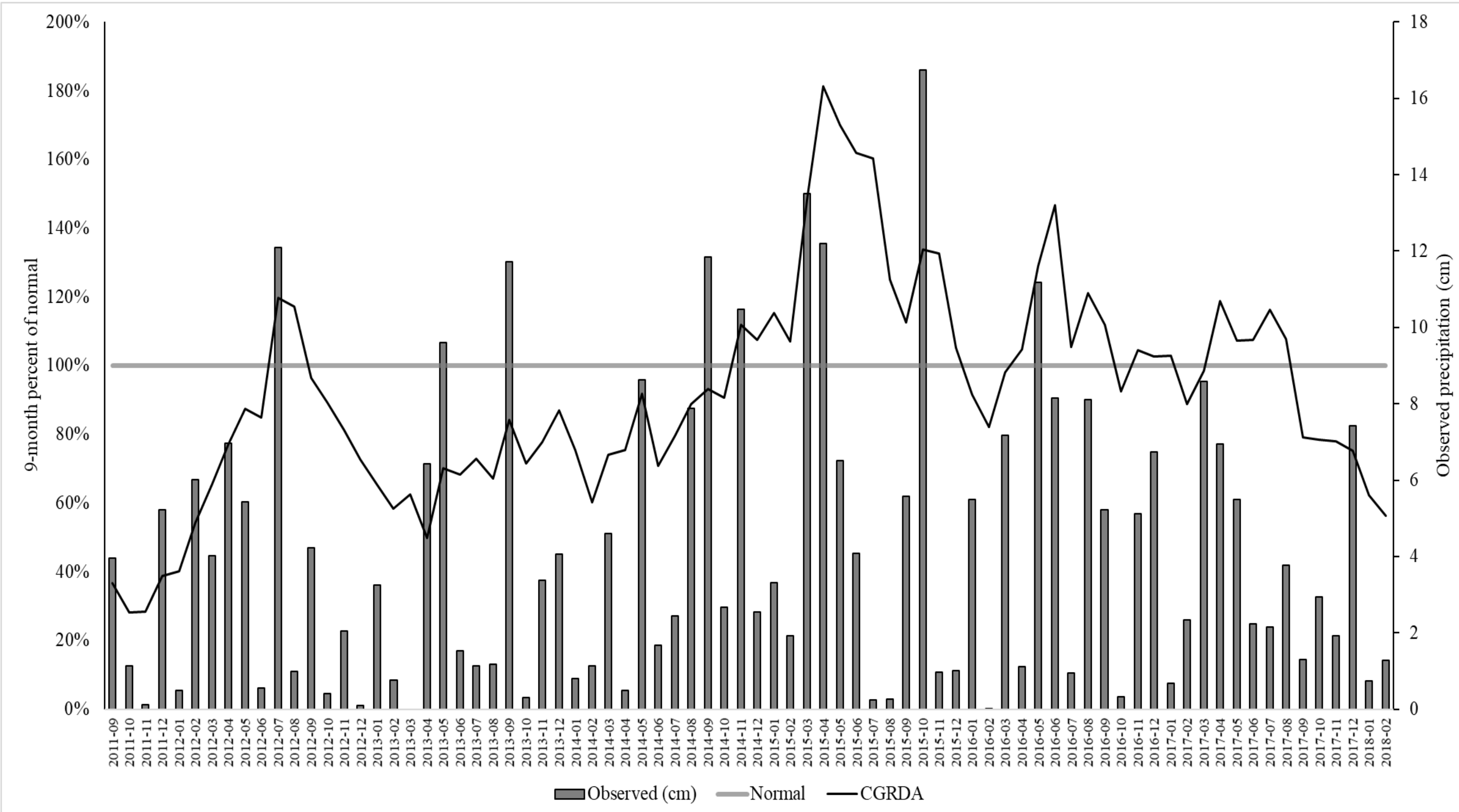

Figure 3.2. Observed cumulative monthly precipitation (grey bars) and the 9-month cumulative average percent of normal precipitation from 2011 to 2018 calculated from the center of the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA. The 9-month cumulative average normal precipitation was calculated using the 30 year monthly normal.

Comitas loamy fine sand (8%), Falfurrias fine sand (4%), and Cuevitas-Randado complex and Tela sandy clay loam (<1%; Soil Survey Staff 2015). The dominant soil series across the 3 reference sites are the Nueces-Sarita association (43% of total area), Falfurrias fine sand (16%), Delmita fine sandy loam (15%), Delmita loamy fine sand (9%), Comitas loamy fine sand (8%), Dune (8%), and Cuevitas-Randado complex (1%; Soil Survey Staff 2015). There are 6 different range sites on the Coloraditas Grazing Research and Demonstration Area of which 3 (Sandy PE 25-44, Loamy Sand PE 19-31, Red Sand Loam PE 19-31) make up 95% of the area (Soil Survey Staff 2015). These 3 range sites comprise 83% of the reference sites.

Honey mesquite (*Prosopis glandulosa*), huisache (*Acacia farnesiana*), Brasil (*Condalia hookeri*), granjeno (*Celtis pallida*), and Texas prickly pear (*Opuntia engelmannii var lindhiemerii*) dominated the woody plant community. Seacoast bluestem (*Schizachyrium scoparium var. littorale*), purple threeawn (*Aristida purpurea*), Lehman lovegrass (*Eragrostis lehmanniana*), spotted beebalm (*Monarda fruticulosa*), and woolly croton (*Croton capitatus*) dominated the herbaceous plant community. Tanglehead *(Heteropogon contortus*) was present on <3% of the total area in 2014.

Defining the bobwhite population.—The South Texas region is approximately 8,080,000 ha where more than 4,7000,000 ha of rangeland has been classified as habitat that will support a wild bobwhite population (Brennan 2014). I define the bobwhite population in this study as the sample population of bobwhites in South Texas within the Coloraditas Grazing Research and Demonstration Area and reference site pasture boundaries on the San Antonio Viejo Ranch from 2014 to 2017.

METHODS

Study Design

My study design goal was to monitor the impact of an environmental disturbance (in this case cattle grazing) on vegetation (forage standing crop, structure, and composition) and annual bobwhite density. I took measurements before and after the disturbance on 2 types of study plots: (1) the Coloraditas Grazing Research and Demonstration Area with 4 grazing (see Treatments below), and (2) 3 reference sites (Morrison et al. 2008). The Coloraditas Grazing Research and Demonstration Area pastures were a part of a before-after (B-A) study comparing vegetation and bobwhite density before and after implementation of 4 different grazing treatments (continuous moderate and high stocking rate, rotational moderate and high stocking rate, defined below).

Due to the inability to prohibit grazing on the San Antonio Viejo, I was unable to include any areas of no grazing control plots to monitor before and after the impact occurred on Coloraditas Grazing Research and Demonstration Area treatments. Reference sites represent 3 separate treatments that were not true replicates of each other because stocking rate and grazing regime varied among and within them over time and space, but conditions on the 3 sites represented changes outside of the controlled treatment area and changes where no grazing deferment took place (see Reference sites below). The reason for selecting these reference sites was to have a baseline for comparison that represented management outside the grazing treatments on the Coloraditas Grazing Research and Demonstration Area.

Grazing treatments. — Prior to the initiation of this study in 2014, the Coloraditas Grazing Research and Demonstration Area lacked the current cross fencing infrastructure and was grazed continuously at a stocking rate of 1 Animal Unit (AU)/12 ha. In March 2014, the Coloraditas Grazing Research and Demonstration Area was deferred from grazing for approximately 1.75 years before the implementation of grazing treatments in late 2015 in order to allow range to recover from drought and intense grazing. East Foundation Ranches LLC introduced 435 first year, same-aged, bred Santa Gertrudis cross heifers onto the Coloraditas Grazing Research and Demonstration Area from 3–16 December 2015. Cows were bred each spring with weaning and palpation occurring each fall to keep treatments stocked consistently. Grazing treatment plans included 4 treatments applied to 10 sub pastures (designated as observational units) within the Coloraditas Grazing Research and Demonstration Area: (1) high stocking– continuous grazing [2 pastures-2 herds]; (2) high stocking– rotational grazing [3 pasture-1 herd]; (3) moderate stocking–continuous grazing [2 pastures-2 herds]; and (4) moderate stocking– rotational grazing [3 pasture-1 herd]. East Foundation Ranches LLC categorized a high stocking rate as 1 AU/14.2 ha and a moderate stocking rate as 1 AU/20.2. The present stocking rates levels were set according to uncited regionally paradigmatic definitions of "high" and "moderate." Dividing the pasture North to South, the western 4 pastures were grazed continuously, and the eastern 6 pastures were grazed rotationally (Fig. 3.1). Once cattle were stocked, the decision to rotate the herds in the rotational high and moderate was based on cattle the foreman's visual assessment of forage standing crop and cattle body condition.

Reference sites. — I incorporated 3 reference sites to allow for better interpretation of treatment effects on bobwhite density and vegetation structure (Fig. 3.1). I initially selected 3-1,618 ha blocks of land that I surveyed in 2014. These blocks overlapped with adjacent pastures, water lots, and traps. To keep track of the stocking on the reference sites more thoroughly, I moved the blocks in 2015 so that they fell entirely within a whole pasture, but without losing most of the data collected in 2014.

The reference site pastures (Atole, Pinto, and Agua Dulce) were located to the south of the Coloraditas Grazing Research and Demonstration Area in the central eastern portion of SAV. The Atole pasture (1,518 ha) was part of a large 4 pasture (total area 5,411 ha) 2-herd rotational regime and the Pinto (7,718 ha), and Agua Dulce (3,830 ha) were large pastures stocked year-round. I sampled across the entire Atole pasture but selected 2 similarly sized areas within the Pinto (1,264 ha) and Agua Dulce (1,592 ha) to improve sampling efficiency and mimic an average-sized ranch in South Texas. Stocking rate on these pastures from December 2014 to December 2017 ranged from 8.8 to 13.12 ha/AU in Atole, 15.16 to 19.69 ha/AU in Pinto and 15.51 to 24.09 ha/AU in the Agua Dulce. Stocking rates on the references sites overlapped with stocking rates on the treatment areas throughout the study.

Due to time constraints, I could not select reference sites based on spatial analysis of similarity. I conducted a retrospective analysis to determine if the pastures I selected out of the 47 potential pastures (>100 ha) were similar to the Coloraditas Grazing Research and Demonstration Area pastures in (1) percent composition of brush, herbaceous, bare ground, and (2) landscape metrics by class (brush, herbaceous vegetation, and bare ground; Appendix A).

Precipitation

I collected cumulative annual and cumulative April–August precipitation for each Coloraditas Grazing Research and Demonstration Area treatment and reference site using the PRISM database. April–August precipitation encompassed the bobwhite breeding season and has been correlated with fluctuations in age ratios, reproductive success, and abundance (Kiel 1976, Campbell 1968, Tri et al. 2013). I collected cumulative monthly precipitation for 2014–2017 at a 400 km^2 resolution. Using the Zonal Statistics tool in ArcMap (Version 10.4.1, ESRI, Redlands, CA), I calculated the mean of monthly precipitation of the cells within each treatment area and reference site pasture and summed the means across months for cumulative precipitation.

Vegetation

I sampled vegetation across pastures within the Coloraditas Grazing Research and Demonstration Area and reference sites to document total forage production and residual herbaceous forage standing crop along with the percent forage utilization at each growing season. Additionally, I sampled the structure and composition of plant communities to draw inferences on how my grazing treatments impacted the vegetation attributes of bobwhite habitat each October. Breakdown of the placement of these enclosures and transects by pasture and range site can be found in Appendix B.

Forage standing crop and utilization. — Because standing crop is likely to vary greatly in the stochastic South Texas environment and with the rotation of cattle among pastures, I collected estimates of residual forage standing crop using 2 separate methods: (1) the comparative yield method and (2) clipping inside and outside of grazing exclosures with paired locations.

For the first methods, I used the comparative yield method (Despain and Smith 1987) each time cattle were rotated after grazing was implemented in addition to each growing season prior to grazing implementation (2014–2017). This method uses double sampling techniques (Bonham 2013) and provided a more rapid assessment of standing crop than clipping frames at each exclosure. I defined forage standing crop as the above ground living and dead material attached to the plant at each sample period (Higgins et al. 2012). For the comparative yield method, I estimated residual forage standing crop in all study pastures ($n = 13$) within 10 days from the time cattle were moved between pastures in the rotation grazing units. I sampled the vacated pastures within 2 days following rotation.

I measured forage standing crop by taking visual estimations of standing crop in 5, 0.5

m^2 frames with frame 5 representing an area with the greatest amount of forage in the area and frame 1 representing an area with the least amount. I clipped 5 frames/pasture and made 1,000 corresponding visual estimations based on those clippings by ranking estimations from 1 to 5 in an area of 0.25 m^2 (50x50 cm) that was immediately in front of my foot every other step (Bonham 2013). This translated to 100 visual estimations (25 estimations in 4 cardinal directions)/10 points/pasture. I sampled visual estimates at points allocated randomly in proportion to ecological site within each pasture. I dried samples in an air forced drying room at 60 °C and weighed forage samples daily (in grams) until I observed no change in weight for three consecutive days. I converted these values from g/0.25m^2 to kg/ha.

Visual estimates and dry weights were estimated at the pasture level. For each pasture, I regressed the dry weights in kg/ha for each category on the visual categories (1–5) and entered the average of the visual estimate into the regression equation to obtain a value of kg/ha (Fulbright and Ortega-S 2013). The prediction equation was:

$$y = mx + b$$

where y was the total forage standing crop in kg/ha, m was the slope of the regression of weight on category, b was the intercept, and x is the average visual estimate. These equations were linear with correlation coefficients (r^2) of 0.86–0.99. I reported average forage standing crop per treatment weighted by the number of exclosures per pasture within a treatment. For each rotational treatment, I reported total forage standing crop per pasture at the entry and exit of herds along with percent utilization between rotations using the formula specified below. For each continuous treatment, I reported the weighted average forage standing crop at the start and end of each rotation period along with percent utilization of the pasture. Because these estimates lacked independence between sample points and were taken at the pasture level, I did not use this data in statistical analyses; rather I used residual forage estimates collected outside each exclosure via clipping at the end of each growing season.

For the second method, I monitored herbaceous forage standing crop and utilization by cattle and other herbivores by using 130, 1.5 × 1.5 × 1.5 m grazing enclosures with paired locations for clipping and estimation across all treatment and reference areas. Grazing enclosures were built using 10 × 10 cm spacing, 6-gauge galvanized cattle panels and 4, 1.8m t-posts. As part of an ongoing study, the East Foundation randomly constructed 10 exclosures in each pasture proportion to the area of each ecological site occurring in each observational unit during June of 2014. The East Foundation determined the number of grazing enclosures based on a preliminary test for sample size adequacy. All enclosures were at least 100 m apart and placed in a grazable area (contained or had the potential to contain grass and forb species). Additionally, I selected 1 location within 10 m of each enclosure that contained a similar vegetation composition as the vegetation within the enclosure and marked it with a t-post in order to obtain an estimate of forage standing crop exposed to grazing.

To estimate forage utilization (the percent difference in dry weight between forage clipped in enclosures compared to forage clipped outside of enclosures), I clipped standing crop of forbs and grass and grass likes separately within enclosures and at the northern point of the paired location (t-post) per enclosure. Clipping took place in 1, 0.5 m^2 frame placed at the center of each enclosure and again at the paired location. All plots were clipped volumetrically inside their respective frames to ground level. Forbs and grass and grass likes were placed in their own respective brown bags and dried in a forage drying room at 60˚C until they reach a constant weight, at which point, I took a dry weight for each sample. After clipping, exclosures and paired points were relocated in a computer-generated random direction 10 m from the current location.

Clippings took place each June and November from starting in November 2015 and continuing through to November 2017 on the Coloraditas Grazing Research and Demonstration Area treatments. The 30 exclosures in the reference sites were not added until Summer of 2016 after grazing was initiated on the Coloraditas Grazing Research and Demonstration Area, clippings took place on the reference sites in conjunction with Coloraditas Grazing Research and Demonstration Area samples from June 2016 through November 2017.

I calculated percent forage utilization (U) for each exclosure by grass, forb, and total (grass + forb). Percent unitization is given by the following equation:

$$U\ (\%) = [\,\frac{(I - O)}{I}\,]$$

where I was the forage inside the enclosure and O was the forage outside the exclosure at the paired location. When standing crop outside the exclosure was greater than standing crop inside the exclosure, utilization resulted in a negative value. I rescaled utilization values so there were bound between -100 and 0% by multiplying negative values by: (100/absolute value of the minimum negative utilization; Hines 2014). Negative utilization or difference values are often zeroed based on the assumption that total standing crop growth inside the exclosure is greater than outside. Bork and Werner (1999) determined that in heterogeneous environments, zeroing data can result in an inflation of percent utilization and over estimation of the degree of herbivory. This was due to the spatial heterogeneity among subplots, despite our assumptions based on an ocular estimation of similarity between plots. I removed any samples where a utilization value could not be calculated; no forage grew inside the exclosure, but grew outside (grass: 20 exclosures, forb: 39 exclosures from 2015–2017).

Vegetation structure and composition. —I collected measurements of vegetation structure and composition along 189 permanent transects to evaluate the condition of vegetation related to bobwhite habitat. In each of the 10 sub pastures on the treatment area and 3 reference areas, I sampled 12–15 permanent, 20×5 m transects. Sample size for transects was determined by a power analysis with an 80% chance in detecting a 20% change in canopy cover at $P \leq 0.05$ (Fig. 3.3). I used the number of transects needed to detect a change in bare ground as the maximum because it encompasses the other 3 measurements.

Transects were stratified proportional to the area of range sites that occurred in each pasture (Bonham 1989).I sampled these each October 2015–2017 to capture the conditions at the end of the summer growing season. Transects did not occur within 200 m of cattle watering facilities to avoid obvious areas of cattle concentration. Transects were permanently marked with a t-post to identify the transect starting point, and oriented 20 m in a random direction (North, South, East, or West). I defined herbaceous cover as the non-woody vegetation, such as grasses and forbs, projected onto the ground (Bonham 2013). I defined bare-ground as the amount of soil that was not covered by any type of vegetation (Holechek et. al. 2011). On each transect I sampled 5, 20×50 cm quadrats (5 m spacing) randomly placed perpendicular to the line at 0.5, 1, 1.5, or 2 m. I started with a frame at 0 distance on the left side of the tape and facing away from the transect start and alternated sides with each frame. The specifics for transect direction and quadrat spacing start remained constant for each transect over the course of the study. Within each quadrat, I measured percent canopy cover by major group (grass, forb, litter, bare ground ≤100%; Higgins et al. 2012) in 5% increments but included increments of 1% for coverages less than 5%. Also, within the frame, I measured frequency of herbaceous plants and sub shrubs (rooted inside the frame) by species. I measured visual obstruction or concealment of a bobwhite by vegetation using a 1 m profile board with 4 25-cm alternating white and black blocks. I

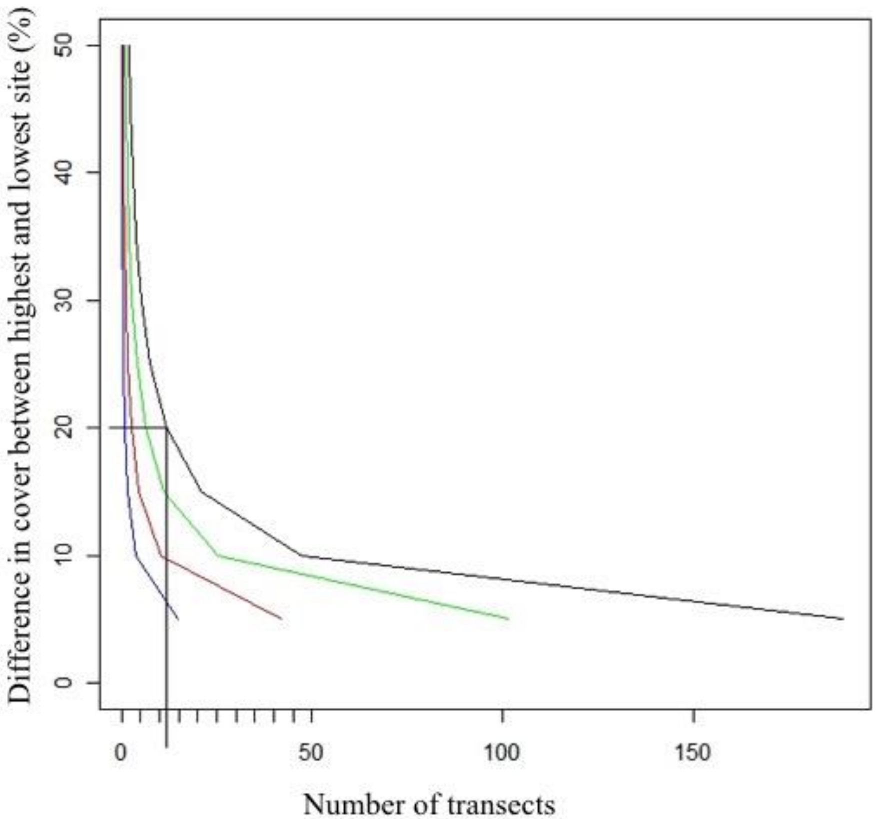

Fig 3.3. Number of transects required to detect a percent change in cover of bare ground, grass, forb, and litter between the area of highest and lowest cover . The black line indicates that 12 transects are needed to determine a 20% chance of detecting a difference.

measured percent obstruction in each of the 4 blocks from 0 (no obstruction) to 100% (complete obstruction) on the board from a random point on the 20 m line (at either, 5, 10, 15, or 20 m) from 8 cardinal directions (North, South, East, West, Northeast, Northwest, Southeast, Southwest), 10 m away at a kneeling position. I quantified suitable bobwhite nest sites by counting bunchgrass clumps ≥22 cm in diameter and ≥15 cm tall (Arredondo et al. 2007) within the 20×5 m. I used the number of suitable nest clumps/0.01 ha (20×5 m) to calculate bunchgrass density scaled up to nest clumps/1 ha. I defined woody canopy cover as the aerial portions of woody vegetation (foliage cover) projected on the ground (Bonham 2013). I collected canopy cover using the line-intercept method (Canfield 1941) to estimate percent woody and succulent cover by species, of all vegetation intercepting the 20 m line. I recorded the amount in centimeters of the ground covered by woody plant materials (leaves and branches) and succulent (cacti) that intercepted the line transect by species (Canfield 1941, Higgins et al. 2012). I excluded gaps in the canopy exceeding 0.5 m from the estimate for that individual plant. I stretched measurement tapes in as straight and close to the ground as possible.

Bobwhite Density

Aerial surveys. — I conducted aerial surveys using an R-44 helicopter to estimate bobwhite density using line-transect distance sampling methods each December 2014–2017. I used the same transect design and protocol described in Chapter II.

Analyses

Analyses focused on 2 types of data collected to evaluate (1) vegetation (forage standing crop, changes by treatment and year and (2) bobwhite density changes by treatment and year (Fig. 3.4).

Forage standing crop, v*egetation structure, and composition*. —I analyzed the response

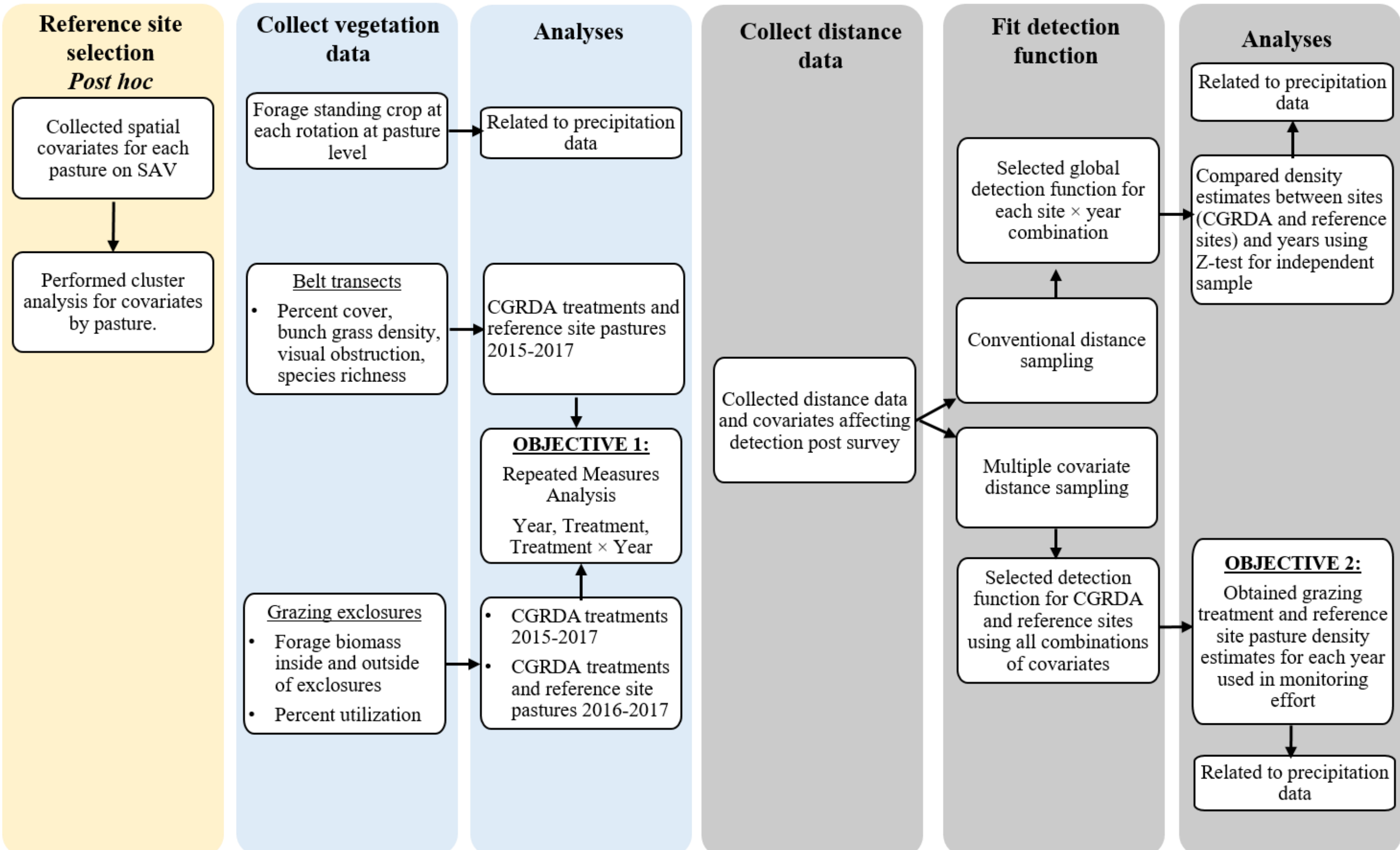

Figure 3.4 Analytic pathway for analyses involving data collected to assess reference site selection (post hoc), and data collected for analyses relating to objective (1) monitoring changes in vegetation by treatment (grazing treatments and reference site pastures) and year and (2) monitoring changes in northern bobwhite density by treatment (grazing treatments and reference site pastures) and year. SAV = San Antonio Viejo Ranch; CGRDA = Coloraditas Grazing Research and Demonstration Area.

of the dependent vegetation variables within grazing treatments using PROC MIXED, repeated measures generalized linear model (GLM) to determine how vegetation structure responded over time (before vs. after) and treatment using SAS University Edition (SAS institute Inc, NC). Response variables included: total forage standing crop inside exclosures (kg/ha), total residual forage standing crop outside exclosures (kg/ha), forage utilization, canopy cover (grass, forbs, litter, bare ground, and woody vegetation), species richness (grass and forbs combined), and visual obstruction (at each 0.5 m interval and averaged over all heights), respectively. I used PROC GLIMMIX with a negative binomial distribution to analyze bunchgrass density (clumps/100 m^2) as a count variable. I tested all dependent variables for normality using the Shaprio-Wilk test (Shapiro and Wilk 1965) and log transformed, or square root transformed dependent variables where P <0.05. Transformed data were presented as back-transformed means with standard errors ($\bar{X}$ ± SE).

Models for vegetation structure and composition include main effects of treatment (continuous high, continuous moderate, rotational high, rotational moderate, Atole, Pinto, Agua Dulce), year (2015, 2016, 2017), and a treatment × year interaction.

Models for total forage standing crop inside, residual forage standing crop outside, and percent utilization include the main effects of Coloraditas Grazing Research and Demonstration Area treatment (continuous high, continuous moderate, rotational high, rotational moderate), year (2015, 2016, 2017), season (fall [November], summer [June]), and a treatment × year interaction. As reference site data were not available in 2015, I included the estimates from the 3 reference sites in an after-only analysis that included the main effects of treatment (continuous high, continuous moderate, rotational high, rotational moderate, Atole, Pinto, Agua Dulce), year (2016, 2017), season (fall, summer), and a treatment × year and season × year interaction.

I treated each pasture repetition nested within treatment and the interaction between repetition nested within treatment × year as the random effect. I specified year as the repeated measure and transect × pasture replication × treatment as the subject. Variance components and autoregressive order 1 covariance structures were selected based on comparison of Akaike's Information Criterion (AIC).

I used CONTRAST statements to compare grazing system (continuous vs. rotational), stocking rate (high vs. moderate), interaction between grazing system and rate (system × rate), region (Coloraditas Grazing Research and Demonstration Area vs. reference sites, where applicable), period (before vs. after grazing implementation, where applicable), and the interaction among period grazing system, and rate (period × system × rate). I used LSMEANS to determine the estimates for each significant effect in the model statement. Significant interactions were followed by simple tests of main effects. Significance was determined at $P <$ 0.05.

Bobwhite density estimation. —I obtained individual treatment and by year estimates through multiple covariate distance sampling (in Program Distance, version 7.0, Release 1 (Thomas et al. 2010). I used the same data exploration and model selection process for conventional distance sampling and multiple covariate distance sampling described in Chapter II but utilized the multiple covariate distance sampling analysis to obtain individual treatment and pasture estimates by year as described below. I reported all density estimates as $\widehat{D} \pm$ SE.

Treatment and year. —I post-processed the data from each complete survey at 100% to group detections and transects into their respective grazing treatments and pastures. I analyzed the 4 grazing treatments in the Coloraditas Grazing Research and Demonstration Area over 4 years in with treatment × year as the stratum. In a separate analysis, I analyzed the 3 pastures of the reference sites over 4 years with pasture × year as the stratum. I included the following covariates in each analysis: stratum, year (2014, 2015, 2016, 2017), treatment (continuous high, continuous moderate, rotational high, rotational moderate) or pasture (Atole, Pinto, Agua Dulce), survey number (1, 2), time of day or hour (factor [first 3 hours, midday, last 3 hours] and continuous [24-hour format]), observer experience (factor [low, moderate, high] and continuous), condition (factor [clear, scattered cloud, mostly cloudy, overcast] and continuous), temperature (factor [low, moderate, moderate high, high] and continuous), wind, and brush cover (PLAND).

Stratum-specific density estimates can be obtained through 3 methods: (1) a pooled $\hat{f}(0)$ (i.e., the estimated probability density function of observed distances) function, (2) a fully stratified $\hat{f}(0)$, and (3) by using multiple covariate distance sampling with stratum as a factor covariate. When a global detection function is used, a $\hat{f}(0)$ is estimated for the detections pooled over all strata and the estimated $\hat{p}$ is applied to the individual detections and transects to estimate density. This may introduce bias into the density estimates if the true detection differs by stratum (Marques et al. 2007). Alternatively, if there are a sufficient number of observations per stratum, a fully stratified approach can be used where a separate detection function is estimated for each stratum and their respective estimated $\hat{p}$ is applied to each density estimate (Marques et al. 2007). If there are a sufficient number of detections per stratum, selection between a pooled or fully stratified $\hat{f}(0)$ can be evaluated through AIC and goodness of fit tests in Program Distance.

Prior to the implementation of multiple covariate distance sampling, a global detection function was the only option to estimate density on subsets of data where detections per stratum were low. Stratification helps eliminate heterogeneity in detection probabilities and is ideal (Marques and Buckland 2003), but often it is hard to obtain sufficient detections to estimate separate detection function per area. The multiple covariate distance sampling method can be applied even when detections per stratum are low and has the added benefit of using fewer parameters than a fully stratified model. When using stratum as a factor covariate in a global multiple covariate distance sampling detection function, density is estimated by applying the detection function to the observations within each stratum:

$$\widehat{D}_v = \frac{1}{a_v}\sum_{i=1}^{n_v}\frac{1}{\widehat{P}_a(z_{iv})}$$

Where for stratum v, $\widehat{D}$ was the estimated density, a_v was the size of the covered region, n_v was the number of observations, and $\widehat{P}_a(z_{iv})$ was the probability of detecting the *i*th bird in stratum v given the observed covariates z_i. In this equation, multiple covariate distance sampling is using the whole data set to provide information about the shape of the detection function where the stratum level data are used only to fit the scale (Marques et al. 2007). Given that I obtained a sufficient number of detections in some strata but not others, I used AIC model selection to determine which method (conventional distance sampling pooled, conventional distance sampling fully stratified, or multiple covariate distance sampling) best estimated density by treatment or pasture and year with the inclusion of covariates affecting detectability. When additional covariates are included, the estimate of detection probability ($\widehat{P}_a(z_{iv})$) was depend on the covariate values (*z*) in that stratum (*v*; Marques et al. 2007). For the final model, I ran a non-parametric bootstrap with 999 resamples, with replacement from lines (Buckland et al. 2001) and presented bootstrapped density estimates and 95% confidence intervals (95% CI[$\hat{D}$]) based on the bootstrapped density estimates in the 2.5 and 97.5% quantiles of the ordered bootstrap estimates (Buckland 1984). Due to bootstrapping convergence failures in the reference site analysis, I presented the density estimates and 95% CI assuming a lognormal distribution for density (Buckland et al. 2001:77) where the standard normal distribution is replaced by a

Student's t distribution (Fewster et al. 2009) and degrees of freedom (df) are calculated using the Satterthwaite approximation (Buckland et al. 2001). A nonparametric bootstrap was not recommended where there are a low number of replicate lines (<20) or if detections were concentrated on fewer transects, which is likely the case with certain years on each pasture.

Comparisons. —On each grazing treatment, I calculated the difference and magnitude of change between in density estimates from before (2014 vs. 2015), after (2016 vs. 2017), before to after grazing in high precipitation (2015 vs. 2016), and before to after grazing in years if low precipitation (2014 vs. 2017).

Where independent estimates (i.e., estimated with a separate detection function) could be made, I used a Z-test for independent samples (Buckland et al. 2001:85 eqn. 3.102) to test the hypothesis H_0: $\hat{D}_1 = \hat{D}_2$. I used a data filter in Program Distance to estimate density for each analysis from the multiple covariate distance sampling model selected. I used the Z-test to test if the global density estimate from the Coloraditas Grazing Research and Demonstration Area was equal to the global density estimate from the reference sites within each year. I also used a Z-test to compare global density estimates between years within the following periods: before (2014 vs. 2015), after (2016 vs. 2017), before to after grazing in high precipitation (2015 vs. 2016), and before to after grazing in years if low precipitation (2014 vs. 2017), for the Coloraditas Grazing Research and Demonstration Area and reference sites, respectively.

Lastly, I used a Z-test to determine whether the global density estimate averaged over all 4 years between each system (continuous vs. rotational) and rate (high vs. moderate) were equal. I also tested whether the global densities within each system and rate averaged over low precipitation (2014 and 2017), high precipitation (2015 and 2016), and in the after grazing period (2016 and 2017) were equal.

I regressed the independent variable (breeding season precipitation [April–August] and residual forage standing crop in November) to independent estimates of the dependent variable (bobwhite density by treatment and pasture year) using simple linear regression in RStudio version 3.4.4 (R Development Core Team 2013). I used the cumulative breeding season precipitation corresponding to each treatment or pasture year. To determine if density estimates were independent, I used a separate detection function for each individual treatment or pasture-year resulting in 28 (7 estimates for each of the 4 years) individual estimates. Due to the low number of detections in some treatment-years, these estimates were only calculated for this analysis. Independent estimates differed by an average of 0.10 bobwhites/ha (range 0.0–0.38) from estimates derived using multiple covariate distance sampling in the full treatment by year model.

RESULTS

Precipitation

Cumulative annual precipitation over the 4 years of the study varied within the before and after grazing periods and varied between the before and after grazing periods. During the pretreatment period (2014 and 2015) cumulative annual precipitation was near or below average in 2014 (55 cm) and above average in 2015 (68 cm). After grazing was implemented on the treatment areas, cumulative annual precipitation was above average in 2016 (61 cm) and below average in 2017 (45 cm). Cumulative April–August precipitation on the Coloraditas Grazing Research and Demonstration Area within years differed by a maximum of 3 cm among grazing treatments in 2014, 2015, and 2017 and by 5 cm in 2016 (Fig. 3.5A). Cumulative April–August precipitation on the reference sites within years differed by a maximum of 7 cm between pastures in 2014, 9

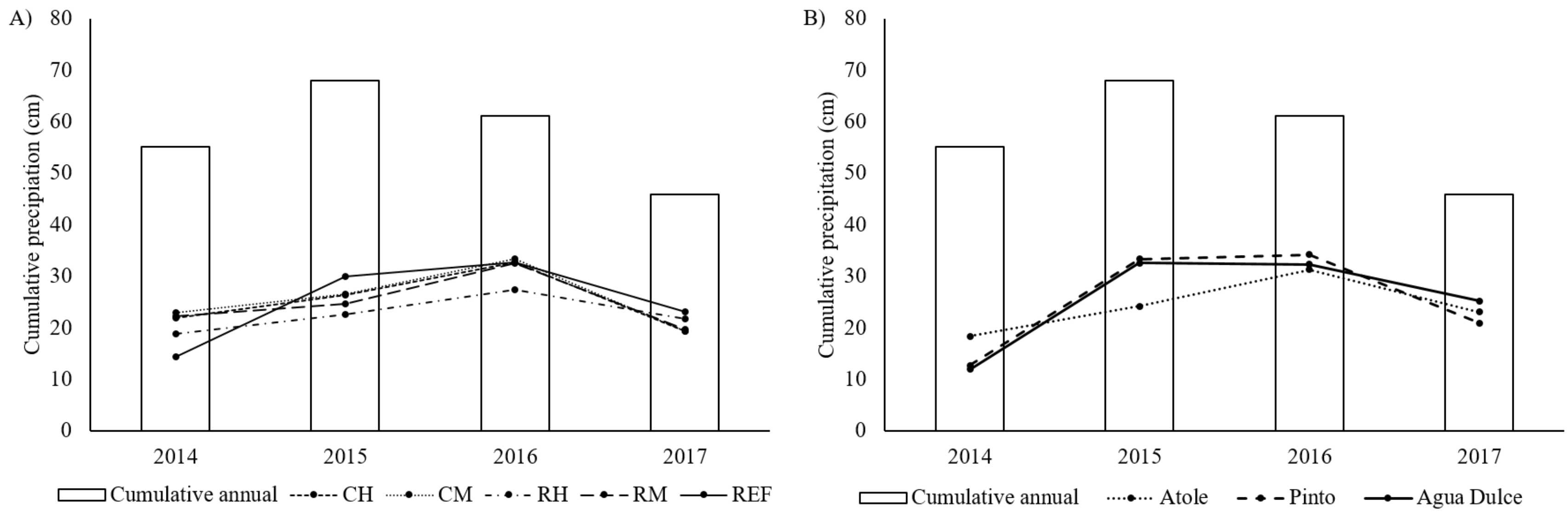

Figure 3.5. Cumulative annual precipitation by year (white bars) and average cumulative April–August precipitation (lines) by (A) treatment site on the Coloraditas Grazing Research and Demonstration Area and pooled reference sites, and (B) individual reference site pastures in Jim Hogg County, Texas, USA, 2014–2017. CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate, REF =Reference (Atole, Pinto, Agua Dulce).

cm in 2015, 3 cm in 2016 and 4 cm in 2017 (Fig. 3.5B).There was a >5 cm discrepancy in the cumulative April–August precipitation between the Coloraditas Grazing Research and Demonstration Area and reference sites in 2014 (7.17 cm) and 2015 (5.00 cm) but was less pronounced in 2016 (1.17 cm) and 2017 (3.02 cm; Fig. 3.5).

Vegetation

Forage standing crop at each grazing rotation. — Average weighted forage standing crop by treatment fluctuated with cumulative precipitation over all 4 years of the study (Fig. 3.6). Average forage standing crop increased by 118–165% on all Coloraditas Grazing Research and Demonstration Area treatments from June 2014 to November 2015 prior to the initiation of grazing. I did not monitor the reference sites until June 2015; from June to November forage standing crop increased by 140% on the reference sites and reached maximum levels during this time. Peak average forage standing crop occurred in November 2015 on the Coloraditas Grazing Research and Demonstration Area ($\bar{X}$ = 4,113.8 kg/ha) and ranged from 800 kg/ha below to 1,000 kg/ha above potential range production estimated by the Natural Resources Conservation Service (NRCS; Soil Survey Staff 2018) in a favorable year (Palmer Drought Severity Index 0.5–4.0) on each individual treatment area. Subsequent peaks occurred in September 2016 and June 2017 but did not rebound to the pretreatment levels in November (Fig. 3.6). Minimums on the Coloraditas Grazing Research and Demonstration Area occurred in April 2016, March 2017, and September 2017 (Fig. 3.6).

From November 2015 to the first rotation in April 2016, there was an 81%, 72%, 78%, 68% decrease in forage standing crop on the continuous high, continuous moderate, rotational high, and rotational moderate treatments, respectively (Fig. 3.6). On the reference pastures, there was a similar overall decrease of 77% from November 2015 to April 2016. During this time,

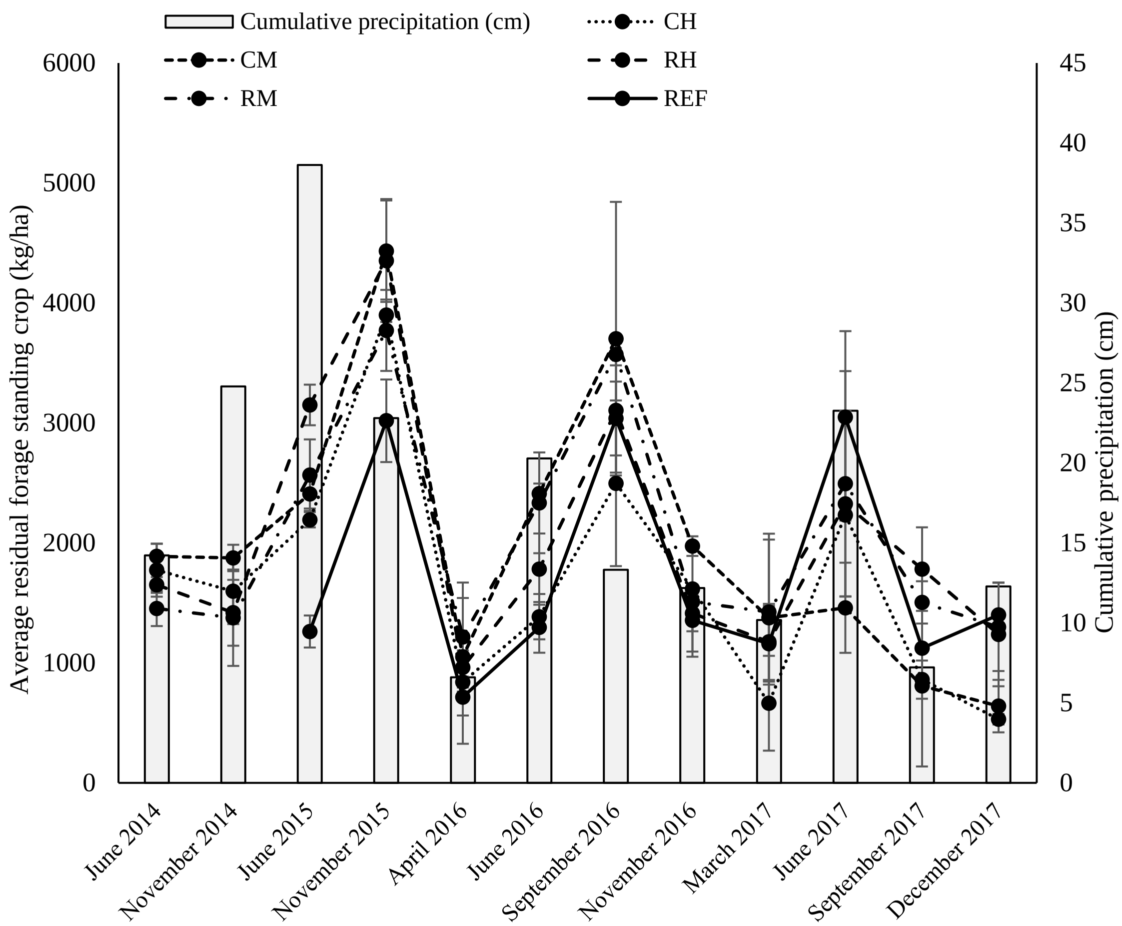

Figure 3.6. Weighted mean (± SE) residual forage standing crop (kg/ ha) by treatment collected at the end of each growing season and at each rotation from June 2014 through March 2018 on the San Antonio Viejo Ranch, Jim Hogg County, Texas, USA, 2014–2017. Cumulative precipitation for each collection period is shown in the grey bars. Grazing was initiated on the Coloraditas Grazing Research and Demonstration Area after November 2015. CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate, REF =Reference (Atole, Pinto, Agua Dulce).

forage standing crop on pastures ranged from 750 to 2,700 kg/ha below potential range production estimated by NRCS in a normal year (Palmer Drought Severity Index -0.5–.99) on each individual pasture.

From June to September 2016, forage standing crop rebounded and remained >1,000 kg/ha until November 2016. Forage standing crop declined during dormancy between November 2016 and March 2017 but rebounded on all pastures with early growing season precipitation culminating in peak forage at the end of June 2017.

In the fall of 2017, the area received <25% of expected precipitation and forage standing crop fell < 1,000 kg/ha on the continuous high and continuous moderate grazing treatments, 2 of the pastures within the rotational high and rotational moderate grazing treatments where Delmita (shallow) soils dominated, and on the Pinto pasture. Forage standing crop in June 2017 on pastures within grazing treatments ranged from 1,170.5 kg/ha below to 1,890 kg/ha above potential range production estimated by NRCS in an unfavorable year (Palmer Drought Severity Index -4.0 – -1.0).

On the rotational high and rotational moderate grazing treatments, forage utilization at the pasture level was negative in the spring growing season in from April 2016 to June 2016 and March 2017 to July 2017 where pastures received over 20 cm of precipitation (Table 3.1 and 3.2). Forage utilization on the rotational high and rotational moderate grazing treatments were highest (~80%) during the December 2015 to April in 2016 and December 2017 to March 2018, and from September to November 2017 in the rotational moderate treatment (Table 3.2). Forage utilization was >50% on the rotational high treatment in 2 out of 9 rotation periods (Table 3.1). Forage utilization was >50% on the rotational moderate treatment in 4 out of 9 rotation periods (Table 3.2). Three of these 4 times, high utilization occurred in the Coloraditas pasture

Table 3.1. Estimated total forage standing crop at the entry and exit for rotation of the San Rafael herd on the rotational high treatment on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2015–2017. Cattle were stocked on all treatments in December 2015. Length of grazing, cumulative precipitation (cm) during the rotation period, change (forage standing crop at entry-exit), kg/ha/day, and percent utilization of the pasture are shown for each period.

Pasture	Entry Date	kg/ha	Exit Date	kg/ha	Days Grazed	Precipitation (cm)	Change	kg/ha/day	% Utilization
Loma	12/14/2015	4931.7	4/7/2016	1469.8	115	13.7	3461.9	26.9	70.2
San Rafael	4/7/2016	759.9	6/29/2016	1627.2	83	20.4	-867.1	-9.3	-114.1
Tequileros	6/29/2016	2358.7	9/13/2016	2070.7	76	11.6	288.0	3.4	12.2
Loma	9/13/2016	2925.7	11/15/2016	1631.9	63	11.5	1293.7	18.3	44.2
San Rafael	11/15/2016	1126.9	3/1/2017	670.3	106	12.1	456.6	3.8	40.5
Tequileros	3/1/2017	926.5	7/5/2017	3359.6	126	23.6	-2433.1	-17.2	-262.6
Loma	7/5/2017	2026.8	10/5/2017	1933.7	92	9.4	93.1	0.9	4.6
San Rafael	10/5/2017	418.4	12/22/2017	385.1	78	12.3	33.3	0.4	8.0
Tequileros	12/22/2017	1790.1	3/1/2018	445.2	69	2.0	1344.8	17.4	75.1

Table 3.2. Estimated total forage standing crop at the entry and exit for rotation of the Guadalupe herd on the rotational moderate treatment on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2015–2017. Cattle were stocked on all treatments in December 2015. Length of grazing, cumulative precipitation (cm) during the rotation period, change (forage standing crop at entry-exit), kg/ha/day, and percent utilization of the pasture are shown for each period.

Pasture	Entry Date	kg/ha	Exit Date	kg/ha	Days Grazed	Precipitation (cm)	Change	kg/ha/day	% Utilization
Coloraditas	12/10/2015	3187.5	4/6/2016	386.3	118	13.5	2801.2	21.2	87.9
Desiderio	4/6/2016	1228.2	6/28/2016	2705.6	84	20.9	-1477.4	-15.7	-120.3
Guadalupe	6/28/2016	5682.3	9/7/2016	4072.0	70	9.0	1610.3	20.5	28.3
Coloraditas	9/7/2016	3384.9	11/15/2016	684.9	69	10.3	2700.1	34.9	79.8
Desiderio	11/15/2016	2298.9	3/1/2017	1439.2	106	13.3	859.6	7.2	37.4
Guadalupe	3/1/2017	2327.3	7/5/2017	4045.4	126	23.1	-1718.0	-12.2	-73.8
Coloraditas	7/1/2017	1279.5	10/5/2017	577.0	96	6.4	702.5	6.5	54.9
Desiderio[a]	10/5/2017	1621.9	12/21/2017	1577.4	77	12.2	44.5	0.5	2.7
Desiderio	12/21/2017	1577.4	3/1/2018	289.4	70	2.0	1287.9	16.4	81.7

[a]Desiderio was not rotated 12/21/2017

On the continuous high and continuous moderate grazing treatments, forage utilization was negative in the spring growing season in April 2016 to June 2016 and March 2017 to July 2017 where pastures received over 20 cm of precipitation (Table 3.3 and 3.4). Negative utilization rates persisted during the following rotation period from July to September 2016 in the continuous high and continuous moderate grazing treatments, and from October to December 2017 in the continuous moderate treatment. Forage utilization on the continuous high and continuous moderate grazing treatment was highest (~80%) during the December 2015 to April in 2016 (Table 3.3 and Table 3.4). Forage utilization was >50% on the continuous high grazing treatment in 4 out of the 9 rotation periods (Table 3.3). Forage utilization was >50% on the continuous moderate in 2 out of the 9 rotation periods (Table 3.4).

Forage standing crop and utilization during each growing season. —Total (grass + forbs) forage standing crop inside exclosures ranged from 1,223–4,644 kg/ha at the end of the spring growing season in June and from 368–5,571 kg/ha at the end of the summer growing season in November (Table 3.5). Across all years for each grazing treatment, total forage standing crop inside exclosures was 3,012 below and 1,473 kg/ha above the NRCS estimated annual range production potential (weighted by area of soil type). Total forage standing crop was above NRCS estimated values on 9 occasions out of 36 sampling occasions (treatment × season × year).

From 2015–2017, total (grass + forbs) forage standing crop inside exclosures significantly differed between year and season, respectively (Table 3.6). There was a difference in forage standing crop inside exclosures from before (2015) to after (2016 and 2017) grazing ($P < 0.001$). By year forage standing crop inside exclosures was highest in 2015, then decreased in 2016, and 2017 (Fig. 3.7A). By season, forage standing crop was highest in June compared to October (Fig. 3.7B). There was no difference by Coloraditas Grazing Research and

Table 3.3. Weighted average forage standing crop for each rotation period in the continuous high treatment on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2015–2017. Cattle were stocked on all treatments in December 2015. Length of grazing, cumulative precipitation (cm) during the rotation period, change (forage standing crop at entry–forage standing crop at exit), kg/ha/day, and percent utilization of the pasture are shown for each period.

Period Start	kg/ha	Period End	kg/ha	Days Grazed	Cum. Precipitation (cm)	Change	kg/ha/day	% Utilization
12/14/2015	3954.2	4/7/2016	737.6	115	13.5	3216.6	28.0	81.3
4/7/2016	737.6	6/29/2016	1503.4	83	20.0	-765.8	-9.2	-103.8
6/29/2016	1503.4	9/13/2016	2432.0	76	12.7	-928.6	-12.2	-61.8
9/13/2016	2432.0	11/15/2016	1615.7	63	11.2	816.3	13.0	33.6
11/15/2016	1615.7	3/1/2017	520.8	106	12.5	1094.9	10.3	67.8
3/1/2017	520.8	7/5/2017	2326.9	126	22.7	-1806.1	-14.3	-346.8
7/5/2017	2326.9	10/5/2017	874.2	92	7.2	1452.6	15.8	62.4
10/5/2017	874.2	12/22/2017	361.1	78	12.2	513.1	6.6	58.7
12/22/2017	361.1	-	-	-	-	-	-	-

Table 3.4. Weighted average forage standing crop for each rotation period in the continuous moderate treatment on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2015–2017. Cattle were stocked on all treatments in December 2015. Length of grazing, cumulative precipitation (cm) during the rotation period, change (forage standing crop at entry–forage standing crop at exit), kg/ha/day, and percent utilization of the pasture are shown for each period.

Period Start	kg/ha	Period End	kg/ha	Days Grazed	Cum. Precipitation (cm)	Change	kg/ha/day	% Utilization
12/14/2015	4431.6	4/7/2016	1051.2	115	13.5	3380.5	29.4	76.3
4/7/2016	1051.2	6/29/2016	2929.4	83	20.4	-1878.2	-22.6	-178.7
6/29/2016	2929.4	9/13/2016	3702.5	76	13.0	-773.2	-10.2	-26.4
9/13/2016	3702.5	11/15/2016	1973.3	63	11.0	1729.2	27.4	46.7
11/15/2016	1973.3	3/1/2017	1234.7	106	12.7	738.6	7.0	37.4
3/1/2017	1234.7	7/5/2017	1459.4	126	22.6	-224.6	-1.8	-18.2
7/5/2017	1459.4	10/5/2017	440.0	92	7.0	1019.4	11.1	69.9
10/5/2017	440.0	12/22/2017	639.9	78	12.3	-199.9	-2.6	-45.4
12/22/2017	639.9	-	-	-	-	-	-	-

Table 3.5. Mean (± SE) residual forage standing crop kg/ha outside exclosures and forage standing crop inside (kg/ha ± SE) grazing exclosures by forbs, grass, and total (forbs + grass) averaged over each treatment weighted by pasture on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, October 2015–October 2017.

			Residual forage standing crop (Outside)			Forage standing crop (Inside)		
Year	Mon	Treatment[a]	Forb	Grass	Total	Forb	Grass	Total
2015	Nov	CH	806.1 ± 173.3	1181.6 ± 131.1	1987.7 ± 42.2	1027.7 ± 44.2	1470.8 ± 34.7	2498.4 ± 78.8
2015	Nov	CM	2234.3 ± 1122.2	2211.4 ± 348.8	4445.7 ± 1470.9	1971.4 ± 955.9	3600 ± 25.3	5571.4 ± 930.6
2015	Nov	RH	1025.3 ± 143.4	1757.9 ± 457.3	2783.2 ± 326.2	1492.6 ± 310.5	1846.3 ± 162.5	3338.9 ± 168.5
2015	Nov	RM	1002.8 ± 137.5	1293.8 ± 262	2296.6 ± 394.5	1063.5 ± 155.9	1693.8 ± 84.6	2757.3 ± 235.3
2016	June	CH	1537.1 ± 48.6	2094.3 ± 62.7	3631.4 ± 111.3	1745.7 ± 166.6	2520 ± 213.6	4265.7 ± 380.2
2016	June	CM	1585.5 ± 152	2374.6 ± 685.2	3960 ± 533.1	1694.5 ± 417.6	2872.7 ± 29.9	4567.3 ± 387.7
2016	June	RH	1660 ± 44.5	1804.3 ± 234.5	3464.3 ± 277.3	1598.6 ± 147.4	2122.9 ± 282.2	3721.4 ± 322.9
2016	June	RM	1453.3 ± 64.3	1943.7 ± 277.9	3397 ± 279.1	1715.5 ± 97.6	2499.3 ± 369.7	4214.8 ± 464.7
2016	June	REF	1888.9 ± 213.2	1724.5 ± 172.5	3613.3 ± 78.4	1777.8 ± 162.5	2866.7 ± 497.7	4644.4 ± 342
2016	Nov	CH	17.2 ± 8.3	771.4 ± 154.3	788.6 ± 146	74.3 ± 28.1	760 ± 213.6	834.3 ± 185.6
2016	Nov	CM	22.2 ± 2	1231.1 ± 115.3	1253.3 ± 113.3	88.9 ± 8	1866.7 ± 95.4	1955.6 ± 103.4
2016	Nov	RH	64 ± 2.3	902.7 ± 194.7	966.7 ± 196.7	84 ± 16	1293.3 ± 183.6	1377.3 ± 169.9
2016	Nov	RM	55.7 ± 17.1	928.6 ± 417.5	984.3 ± 434	98.6 ± 52.9	924.3 ± 381.7	1022.9 ± 433.1
2016	Nov	REF	265 ± 133.1	615 ± 110.2	880 ± 193.7	212.5 ± 66	1038.7 ± 49.3	1251.2 ± 55.6
2017	June	CH	177.1 ± 89.1	608.6 ± 24.7	785.7 ± 64.3	497.1 ± 38	725.7 ± 127.8	1222.9 ± 89.9

Table 3.5. continued

			Residual forage standing crop (Outside)			Forage standing crop (Inside)		
Year	Month	Treatment[a]	Forb	Grass	Total	Forb	Grass	Total
2017	June	CM	283.7 ± 84.3	709.1 ± 24.5	992.7 ± 108.9	294.5 ± 103.6	1094.6 ± 385.7	1389.1 ± 282.2
2017	June	RH	336 ± 72	869.3 ± 148.7	1205.3 ± 210.8	384 ± 86	1338.7 ± 174.5	1722.7 ± 243.2
2017	June	RM	485.7 ± 170.5	662.8 ± 127.4	1148.6 ± 172	445.7 ± 100.2	982.9 ± 148.8	1428.6 ± 120.7
2017	June	REF	457.5 ± 75.8	531.3 ± 33.4	988.8 ± 104.4	582.5 ± 194	710 ± 34.4	1292.5 ± 212.6
2017	Nov	CH	59 ± 47.5	183.1 ± 47.3	242.1 ± 94.8	33.7 ± 15.1	334.8 ± 245.9	368.4 ± 261
2017	Nov	CM	62 ± 42	406 ± 18	468 ± 24	60 ± 40	614 ± 318	674 ± 358
2017	Nov	RH	125.7 ± 58.6	687.1 ± 232.6	812.9 ± 289.5	125.7 ± 33.9	1290 ± 282.8	1415.7 ± 284.8
2017	Nov	RM	102.7 ± 13.9	594.7 ± 366.5	697.3 ± 363.5	88 ± 17.4	836 ± 111.5	924 ± 123.2
2017	Nov	REF	198.7 ± 67	726.7 ± 179.5	925.3 ± 242.8	400 ± 154.1	1073.3 ± 257.1	1473.3 ± 410.8

[a]Treatments: CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate, REF =Reference (Atole, Pinto, Agua Dulce).

Table 3.6. Results of repeated-measures ANOVAs for dependent variables collected outside (residual forage standing crop), inside (forage standing crop) grazing exclosures, and forage utilization (%) from 2015–2017 and after grazing was implemented (2016–2017) on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, October 2015–2017. Main effects: treatment = continuous high, continuous moderate, rotational high, rotational moderate, Atole, Pinto, Agua Dulce; season = June, November; year = 2015, 2016, 2017.

Variable	Effect	df	*F*	*P*
Residual forage (2015-2017)	Treatment	3	8.1	0.1492
	Season	1	78.52	<0.0001
	Year	2	48.54	<0.0001
	Treatment × Year	6	1.64	0.2125
Residual forage after (2016-2017)	Treatment	6	1.88	0.2259
	Season	1	103.48	<0.0001
	Year	1	37.57	0.0008
	Treatment × Season	6	0.2	0.9768
	Treatment × Year	6	6.14	0.2073
	Season × Year	1	17.05	<0.0001
Forage standing crop (2015-2017)	Treatment	3	7.79	0.1687
	Season	1	145.28	<0.0001
	Year	2	81.58	<0.0001
	Treatment × Year	6	3.49	0.0431
Forage standing crop after (2016-2017)	Treatment	6	1.57	0.2957
	Season	1	153.32	<0.0001
	Year	1	46.03	0.0002
	Treatment × Season	6	2.95	0.0930
	Treatment × Year	6	2.3	0.1655
	Season × Year	6	13.57	0.0003

Table 3.6 continued

Variable	Effect	df	*F*	*P*
Forage utilization (2015-2017)	Treatment	3	0.09	0.9646
	Season	1	10.05	0.0017
	Year	2	5.54	0.0043
	Treatment × Year	6	0.41	0.9114
Forage utilization after (2016-2017)	Treatment	6	0.67	0.6789
	Season	1	12.67	0.0004
	Year	1	4.07	0.0683
	Treatment × Season	6	0.96	0.5355
	Treatment × Year	6	1.21	0.425
	Season × Year	1	0.47	0.4951

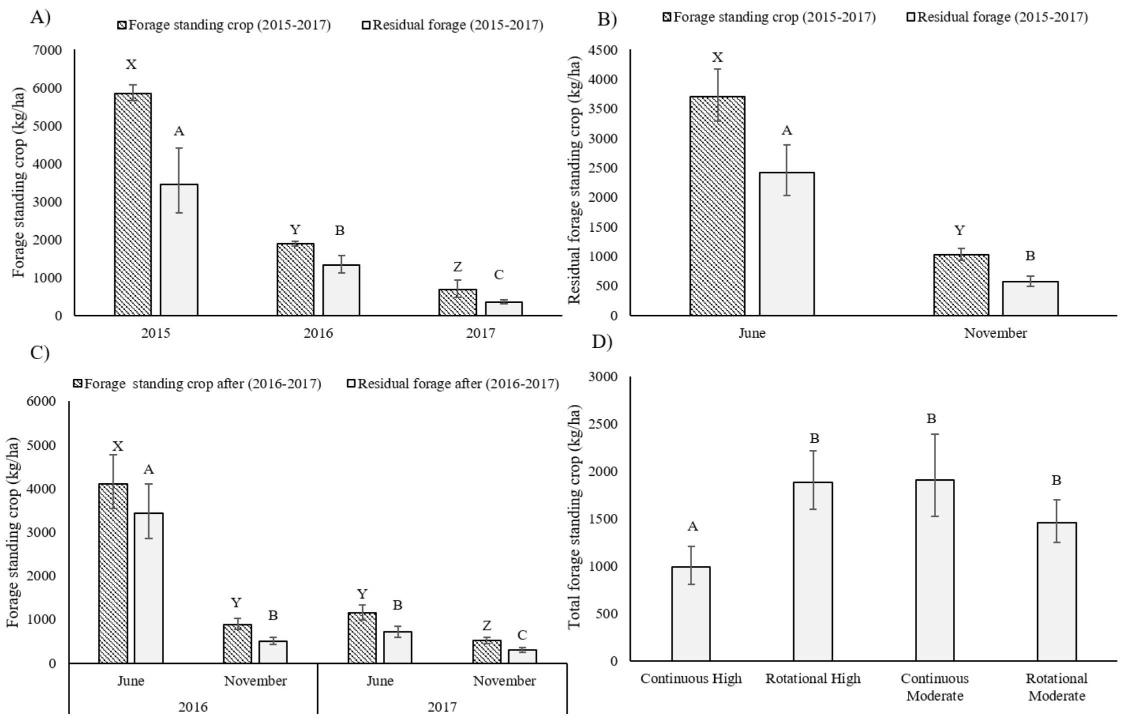

Figure 3.7. Mean (± SE) forage standing crop inside and residual forage outside exclosures on the Coloraditas Grazing Research and Demonstration Area treatments in Jim Hogg County, Texas, USA from before to after grazing (2015–2017) between (A) years and (B) seasons. (C) Mean (± SE) forage standing crop inside and residual forage outside exclosures on the Coloraditas Grazing Research and Demonstration Area treatments and reference sites in the after grazing (2016–2017) period among season × year. (D) Mean (± SE) forage standing crop inside exclosures on the Coloraditas Grazing Research and Demonstration Area between treatments pooled across years (2015–2017) and seasons. Means followed by the same letter are not significantly different ($P < 0.05$).

Demonstration Area treatment or by a treatment × year (Table 3.6). After grazing was initiated (2016 to 2017), forage standing crop inside exclosures differed by year, season, and a season × year interaction (Table 3.6). Forage standing crop inside exclosures was higher in June 2016 (6 months after grazing), significantly lower in November 2016 and June 2017, and lower in October 2017 (Fig. 3.7C). After grazing, there was no difference in forage standing crop inside exclosures by Coloraditas Grazing Research and Demonstration Area treatment or reference site pasture or by a treatment × year or season × year interaction (Table 3.6). From before to after grazing (2015–2017), and after grazing only (2016–2017), there was no difference in forage standing crop inside exclosures between grazing systems (Continuous = Rotational; $P = 0.499$, 0.092), stocking rates (Moderate = High; $P = 0.303$, 0.513) or between Coloraditas Grazing Research and Demonstration Area systems and reference sites ($P = 0.330$) in the after period (2016–2017). There was an interaction between system × rate ($P = 0.044$; Fig. 3.7D) pooled over 2015–2017, but weakly from 2016–2017 ($P = 0.056$).

Total (grass + forbs) residual forage standing crop outside of exclosures ranged from 785–3,960 kg/ha at the end of the spring growing season in June and from 242.10–4,445 kg/ha. at the end of the summer growing season in November (Table 3.5). From 2015–2017, residual forage standing crop on the Coloraditas Grazing Research and Demonstration Area treatments outside differed by year and season in the same pattern as forage standing crop inside exclosures (Table 3.6; Fig. 3.7A, B). After grazing was initiated (2016 to 2017), total forage standing crop outside exclosures on the Coloraditas Grazing Research and Demonstration Area treatments and reference sites followed the same results as total forage standing crop inside exclosures (Table 3.6; Fig. 3.7C). There was no difference by treatment or by a treatment × year (Table 3.6). From before to after grazing (2015–2017), and after grazing only (2016–2017), there was no difference in forage standing crop outside exclosures between grazing systems (Continuous = Rotational; P = 0.083, 0.095, respectively), stocking rates (Moderate = High; P = 0.345, 0.169, respectively) or between treatment grazing systems and reference sites (P = 0.255) in the after period (2016–2017). There was not an interaction between system × rate from before to after grazing (2015–2017; P = 0.162) or after grazing only (2016–2017; P = 0.076).

Grass, forbs, and total forage standing crop was greater in the paired point outside exclosures compared to inside (negative utilization) at 148, 157, and 154 exclosures, respectively, over all 4 years (n = 538 total paired points). Pooled across 2015–2017, average utilization of forbs, grass, and total forage was 27, 35, and 28% from 2015–2017, 31, 40, and 32% in November and 21, 28, and 22% in June (Table 3.7).

From 2015–2017, total forage utilization on the Coloraditas Grazing Research and Demonstration Area different between years and seasons (Table 3.6). Forage utilization was different from before to after grazing (P = 0.043). Forage utilization was lowest in 2015, and highest in 2017, but similar between 2015 and 2016, and similar between 2016 and 2017 (Fig. 3.8A). There was no difference by grazing treatment or by treatment × year (Table 3.6). After grazing was initiated (2016 to 2017) forage utilization was higher in November than June on the Coloraditas Grazing Research and Demonstration Area treatments and reference site pastures (Fig. 3.8B), but no interaction by treatment, year, or treatment × year. From before to after grazing (2015–2017), and after grazing only (2016–2017), there was no difference in forage utilization between grazing systems (Continuous = Rotational; P = 0.688, 0.570), stocking rates (Moderate = High; P = 0.983, 0.364), or between treatment grazing systems and reference sites (P = 0.430) in the after period (2016–2017). There was no interaction between system × rate (P = 0.085, 0.631).

Table 3.7. Mean (% ± SE), minimum, and maximum forage utilization by forbs, grass, and total (forbs + grass) averaged over each treatment weighted by pasture on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, October 2015–October 2017.

Year	Mon	Treatment[a]	Forb Utilization (%)	Min	Max	Grass Utilization (%)	Min	Max	Total Utilization (%)	Min	Max
2015	Nov	CH	35.95 ± 13.01	-5.2	100	26.67 ± 7.53	-1.7	100	23.36 ± 0.5	-5.8	100
2015	Nov	CM	33.51 ± 9.35	-4.6	100	38.51 ± 11.25	-0.2	100	28.47 ± 14.19	-0.4	100
2015	Nov	RH	21.81 ± 4.47	-2.6	80.6	22.34 ± 6.46	-11	100	17.96 ± 2.02	-6.8	77.7
2015	Nov	RM	21.32 ± 2.15	-14	81.4	33.46 ± 8.5	-4.3	100	24.4 ± 3.98	-9	72.2
2016	June	CH	19.06 ± 4.55	-2.8	62.3	25.97 ± 0.84	-4.5	57.6	21.29 ± 1.29	-7.1	57.9
2016	June	CM	11.31 ± 8.12	-3.7	51.3	24.93 ± 13.94	-2.2	64.3	20.04 ± 11.65	-2	60.2
2016	June	RH	9.75 ± 5.37	-8.4	55	16.74 ± 3.82	-1.2	52.8	19.31 ± 3.43	-1.7	35.7
2016	June	RM	7.59 ± 5.04	-6.9	70.1	23.03 ± 3.51	-3	72.4	10.63 ± 0.44	-1.5	48.5
2016	June	REF	19.1 ± 3.73	-9.5	58.3	30.59 ± 6.18	-1.1	84.4	18.23 ± 1.8	-1.7	75.9
2016	Nov	CH	57.37 ± 26.53	0	100	34.84 ± 20.49	-12.5	100	31.57 ± 15.44	-28.3	100
2016	Nov	CM	54.64 ± 10.78	0	100	39.43 ± 11.93	-4.9	82.2	40.76 ± 10.34	-2.9	82.2
2016	Nov	RH	23.91 ± 6.95	-18.2	100	44.37 ± 8.83	-26.9	100	31.73 ± 9.06	-9.6	100
2016	Nov	RM	33.07 ± 7.24	-9.1	100	35.1 ± 6.73	-18.6	83.3	41 ± 7.59	-76.9	83.3
2016	Nov	REF	41.51 ± 8.09	-40.9	100	43.93 ± 5.44	-14.1	100	25.93 ± 1.23	-8.3	100
2017	June	CH	47.71 ± 2.18	-3.9	100	35.03 ± 2.57	-6.9	100	34.3 ± 2.42	-3.4	100
2017	June	CM	22.06 ± 4.53	-27.3	100	36.39 ± 13.05	-1.9	67.6	29.66 ± 10.56	-1.4	73.3
2017	June	RH	25.04 ± 5.6	-22.7	100	33.7 ± 4.1	-37.5	100	24.49 ± 4.8	-10.2	93.4
2017	June	RM	30.2 ± 5.83	-18.2	100	36.8 ± 7.27	-6	84.7	28.57 ± 3.59	-2.4	81.8

Table 3.7 continued

Year	Mon	Treatment[a]	Forb Utilization (%)	Min	Max	Grass Utilization (%)	Min	Max	Total Utilization (%)	Min	Max
2017	June	REF	32.86 ± 9.1	-47.7	100	27.72 ± 1.39	-43.8	94.6	25.94 ± 10	-22.2	79.7
2017	Nov	CH	16.57 ± 5.34	-22.7	100	54.61 ± 5.79	-28.1	100	36.3 ± 13.28	-41.7	100
2017	Nov	CM	34.05 ± 2.35	-100	100	43.5 ± 18.2	-53.1	100	33.45 ± 16.85	-47.2	94.3
2017	Nov	RH	33.93 ± 11.59	-38.6	100	48.64 ± 4.67	-7.7	100	31.6 ± 6.51	-5.4	100
2017	Nov	RM	27.33 ± 11.71	-31.8	100	43 ± 13.6	-100	100	46.18 ± 5.58	-10.7	100
2017	Nov	REF	36.63 ± 5.47	-9.1	100	38.77 ± 11.67	-28.1	100	38.63 ± 11.37	-100	91.1

[a]CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate, REF =Reference (Atole, Pinto, Agua Dulce)

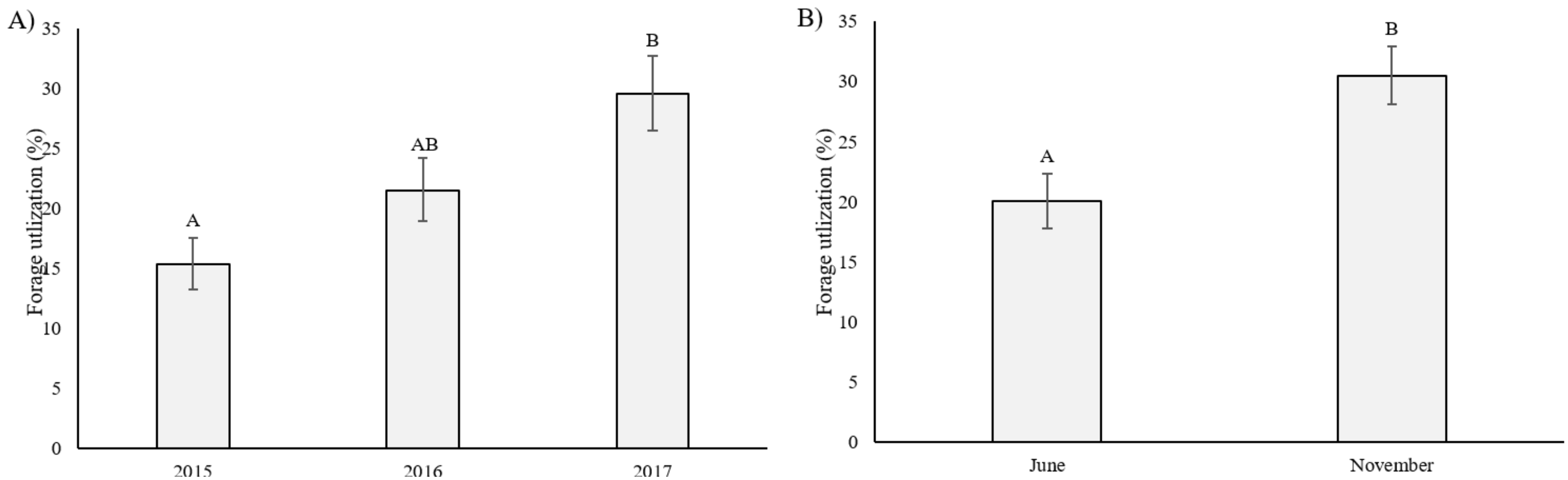

Figure 3.8. (A) Mean (% ± SE) forage utilization on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA 2015–2017 by the main effects of year. (B) Mean (% ± SE) forage utilization on and reference sites by season pooled across treatments in the after-grazing period from 2016–2017. Means followed by the same letter are not significantly different (*P* < 0.05).

Vegetation structure and composition. —Percent grass cover decreased with each year from 2015–2017 (Table 3.8, Fig. 3.9A) and from before to after grazing ($P < 0.0001$). There was no difference in percent grass cover by individual treatment and no treatment × year interaction (Table 3.10). There was no difference in percent grass cover by system (Continuous = Rotational; $P = 0.195$), or rate (Moderate = High; $P = 0.256$). There was no difference between the treatment grazing systems and the reference sites ($P = 0.478$). There was no interaction between system × rate ($P = 0.085$) or between system × rate × period ($P = 0.719$).

Percent bare ground cover decreased with each year from 2015–2017 (Table 3.8, Fig. 3.9B) and from before to after grazing ($P < 0.001$). There was no difference in percent bare ground cover by individual treatment or a treatment × year interaction (Table 3.8). There was no difference in percent bare ground cover by system (Continuous = Rotational; $P = 0.918$), or rate (Moderate = High; $P = 0.343$). There was no difference between the treatment grazing systems and the reference sites ($P = 0.931$). There was no interaction between system × rate ($P = 0.933$) or between system × rate × period ($P = 0.641$).

There was no difference in percent litter (Fig. 3.9C) and woody cover (Fig. 3.9D) between main and interaction effects (treatments, years, or a treatment × year interaction) or contrast statements of system, rate, and period.

There was a treatment × year interaction between percent forb cover (Table 3.8, Fig. 3.10). Within years among grazing treatments, forb cover was highest on the Atole and Agua Dulce pastures in 2015, highest on the Atole pasture in 2016, and highest on the rotational high, Atole, Pinto, and Agua Dulce pasture in 2017 (Fig. 3.10A). Within grazing treatments and among years, forb cover was similar between 2015 and 2016 on the continuous moderate and rotational moderate grazing treatments, but lower in 2017 (Fig. 3.10B). Forb cover was highest

Table 3.8. Results of repeated-measures ANOVAs for dependent variables collected within a 20x5m belt transect on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA October 2015– October 2017. Main effects: treatment = continuous high, continuous moderate, rotational high, rotational moderate, Atole, Pinto, Agua Dulce; year = 2015, 2016, 2017.

Variable	Effect	df	*F*	*P*
Grass (%)	Treatment	6	0.90	0.5507
	Year	2	26.83	< 0.0001
	Treatment × Year	12	0.26	0.9859
Forb (%)	Treatment	6	6.26	0.0210
	Year	2	25.88	<0.0001
	Treatment × Year	12	6.60	0.0013
Bare ground (%)	Treatment	6	0.19	0.9683
	Year	2	49.46	<0.0001
	Treatment × Year	12	1.89	0.1616
Litter (%)	Treatment	6	1.06	0.4087
	Year	2	1.05	0.3750
	Treatment × Year	12	1.98	0.1030
Woody (%)	Treatment	6	0.60	0.7238
	Year	2	2.48	0.1286
	Treatment × Year	12	0.78	0.6607
Species Richness	Treatment	6	0.83	0.5861
	Year	2	29.47	<0.0001
	Treatment × Year	12	3.46	0.0196
Bunchgrass density (clumps per ha)	Treatment	6	0.94	0.5307
	Year	2	16.81	0.0003
	Treatment × Year	12	2.00	0.1214
Visual obstruction (% at 2 meters)	Treatment	6	0.50	0.7883

Table 3.8. continued

Variable	Effect	df	*F*	*P*
	Year	2	1.17	0.3443
	Treatment × Year	12	1.98	0.1250
Visual obstruction (% at 1.5 meters)	Treatment	6	0.51	0.7825
	Year	2	2.74	0.1070
	Treatment × Year	12	0.83	0.6277
Visual obstruction (% at 1 meter)	Treatment	6	1.24	0.4040
	Year	2	6.25	0.0218
	Treatment × Year	12	1.04	0.4910
Visual obstruction (% at 0.5 meters)	Treatment	6	0.39	0.8749
	Year	2	9.01	0.0020
	Treatment × Year	12	0.59	0.8209
Visual obstruction (average %)	Treatment	6	1.01	0.4876
	Year	2	23.35	0.0015
	Treatment × Year	12	1.99	0.2052

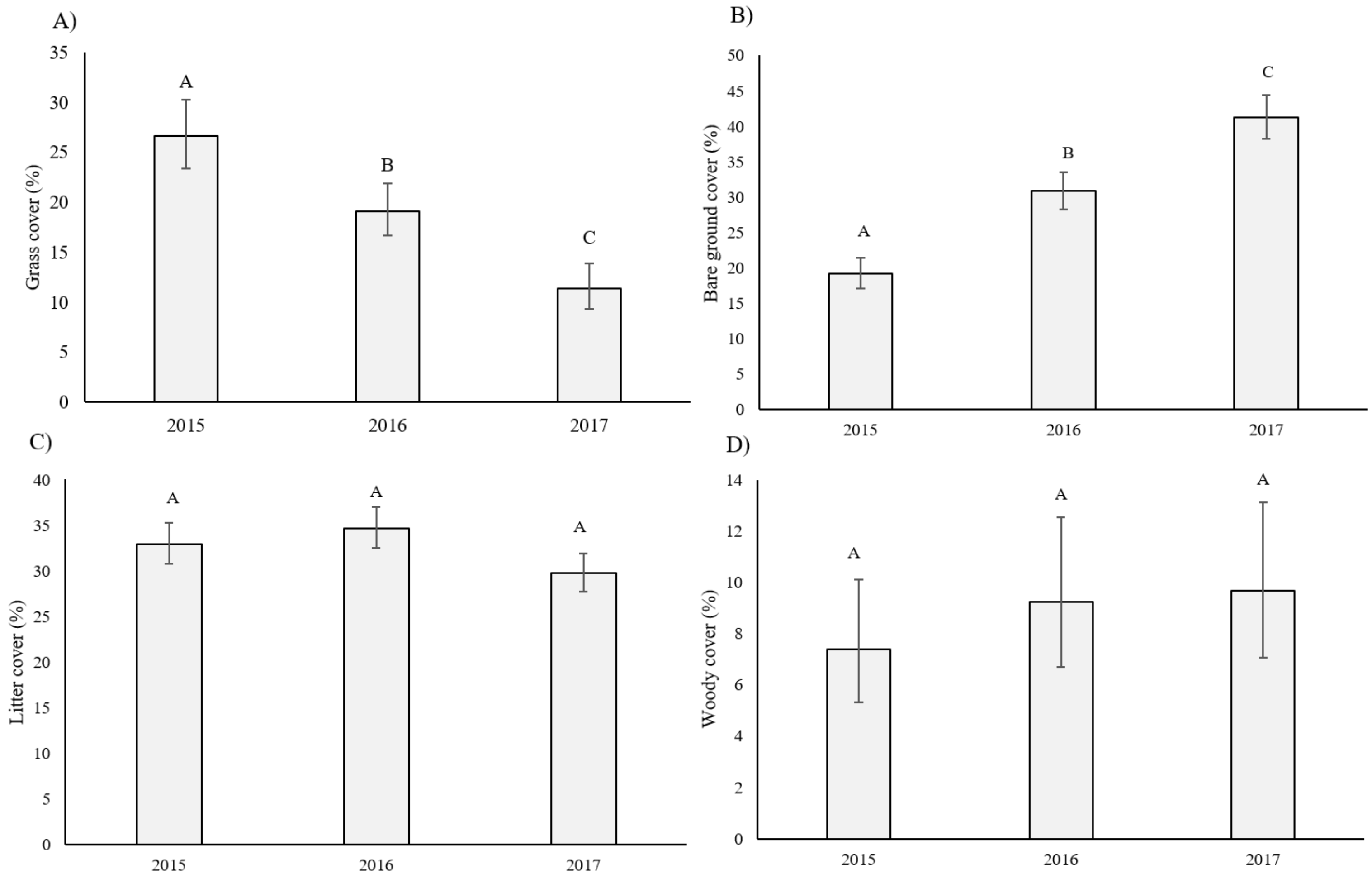

Figure 3.9. Mean (± SE) percent cover of (A) grass, (B) woody, (C) bare ground by year pooled across 7 treatments on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA October 2015– October 2017. Means followed by the same letter are not significantly different ($P < 0.05$).

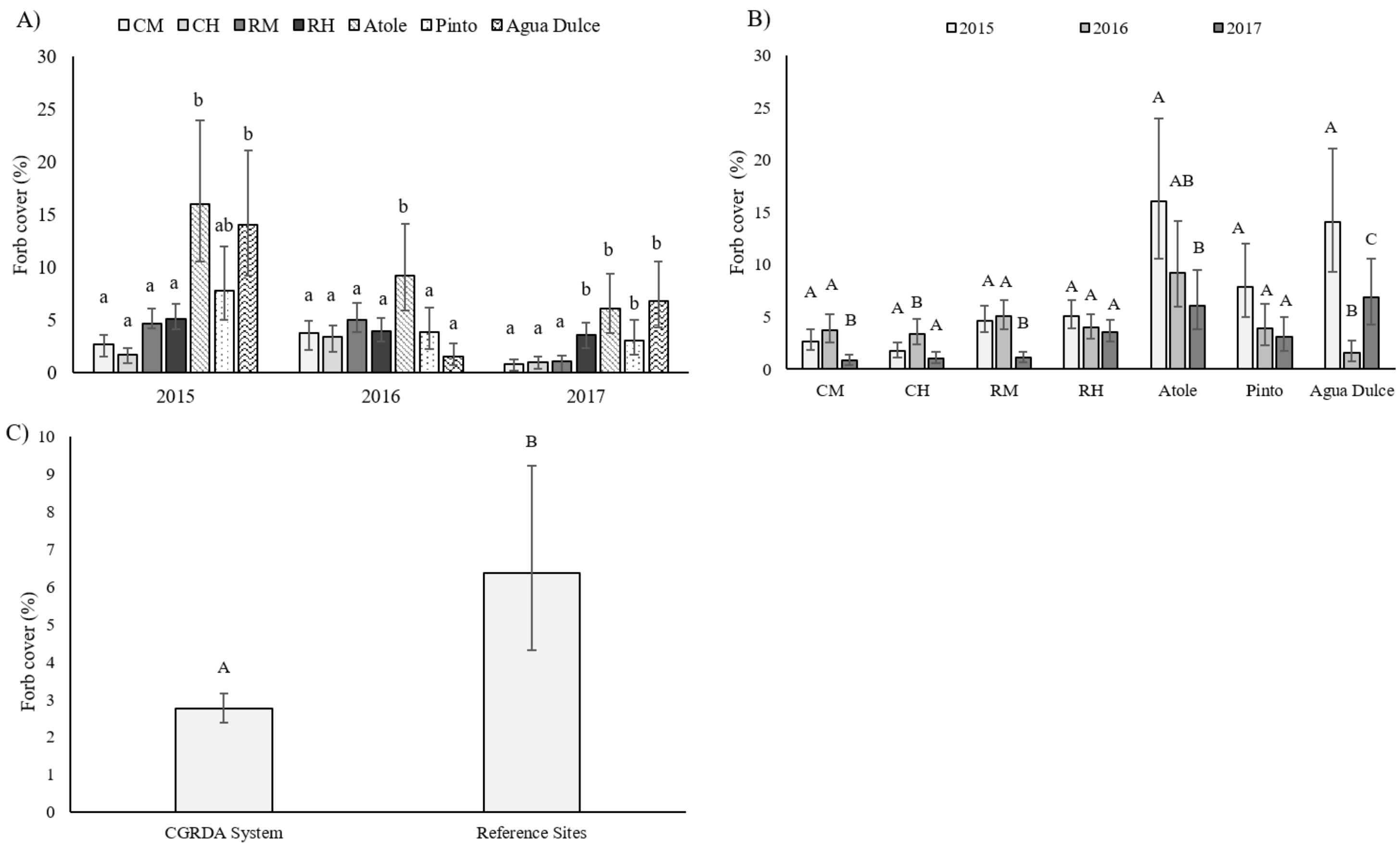

Figure 3.10. Mean (% ± SE) percent cover of forbs (A) within year among treatments and (B) within treatments among years on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA October 2015–October 2017. (C) Mean (% ± SE) percent cover of forbs averaged over grazing system on the (continuous and rotational) and reference site pastures from October 2015–2017. Means followed by the same letter are not significantly different (*P* < 0.05).

on the continuous high treatment in 2016, but similar between 2015 and 2017. Forb cover was similar from 2015–2017 on the rotational high treatment. Forb cover on Atole was similar between 2015 and 2016, and similar between 2016 and 2017, but different between 2015 and 2017. Forb cover on the Pinto was similar across 2015–2017. Forb cover was different in each year on the Agua Dulce pasture. Pooled over grazing treatments, forb cover was different from before to after grazing ($P < 0.001$). Forb cover was similar between grazing systems (Continuous = Rotational; $P = 0.090$) and stocking density ($P = 0.774$), but different between the treatment grazing systems on the and reference sites ($P = 0.021$; Fig. 3.10C). There was no interaction between system × rate ($P = 0.501$) or between system × rate × period ($P = 0.807$).

Total species richness was similar among grazing treatments, but different among years and a treatment × year interaction (Table 3.8, Fig. 3.11). Within each year species richness was similar among treatments (Fig. 3.11A). Within grazing treatments and among years, species richness was similar between 2015 and 2016 on the continuous moderate, continuous high, rotational moderate, Atole, and Pinto pasture, but lower in 2017 (Fig. 3.11B). On the rotational high grazing treatment, species richness was different among years and highest in 2016. On the Agua Dulce pasture, species richness was different among years and highest in 2016 and lowest in 2017. Pooled over grazing treatments, there was a difference in species richness from before to after grazing ($P = 0.005$). Total species richness was similar ($P = 0.349$) between 2015 and 2016 but was lower ($P < 0.001$) in 2017. There was no difference between grazing systems (Continuous = Rotational; $P = 0.113$) or stocking rates (Moderate = High; $P = 0.991$). There was no difference in species richness between the treatment grazing systems and the reference sites ($P = 0.433$). There was no interaction between system × rate ($P = 0.612$) or between system × rate × period ($P = 0.634$).

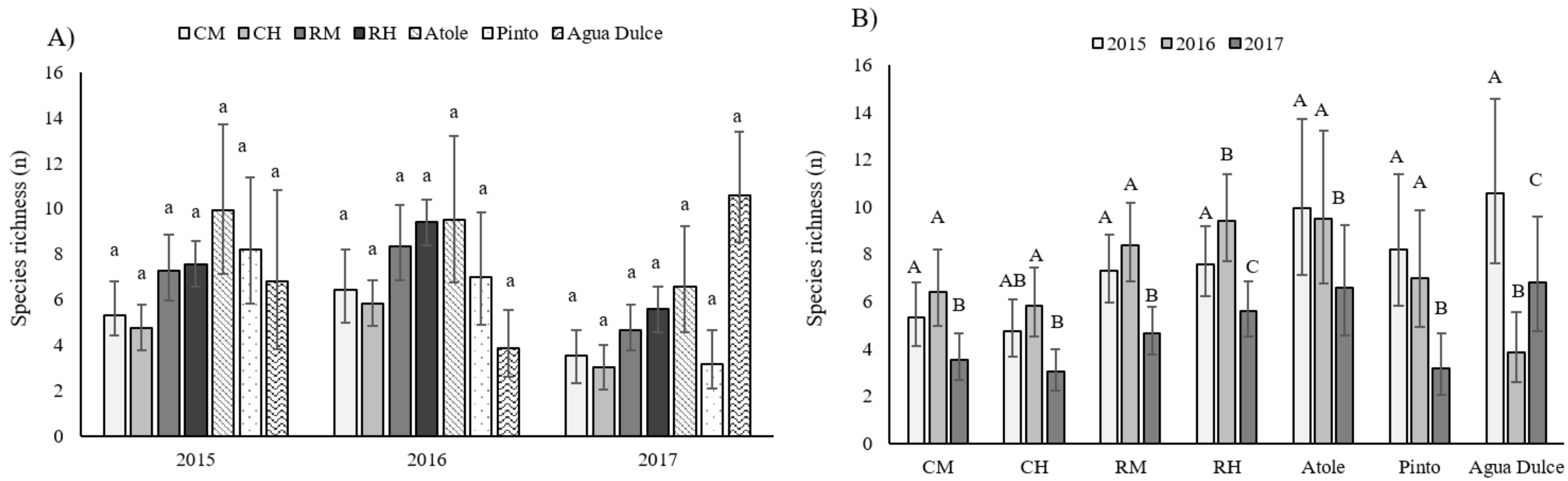

Figure 3.11. Mean (± SE) total species richness of grass and forbs (A) within year among treatments and (B) within treatments among years on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA October 2015–October 2017. Means (A) within year and (B) within treatments followed by the same letter are not significantly different (*P* < 0.05).

Bunchgrass density (clumps/ha) was different among years (Table 3.8, Fig. 3.12A). Pooled over grazing treatments, bunchgrass density was different from before to after grazing ($P < 0.001$). Bunchgrass density was higher in 2015 compared to 2016 and 2017, but similar between 2016 and 2017 (Fig. 3.12A). There was no treatment or treatment × year interaction (Table 3.10). There was no difference in bunchgrass density between grazing systems (Continuous = Rotational; $P = 0.400$) or stocking rates (Moderate = High; $P = 0.079$). There was no difference in bunchgrass density between the grazing systems on the Coloraditas Grazing Research and Demonstration Area and reference sites ($P = 0.849$). There was not an interaction between system × rate ($P = 0.856$) or between system × rate × period ($P = 0.427$).

There was no difference in percent visual obstruction between grazing treatments, years, or a treatment by year interaction at a height of 1.5 and 2 m, respectively. Percent visual obstruction at 0.5 and 1 m was similar between 2015 and 2016, but decreased in 2017, respectively (Table 3.8; Fig. 3.12B). Percent visual obstruction at 0.5 m was higher before than after grazing ($P = 0.394$), but not at 1 m ($P = 0.118$). There was no difference in visual obstruction at 0.5 or 1 m between grazing systems (Continuous = Rotational; $P = 0.927$, 0.113) or stocking rates (Moderate = High; $P = 0.693$, 0.842). There was no difference in bunchgrass density between the treatment grazing systems and reference sites ($P = 0.353$, 0.217). There was no interaction between system × rate ($P = 0.415$, 0.340) or between system × rate × period ($P =$ 0.520, 0.947).

Percent visual obstruction averaged from 0 to 2 m was similar between grazing treatments, but different between years (Table 3.8, Fig. 3.12B). Between years, visual obstruction was similar between 2015 and 2016, but lower in 2017. Percent visual obstruction was higher ($P = 0.009$) before than after grazing was implemented. There was no treatment or

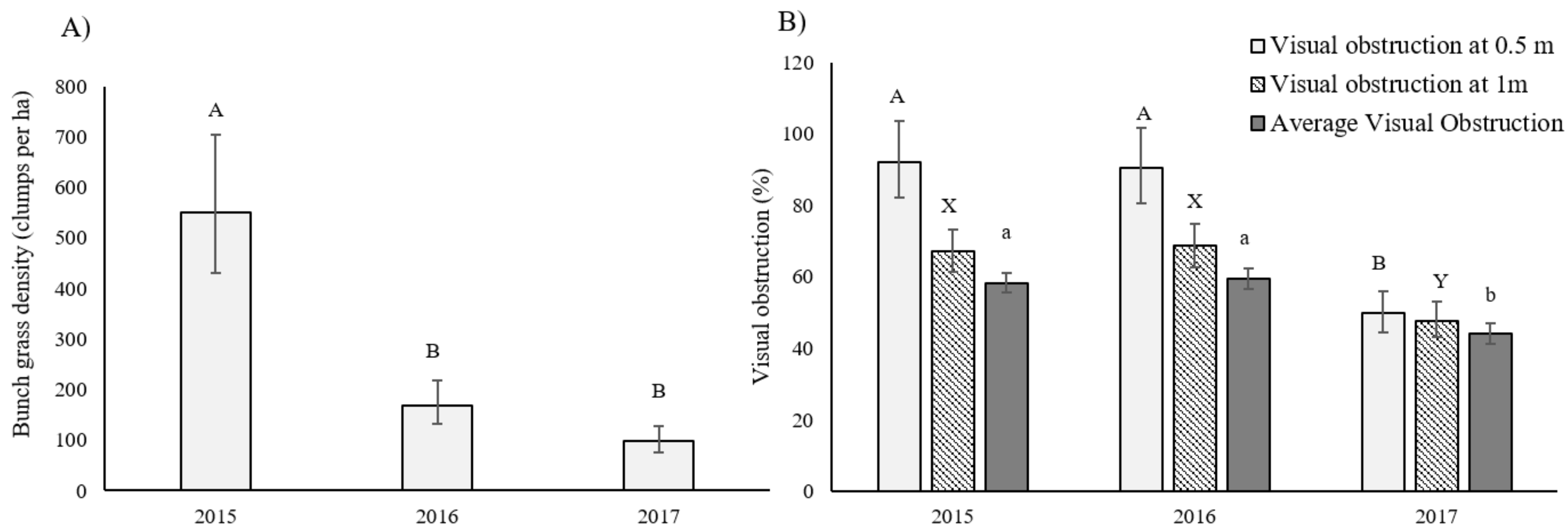

Figure 3.12. Mean (± SE) percent cover of (A) bunch grass density (clumps per ha) and (B) percent visual obstruction by year pooled across 7 treatments on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA October 2015–October 2017. Means followed by the same letter are not significantly different ($P < 0.05$).

treatment × year interaction. There was no difference in percent visual obstruction between grazing systems (Continuous = Rotational; $P = 0.242$) or stocking rates (Moderate = High; $P = 0.843$). There was no difference in percent visual obstruction between the treatment grazing systems and reference sites ($P = 0.825$). There was no interaction between system × rate ($P = 0.652$) or between system × rate × period ($P = 0.516$).

Bobwhite Density

By grazing treatment and year. — I detected 1,221 coveys from 2014 to 2017 pooled across all surveys and grazing treatments on the Coloraditas Grazing Research and Demonstration Area. I detected 142, 420, 382, and 277 coveys in 2014, 2015, 2016, and 2017 with an encounter rate (n/L) of 0.37, 1.1, 1.0, and 0.72 coveys/km across all treatments, respectively. While the pooled bobwhite density estimates between survey 1 (1.26 ± 0.08 bobwhites/ha) and survey 2 (1.17 ± 0.09 bobwhites/ha) in 2015 were similar, I excluded the data from the first 2015 survey from all analyses in this chapter. Density estimates from this survey were unreliable due to violation of model assumptions, lack of fit, and high variation in the detection probability (Chapter II: Table 2.3B, Fig. 2.10A) I excluded the data from the 2015 survey 2 survey flown with transects oriented North to South to keep data consistent across years.

The top model included distance, survey number, and year and was fit with a half-normal model with no adjustments (Appendix C, Fig. 3.13, Fig. 3.14). All models satisfied goodness-of-fit tests (Appendix C). An exploratory analysis of covariates revealed that covariates such as experience, condition, hour, and temperature may influence detectability . I excluded coveys that did not fall within grazing treatments (i.e., center cattle lane) as I had no way to associate their location with a treatment. I truncated 10% ($w = 40$ m) of detections resulting in 1,065

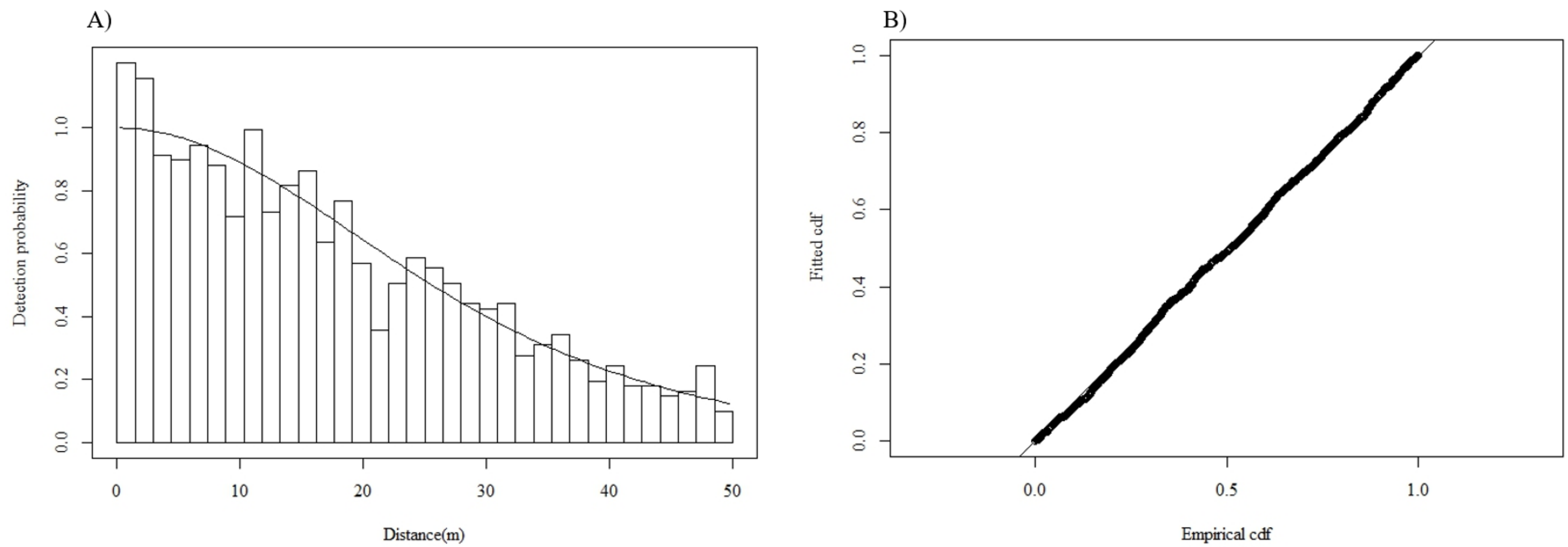

Figure 3.13. (A) Frequency histogram of northern bobwhite covey detections by distance with global fitted detection function and (B) quantile-quantile plots for coveys detected on the Coloraditas Grazing Research and Demonstration Area each December in Jim Hogg County, Texas, USA, 2014–2017.

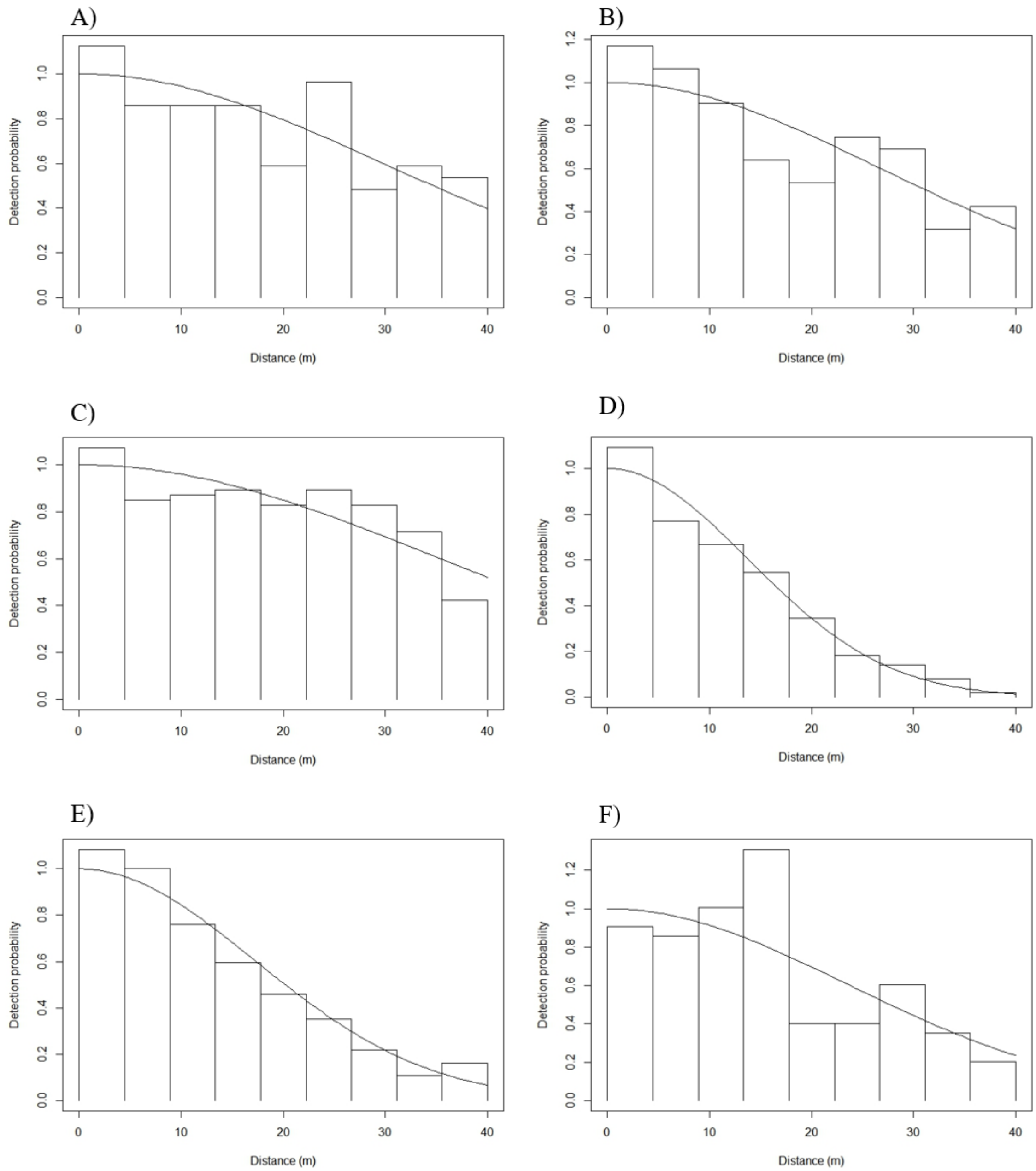

Figure 3.14. Frequency histogram of covey detections by distance and fitted detection function for annual estimates of northern bobwhite density pooled over treatments with a model including year and survey number as factor covariates on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA (A) 2014, (B) 2015, (C) 2016 survey 1, (D) 2016 survey 2, (E) 2017 survey 1, and (F) 2017 survey 2.

coveys. In addition to survey and year, condition, temperature, and hour as continuous covariates were fit to models within ΔAIC values <2.0 (Appendix C). The detection function did not differ by individual treatment within a single year. The coefficient of variation (% CV [$\hat{D}$]) for 2014 was above the recommended 20% in all grazing treatments (detections <40 in all treatments; Table 3.9). The % CV [$\hat{D}$] was below the recommended 20% in all subsequent treatment × years except for the continuous moderate treatment in 2017, which only had 36 detections (Table 3.9). The lowest density estimate over the 4 years was in the rotational high treatment in 2014 at 0.36 ± 0.09 bobwhites/ha or a bobwhite/2.7 ha and the highest was on the continuous moderate and rotational high treatment in 2016 at 2.41 ± 0.26 and 2.42 ± 0.32 bobwhites/ha, respectively, or a bobwhite/0.4 ha (Table 3.9; Fig. 3.15).

I detected 483 coveys from 2014 to 2017 pooled across all surveys and pastures on the reference sites. I detected 71, 163, 123, and 126 coveys in 2014, 2015, 2016, and 2017 with an encounter rate (n/L) of 0.39, 0.78, 0.62, and 0.60 coveys/km across all pastures, respectively.

All models satisfied goodness of fit tests (Appendix C). An exploratory analysis of covariates revealed that covariates such as experience, condition, hour, and temperature may influence detectability. I truncated 10% (w = 45 m) of detections resulting in 435 coveys. The top model included distance, year, and wind and was fit with a half-normal model with no adjustments (Appendix C, Fig. 3.16, Fig. 3.17). In addition to year and wind, hour, PLAND, and experience as well as temperature on its own as continuous covariates were fit to models within ΔAIC values <2.0 (Appendix C). The detection function did not differ by individual reference site pasture within a single year. The % CV ($\hat{D}$) in all pastures and years was above the recommended 20% except for the Agua Dulce pasture in 2015 (19.75%), the Atole pasture in 2016 (18.97%), and the Atole pasture in 2017 (16.81%; Table 3.10).

Table 3.9. Number of transects (k), total transect length, (L), number of northern bobwhite covey detections (n), density (bobwhites/ha [$\widehat{D}$ ± SE]), coefficient of variation (%CV[$\hat{D}$]), degrees of freedom (df), 95% Bootstrap confidence intervals (95%CI[D]) and quantile confidence intervals (2.5 and 97.5% CI[D]), from surveys on the Coloraditas Grazing Research and Demonstration Area, by treatment site, in Jim Hogg County, Texas, USA 2014–2017.

Year	Treatment[a]	k	L (m)	n	$\hat{D}$± SE	% CV ($\hat{D}$)	#	df	95% CI BS	Quantile BS
2014	CH	33	96085	28	0.44 ± 0.11	24.31	999	58.77	(0.27–0.71)	(0.23–0.67)
	CM	30	68566	29	0.65 ± 0.16	20.95	999	47.74	(0.43–0.99)	(0.42–0.94)
	RH	31	107290	30	0.36 ± 0.09	23.78	999	71.72	(0.23–0.58)	(0.21–0.54)
	RM	32	100370	41	0.52 ± 0.09	22.55	999	89.06	(0.34–0.81)	(0.30–0.76)
2015	CH	33	96085	77	0.92 ± 0.12	19.09	999	83.67	(0.63–1.34)	(0.60–1.27)
	CM	30	68566	70	1.67 ± 0.28	14.21	999	72.89	(1.26–2.21)	(1.21–2.15)
	RH	31	107290	122	1.59 ± 0.19	17.28	999	58.39	(1.13–2.24)	(1.09–2.15)
	RM	32	100370	98	1.34 ± 0.18	14.97	999	83.45	(1.00–1.80)	(0.99–1.76)
2016	CH	33	96085	82	1.78 ± 0.30	16.12	999	107.2	(1.30–2.45)	(1.26–2.39)
	CM	30	68566	85	2.42 ± 0.32	14.46	999	115.31	(1.82–3.21)	(1.82–3.18)
	RH	31	107290	138	2.41 ± 0.26	11.11	999	120.11	(1.93–3.00)	(1.91–2.95)
	RM	32	100370	72	1.58 ± 0.27	15.66	999	68.18	(1.15–2.13)	(1.11–2.04)
2017	CH	33	96085	63	0.76 ± 0.13	16.35	999	82.27	(0.55–1.05)	(0.55–1.03)
	CM	30	68566	36	0.59 ± 0.14	23.27	999	63.95	(0.38–0.94)	(0.35–0.89)
	RH	31	107290	77	0.73 ± 0.13	17.98	999	57.16	(0.51–1.04)	(0.51–1.01)
	RM	32	100370	90	0.86 ± 0.12	14.87	999	80.91	(0.64–1.15)	(0.63–1.14)

[a]CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate

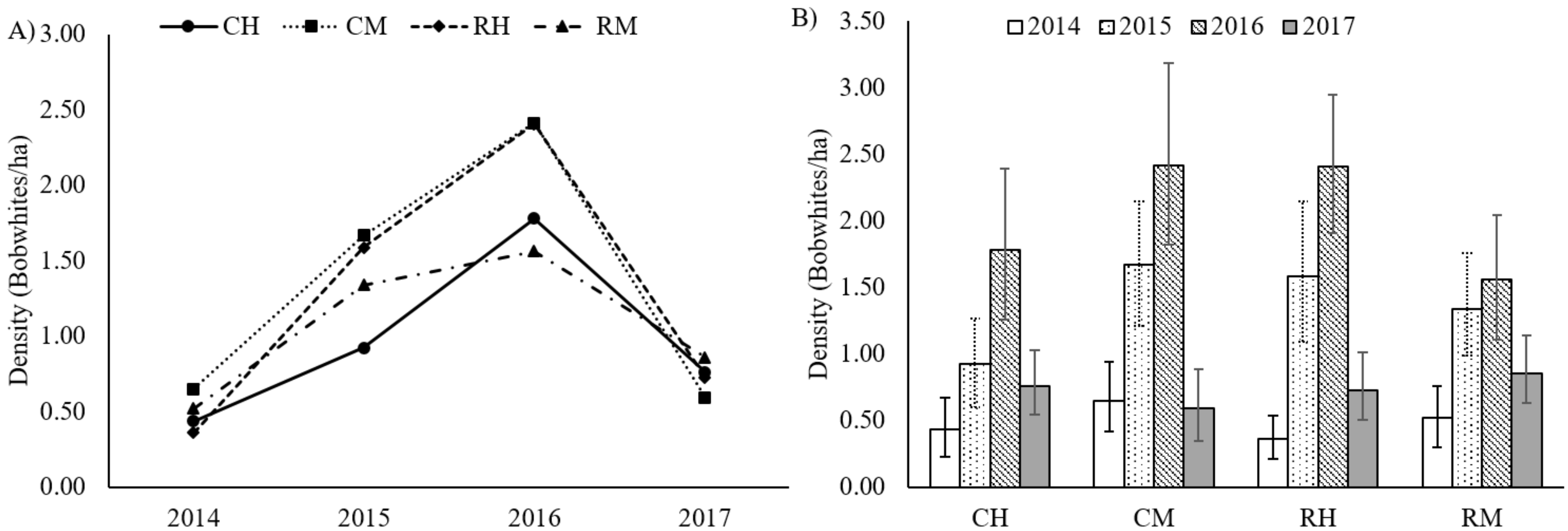

Figure 3.15. Estimated annual in northern bobwhite density (quail/ha [D̂]) (A) within years among treatments (B) within treatments among years on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, 2014–2017. Error bars represent corresponding 95% CI. CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate.

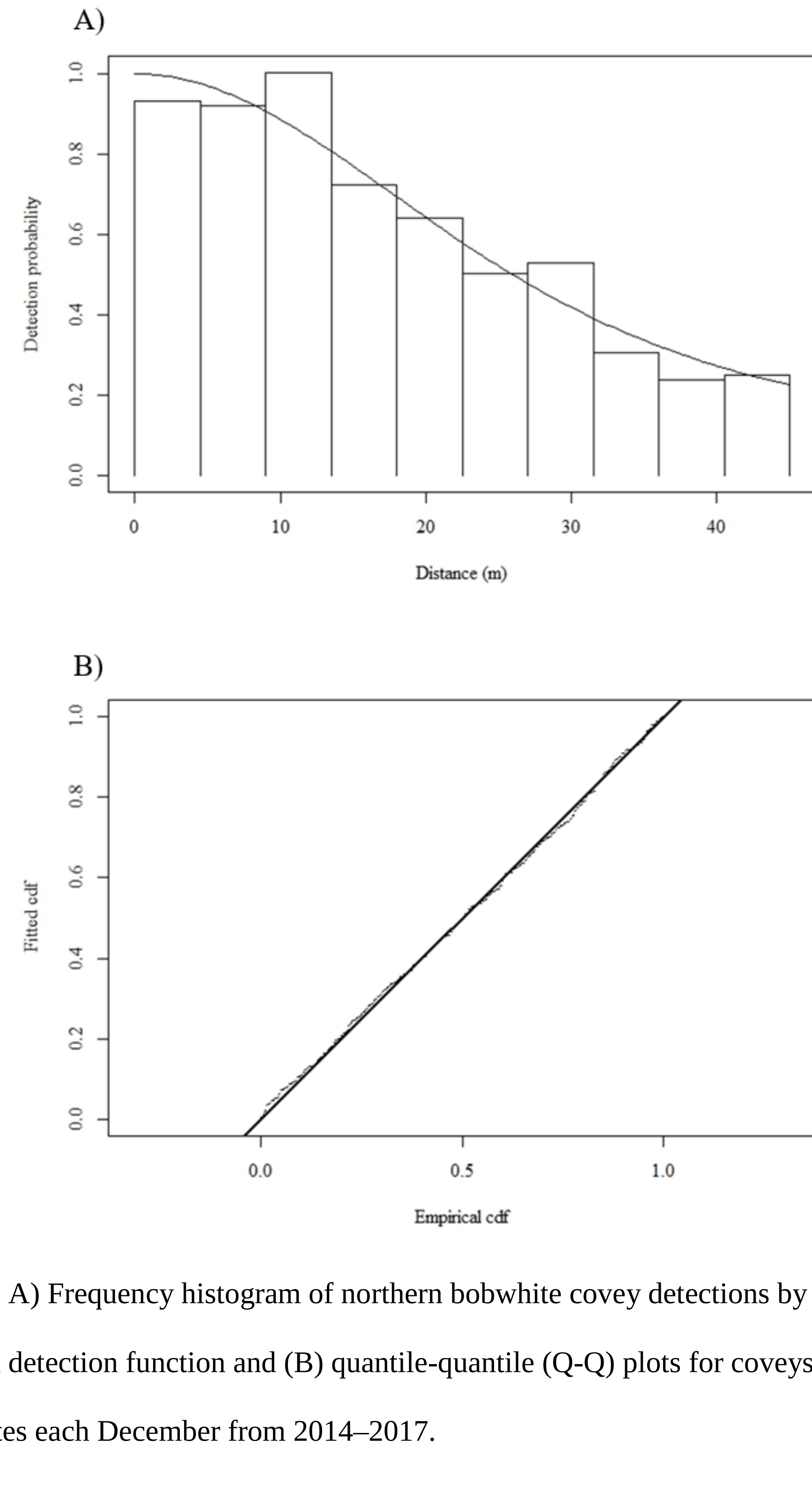

Figure 3.16. A) Frequency histogram of northern bobwhite covey detections by distance with global fitted detection function and (B) quantile-quantile (Q-Q) plots for coveys detected on the reference sites each December from 2014–2017.

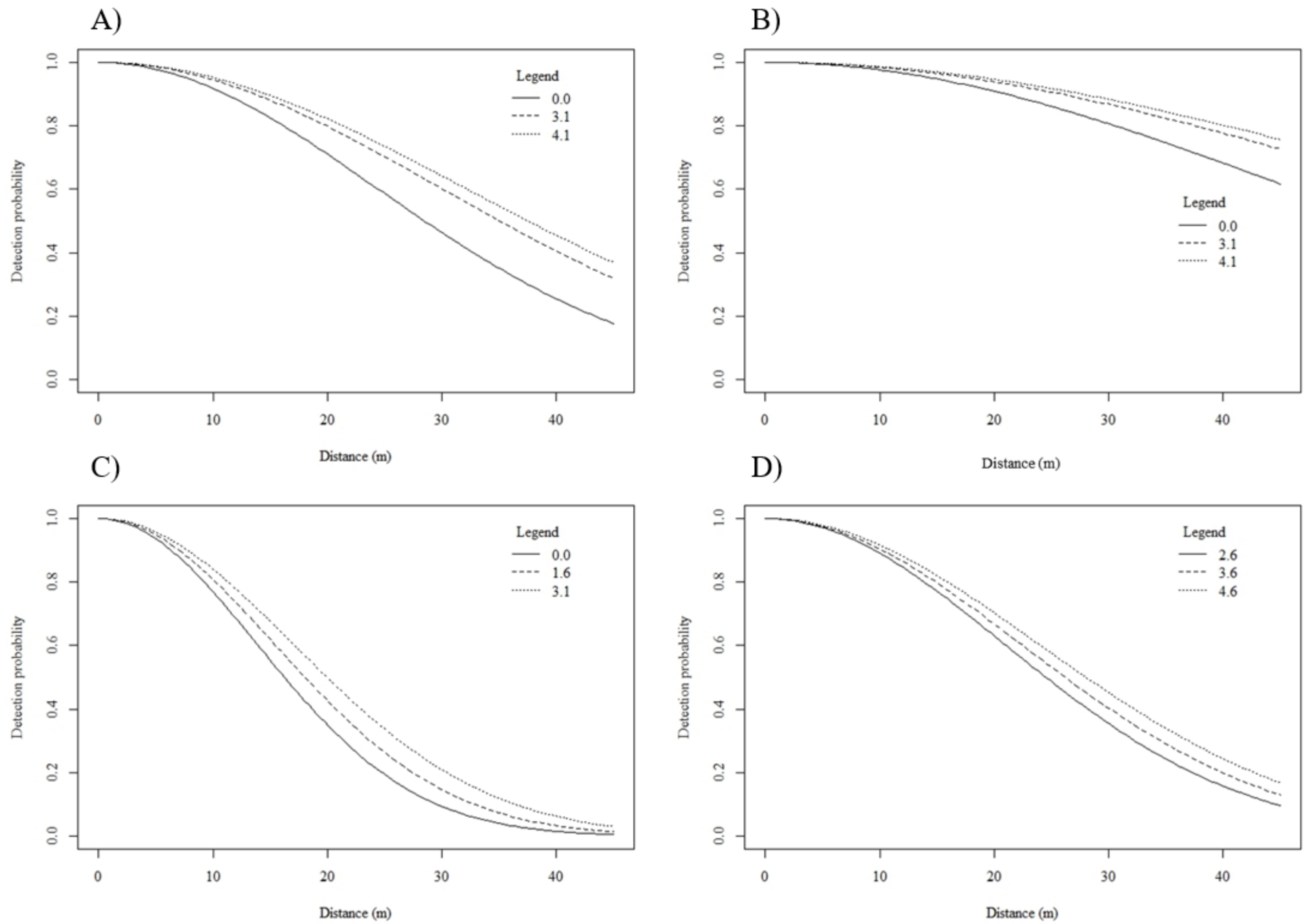

Figure 3.17. Marginal detection functions for annual estimates of northern bobwhite density on the pooled over reference site pasture in Jim Hogg County, Texas, USA plotted for a model fitted with wind speed as a continuous covariate within year as a factor covariate (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

Table 3.10. Number of transects (k), total transect length, (L), number of northern bobwhite covey detections (n), density (bobwhite/ha [$\hat{D}$] ± SE), coefficient of variation (CV[$\hat{D}$]), degrees of freedom (df), 95% confidence intervals, from surveys on reference sites, by pasture, in Jim Hogg County, Texas, USA, 2014–2017.

Year	Pasture	k	L(m)	n	$\hat{D}$±SE	% CV ($\hat{D}$)	df	95% CI
2014	Atole	20	55737	31	0.78 ± 0.16	21.51	57.39	(0.51–1.19)
	Pinto	19	59679	14	0.39 ± 0.14	36.45	40.04	(0.19–0.79)
	Agua Dulce	16	64000	19	0.48 ± 0.13	27.96	47.66	(0.28–0.84)
2015	Atole	23	73289	48	0.73 ± 0.15	20.57	54.86	(0.49–1.10)
	Pinto	19	59546	32	0.57 ± 0.11	20.30	52.44	(0.38–0.86)
	Agua Dulce	19	76532	52	0.81 ± 0.16	19.75	40.67	(0.55–1.21)
2016	Atole	23	73289	57	1.50 ± 0.28	18.97	61.84	(1.03–2.19)
	Pinto	19	59546	36	1.43 ± 0.37	26.30	43.24	(0.85–2.42)
	Agua Dulce	16	64448	26	0.81 ± 0.23	28.68	46.68	(0.46–1.43)
2017	Atole	23	73289	54	0.70 ± 0.12	16.81	62.51	(0.50–0.98)
	Pinto	19	59546	26	0.54 ± 0.14	25.52	56.61	(0.32–0.89)
	Agua Dulce	19	76532	40	0.59 ± 0.13	22.96	39.91	(0.38–0.94)

The lowest density estimate I recorded over the 4 years was in the Pinto pasture in 2014 at 0.39 ± 0.14 bobwhite/ha or a bobwhite/2.5 ha and the highest was on the Atole pasture in 2016 at 1.50 ± 0.28 bobwhites/ha or a bobwhite/0.6 ha (Table 3.10, Fig. 3.18); detections in these pasture-years were above 50 coveys.

Magnitude of change. —Differences in density estimates among individual grazing treatments and reference site pastures in 2014 (73% difference between the highest and lowest density estimate) and 2017 (45%) were small compared to 2015 (94%) and 2016 (99%). The percent difference in 2014 was smaller (57%) when estimates from the original reference site boundaries were used; reconfiguring estimates may have biased density in 2014 (see Chapter IV).

Bobwhite density estimates on the individual treatments of the Coloraditas Grazing Research and Demonstration Area and reference site pastures fluctuated with cumulative average April–August precipitation (Fig. 3.19), which differed between Coloraditas Grazing Research and Demonstration Area and reference sites. Density estimates for each Coloraditas Grazing Research and Demonstration Area treatment between years were higher in 2015 and 2016 than 2014 and 2017 (Fig. 3.19). Between 2014 to 2015, before grazing was initiated, density estimates on each treatment increased by >100% on each treatment (Table 3.11). Between 2015 and 2016, after 1 year of grazing and an increase in cumulative average April–August precipitation in 2016, the magnitude of change was highest (93%) on the continuous high treatment and lowest on the rotational moderate treatment (17%; Table 3.11). Densities between 2015 and 2016 on the Atole and Pinto pastures increased by >100% with an increase in cumulative average April–August precipitation from 2015 to 2016 but remained similar on the Agua Dulce pasture (Table 3.11).

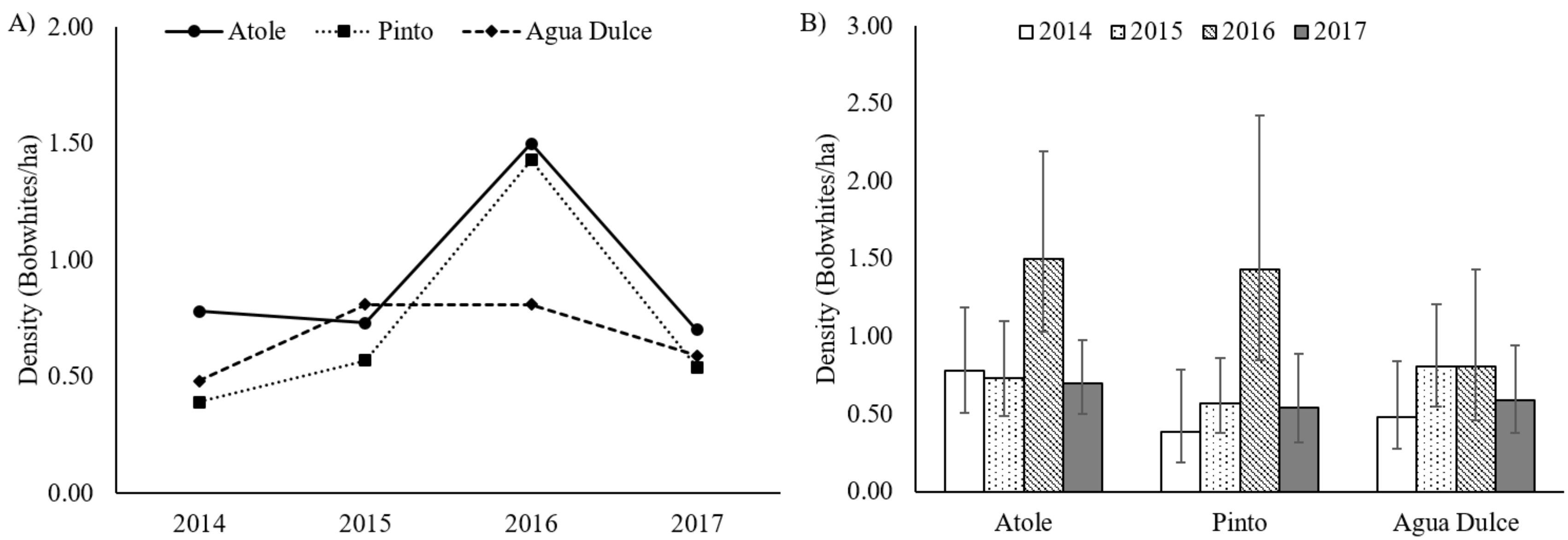

Figure 3.18. Estimated annual in northern bobwhite density (bobwhite/ha [$\hat{D}$]) (A) within years among pastures (B) within pastures among years on the reference sites in Jim Hogg County, Texas, USA, 2014–2017. Error bars represent corresponding 95% confidence intervals.

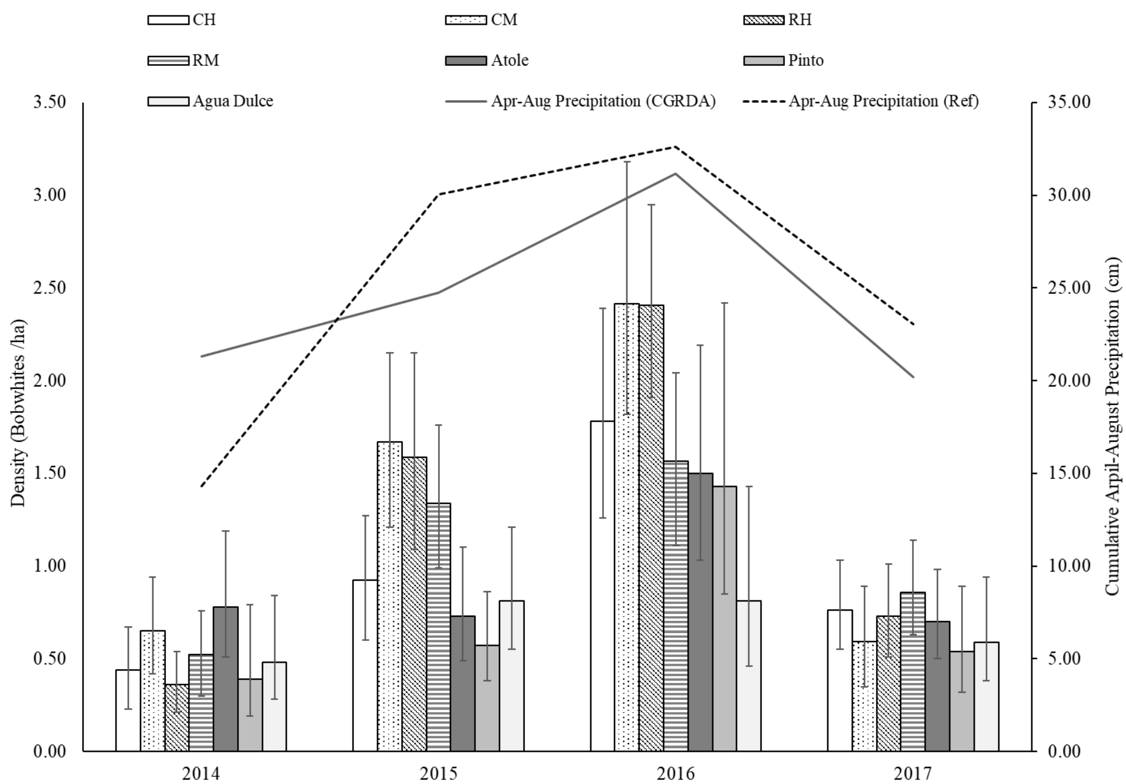

Figure 3.19. Estimated annual in northern bobwhite density (bobwhite/ha [$\hat{D}$]) within years among treatments on the Coloraditas Grazing Research and Demonstration Area and individual reference site pastures (Atole, Pinto, and Agua Dulce) along with average cumulative April – August precipitation on the Coloraditas Grazing Research and Demonstration Area (solid line) and reference sites (dashed line) in Jim Hogg County, Texas, USA, 2014–2017. Error bars represent 95% CI . CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate.

Table 3.11. The difference ($\bar{X}_1 - \bar{X}_2$) and percent magnitude of change (difference/$\bar{X}_1 \times 100$) between northern bobwhite density before, after, and before vs. after grazing treatment implementation in years of low and high precipitation on each Coloraditas Grazing Research and Demonstration Area treatment and reference site in Jim Hogg County, Texas, USA, 2014–2017.

	Before (2014 vs. 2015)		After (2016 vs. 2017)		Before vs. After (2014 vs. 2017)		Before vs. After (2015 vs. 2016)	
	Difference	% change	Difference	% change	Difference	% change	Difference	% change
CGRDA[a]								
CH	0.48	110.81	-1.02	-57.11	0.33	74.49	0.86	93.00
CM	1.02	155.83	-1.82	-75.37	-0.06	-8.77	0.75	44.80
RH	1.23	340.23	-1.68	-69.78	0.37	101.72	0.82	51.61
RM	0.82	156.19	-0.71	-45.09	0.34	64.40	0.23	16.87
Reference Sites								
Atole	-0.05	-6.41	-0.80	-53.33	-0.08	-10.26	0.77	105.48
Pinto	0.18	46.15	-0.89	-62.24	0.15	38.46	0.86	150.88
Agua Dulce	0.33	68.75	-0.22	-27.16	0.11	22.92	0.00	0.00

[a]CH= Continuous High, CM= Continuous Moderate, RH= Rotational High, RM= Rotational Moderate, REF =Reference (Atole, Pinto, Agua Dulce).

Regardless of grazing treatment on the Coloraditas Grazing Research and Demonstration Area or reference site pasture, densities decreased in 2017 with a decrease in cumulative average April–August precipitation (Table 3.11 Fig. 3.19). The largest percent decrease (75%) between 2016 and 2017 occurred on the continuous moderate and rotational high pastures, while the smallest (27%) occurred on the Agua Dulce pasture.

Pooled differences. **—**There was no difference between bobwhite density estimates on the Coloraditas Grazing Research and Demonstration Area (pooled over treatment, 0.48 ± 0.06 bobwhites/ha) and reference sites (pooled over pasture, 0.50 ± 0.08 bobwhites/ha) in the first pre-treatment year, 2014 (Table 3.12). However, in 2015, the second pretreatment year, density estimates differed (Table 3.12) between the Coloraditas Grazing Research and Demonstration Area (1.32 ± 0.09 bobwhites/ha) and reference sites (0.69 ± 0.09 bobwhites/ha). In 2016, after 1 year of cattle grazing, pooled density estimates between the Coloraditas Grazing Research and Demonstration Area (1.37 ± 0.18 bobwhites/ha) and reference sites (2.05 ± 0.15 bobwhites/ha) were different, but similar in 2017 after 2 years of grazing.

Within the pre-treatment period, the Coloraditas Grazing Research and Demonstration Area bobwhite density estimates between 2014 and 2015 were different (Table 3.13). Within the after period, the Coloraditas Grazing Research and Demonstration Area density estimates between 2016 and 2017 were different (Table 3.13). To explore these differences, I characterized 2015 (68 cm) and 2016 (61 cm) as years of high cumulative precipitation and 2014 (55 cm) and 2017 (46 cm) as years of low precipitation and compared the Coloraditas Grazing Research and Demonstration Area estimates before to after grazing in low precipitation and the Coloraditas Grazing Research and Demonstration Area estimates before to after grazing in high precipitation. Density estimates on the Coloraditas Grazing Research and Demonstration Area within years of

Table 3.12 Summary statistics for annual differences in northern bobwhite densities between the Coloraditas Grazing Research and Demonstration Area (CGRDA) and reference Sites (REF) in Jim Hogg County, Texas, USA before (2014 and 2015) and after (2016 and 2017) cattle grazing on the CGRDA. Difference = CGRDA − REF; SE for the diff. = √SE2CGRDA+SE2REF; z-score = difference/SE for the diff.

	Before		After	
	2014	2015	2016	2017
Difference	-0.02	0.63	0.68	0.12
SE for the diff.	0.10	0.13	0.24	0.11
z-score	-0.17	4.75	2.83	1.11
P-value two tailed	0.87	< 0.00001	0.005	0.27

Table 3.13. Summary statistics for differences in annual northern bobwhite densities on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, before (2014 and 2015) grazing, after (2016 and 2017) grazing, and before vs. after cattle grazing between years of high precipitation (>55 cm) and years of low precipitation (< 55 cm). Difference = Year1 − Year2; SE for the diff. = √SE2Year1+SE2Year2; z-score = difference/SE for the diff.

	Before 2014 vs 2015	After 2016 vs 2017	Before vs. After (high precipitation) 2015 vs 2016	Before vs. After (low precipitation) 2014 vs 2017
Difference	0.84	-1.31	0.72	0.25
SE for the diff.	0.11	0.17	0.18	0.09
z-score	7.44	-7.78	4.00	2.71
P-value two tailed	< 0.00001	< 0.00001	0.00006	< 0.00001

similar precipitation was different from before to after grazing from 2015 to 2016 and from 2014 to 2017 (Table 3.13).

On the Coloraditas Grazing Research and Demonstration Area, there was no difference in bobwhite density averaged over the continuous grazing treatments (1.04 ± 0.08) compared to the rotational grazing treatments (1.06 ± 0.08; Table 3.14). When averaged over years of low precipitation (2014 and 2017), high precipitation (2015 and 2016), there was no difference in densities on continuous grazing treatments (0.60 ± 0.06, 1.95 ± 0.20) compared to rotational grazing treatments (0.62 ± 0.06, 2.42 ± 0.29; Table 3.14). There was no difference in density between continuous grazing treatments (1.28 ± 0.11) and rotational grazing treatments (1. 39 ± 0.11) when averaged across years after grazing was implemented (2016 and 2017; Table 3.14). There was no difference in density averaged over the high stocked grazing treatments (1.07 ± 0.08) compared to the moderate stocked grazing treatments (1.08 ± 0.08; Table 3.14). When averaged over years of low precipitation (2014 and 2017), high precipitation (2015 and 2016), there was no difference in bobwhite densities on high stocked grazing treatments (0.53 ± 0.05 bobwhites/ha vs. 2.15 ± 0.19 bobwhites/ha) compared to moderate grazing treatments (0.69 ± 0.07 bobwhites/ha vs. 1.8 ± 0.19 bobwhites/ha; Table 3.14). There was no difference in bobwhite density between high stocked grazing treatments (1.34 ± 0.10 bobwhites/ha) and moderate stocked grazing treatments (1.25 ± 0.10 bobwhites/ha) when averaged across years after grazing was implemented (2016 and 2017; Table 3.14).

Grazing was consistent on the reference sites throughout all 4 years of the study. Within the before period, the reference site estimates between 2014 and 2015 were similar (Table 3.15). Within the after period, the reference site estimates between 2016 and 2017 were different (Table 3.15). Density estimates on the reference sites within years of similar precipitation were different

Table 3.14. Summary statistics for differences in annual northern bobwhite densities on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, between system (continuous vs. rotational), rate (high vs. moderate), and system and rate averaged over: years of low precipitation (>55 cm; 2014 and 2017), years of high precipitation (< 55 cm; 2015 and 2016) and after cattle grazing (2016 and 2017). Difference = Mean1 − Mean2; SE for the diff. = √SE2Mean1+SE2Mean2; z-score = difference/SE for the diff.

	System	Rate	Low precipitation ($\bar{X}$ 2014 and 2017)		High Precipitation ($\bar{X}$ 2015 and 2016)		After ($\bar{X}$ 2016 and 2017)	
	Continuous vs. Rotational	High vs. Moderate	Continuous vs. Rotational	High vs. Moderate	Continuous vs. Rotational	High vs. Moderate	Continuous vs. Rotational	High vs. Moderate
Difference	0.019	0.016	0.02	0.161	0.467	-0.321	0.116	-0.09
SE for the diff.	0.122	0.124	0.092	0.094	0.358	0.271	0.162	0.148
z-score	0.156	0.129	0.221	1.71	1.304	-1.184	0.717	-0.61
P-value two tailed	0.873	0.897	0.826	0.087	0.194	0.238	0.478	0.542

Table 3.15. Summary statistics for differences in annual northern bobwhite densities on the reference sites during the pretreatment period (2014 and 2015) and during the grazing period (2016 and 2017) in Jim Hogg County, Texas, USA, before vs. after cattle grazing between years of high precipitation (>55 cm) and years of low precipitation (< 55 cm). Difference = Year1 − Year2; SE for the diff. = √SE2Year1+SE2Year2; z-score = difference/SE for the diff.

	Before 2014 vs 2015	After 2016 vs 2017	Before vs After (high precipitation) 2015 vs 2016	Before vs. After (low precipitation) 2014 vs 2017
Difference	0.20	-0.75	0.68	0.12
SE for the diff.	0.12	0.20	0.21	0.11
z-score	1.57	-3.73	3.26	1.05
P-value two tailed	0.12	< 0.00001	< 0.00001	0.29

between 2015 and 2016 during years of high precipitation, but similar between 2014 and 2017 during years of low precipitation (Table 3.15).

Precipitation and density. —Breeding season precipitation explained 36% of the fluctuations in annual density on Coloraditas Grazing Research and Demonstration Area treatments and reference site pastures from 2014 to 2017 (r^2=0.36, P = 0.006; Fig. 3.20). Adding residual forage standing crop at the end of the summer growing season (November) did not significantly improve the model ($F_{26, 1}$= 13.42, P = 0.767).

On the Coloraditas Grazing Research and Demonstration Area treatments alone, breeding season precipitation explained 59% of the fluctuations in annual density (r^2 = 0.59, P = 0.005; Fig. 3.21). Adding residual forage standing crop did not improve the model fit (P = 0.791). On the reference sites alone, breeding season precipitation explained 46% of the variation in fluctuations in annual density (r^2=0.46, P = 0.015; Fig. 3.22). Adding residual forage standing crop did not improve the model fit (P = 0.267).

DISCUSSION

Forage Standing Crop Response

Deferment. —The increase in forage standing crop during the deferment period (2014–2015) demonstrated the resiliency of the rangeland in South Texas in response to increased precipitation and rest from grazing following a 3-year drought. South Texas rangelands evolved with large wild ungulates, but stabilization was facilitated by periods of rest (Frank and McNaughton 2002). In a semi-arid environment, rest periods have a higher potential to increase range condition than destocking and restocking without a planned rest (Müller et al. 2007). Before the deferment period, the stocking density was higher (12.8 ha/AU) than the currently classified “high” stocking density during this study; initiating the grazing study without

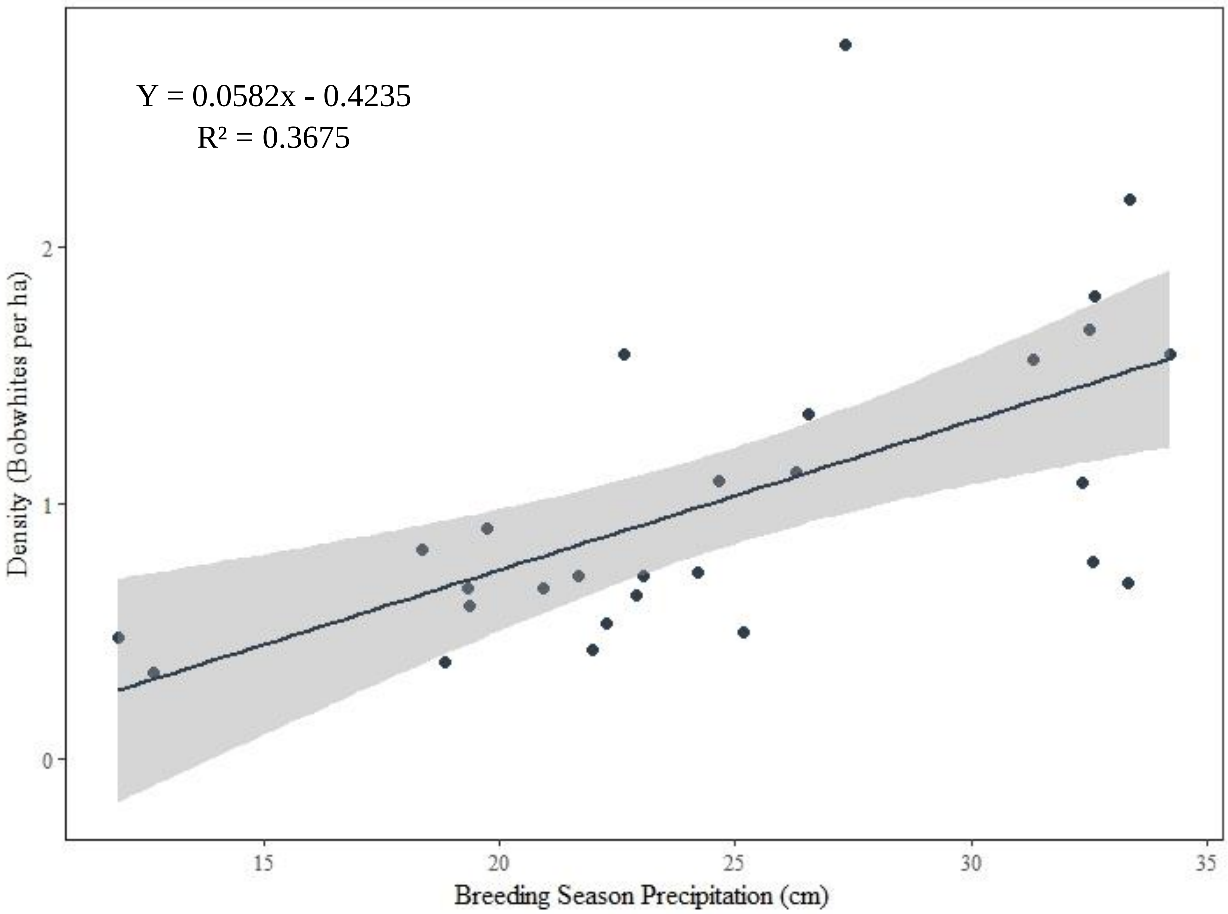

Figure 3.20. Linear regression of cumulative breeding season precipitation (April –August) and density (bobwhites/ha) for each treatment on the Coloraditas Grazing Research and Demonstration Area and reference site pasture in Jim Hogg County, Texas, USA, 2014–2017.

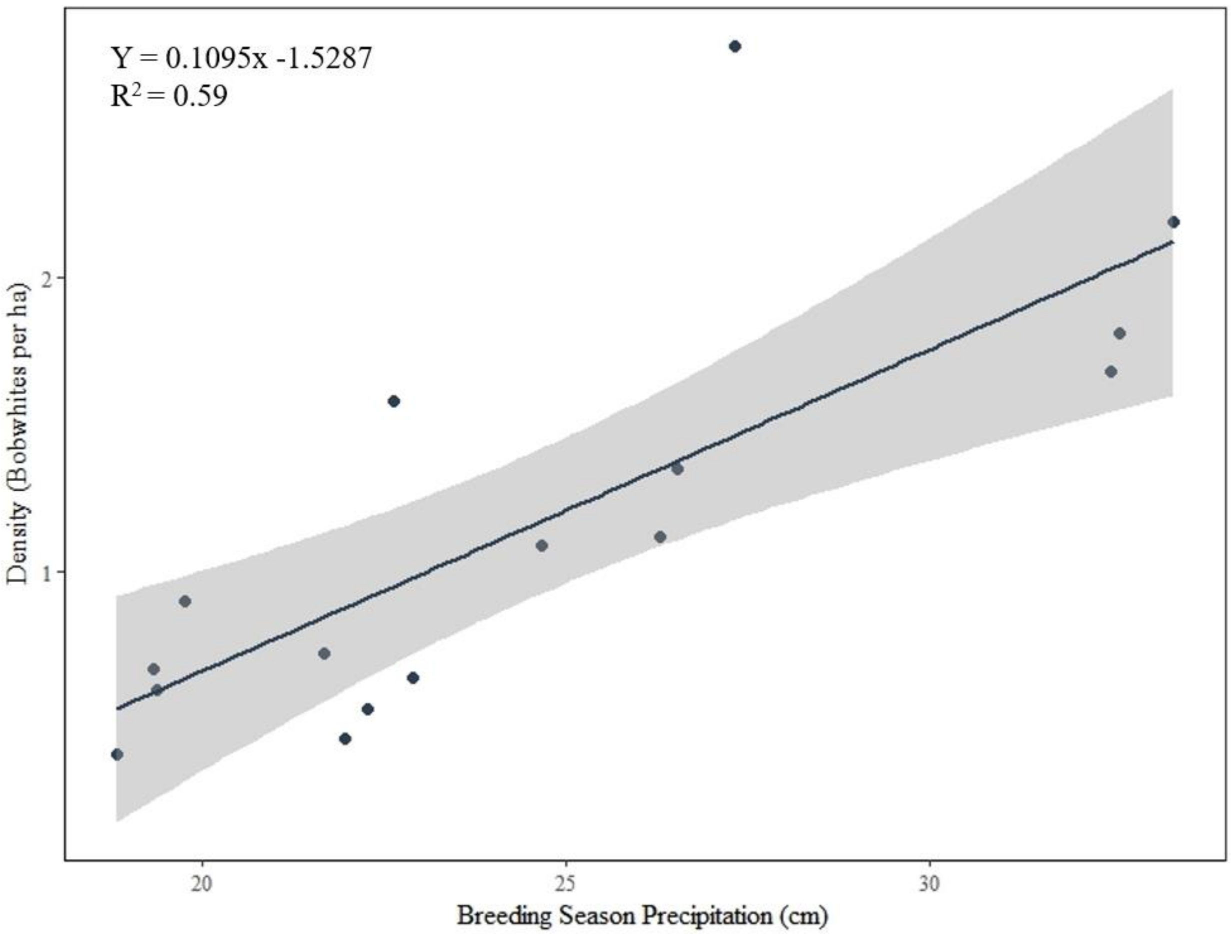

Figure 3.21. Linear regression of cumulative breeding season precipitation (April –August) and density (bobwhites/ha) for each treatment on the Coloraditas Grazing Research and Demonstration Area, in Jim Hogg County, Texas, USA, 2014–2017.

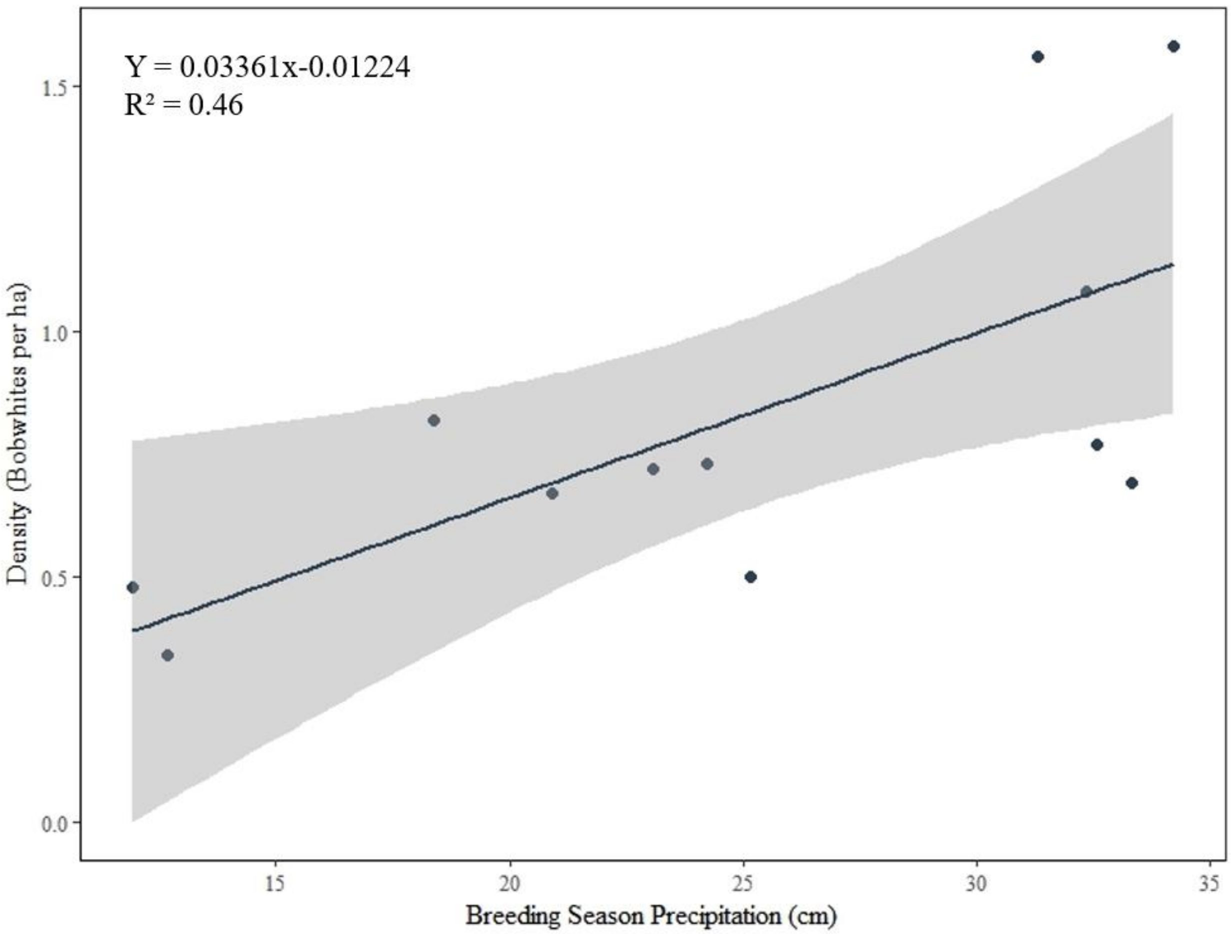

Figure 3.22. Linear regression of cumulative breeding season precipitation (April –August) and density (bobwhites/ha) for each treatment on each reference site pasture, in Jim Hogg County, Texas, USA, 2014–2017.

deferment may have resulted in irreversible rangeland degradation. While the removal of grazing animals entirely may cause losses in herbivore dependent plant species and reduce nutrient cycling, overstocking can lead to shifts in the stable state of rangelands (Teague et al. 2008), particularly when coupled with drought conditions (Van de Koppel and Rietrek 2000). From the onset of deferment to the first measurement of forage standing crop (March–June 2014), the ranch received 25% of its cumulative annual precipitation for the year and 66% of its April–August growing season precipitation. Increased precipitation left pastures with 1,194–2,028 kg/ha of dry forage. This is just above the minimum recommended residue levels (840–1120 kg/ha) suggested to sustain mid-grass rangelands in Texas (White and McGinty 1992). By November 2015, 1 month before grazing implementation, average forage standing crop/treatment ranged between 3,000 and 4,500 kg/ha.

Hypothesis 1.A —The data supported my hypothesis there would be no difference in residual forage standing crop (outside exclosures) between grazing systems. After grazing implementation, individual grazing systems did not produce in differences of residual forage standing crop on the Coloraditas Grazing Research and Demonstration Area or reference sites. In each analysis, forage standing crop fluctuated among the years and between seasons, likely corresponding to annual variation in precipitation. Briske et al. (2008) discussed the preference of rotational over continuous systems by researchers, despite empirical evidence providing no clear distinction between the 2 systems' impacts on rangelands. Similar to this study, Hart et al. (1988) found no significant differences in total production of peak standing crop or forage utilization among grazing systems (continuous and rotational) from 1982–1987 and attributed fluctuation between years to precipitation. Manley et al. (1997) reported no differences in peak forage standing crop among continuous, rotational, and time controlled rotational grazing from

1982–1994 in northern mixed prairies. Barrett et al. (2002) reported that annual precipitation was highly correlated with peak forage standing crop in the Great Plains. The collective results from a 24-year study determined different stocking rates rather than grazing systems result in differences in peak standing crop (Hart et al. 1988, Manley et al. 1997, Derner and Hart 2007).

Hypothesis 2.A — The data did support my hypothesis that forage standing crop inside exclosures would be lower at high stocking density but did not support my hypothesis for residual forage standing crop outside exclosures. However, this result only occurred in the continuous high stocked treatment. I speculated that forage standing crop inside exclosures was lowest in the continuous high treatment because forage regrowth was no longer compensatory with grazing, whereas seasonal deferment or moderate stocking on the other grazing treatments aided in regrowth when caged from grazing. There is some indication that the continuous high stocked pastures entered rangeland degradation (i.e., lowering of productive capacity) faster than the other grazing treatments when drought conditions prevailed after June 2017. Williamson et al. (1987) found that after summer drought, that above ground net primary production was higher with moderate to light levels of grazing than heavy grazing. This result was similar to findings from McNaughton (1976) and Heitschmidt et al. (1982) leading to the speculation that compensatory growth in short grasses most likely occurs after precipitation following a dry period. High stocking rates coupled with continuous grazing reduced residual forage standing crop levels (measured at each rotation) well below the recommended levels (840 kg/ha) from September to December 2017. The rotational high and moderate grazing treatments were not far behind the continuous grazing treatments regarding low residual forage inside and outside of exclosures. With drought persisting in March of 2018, residual forage standing crop values were <840 kg/ha on all grazing treatments and reference sites (unpublished data).

Hypothesis 3.A — The data did not support my hypothesis there would be a difference in forage utilization between grazing systems or stocking rates on the Coloraditas Grazing Research and Demonstration Area. Similar to residual forage standing crop, forage utilization fluctuated seasonally and annually. The inclusion of negative utilization values in this analysis may explain why differences between grazing systems and stocking rates were not detected. Compensatory growth in response to higher utilization in certain pasture-years may have masked the effects of lower utilization in moderately stocked pastures (McNaughton 1984), particularly over the short term.

In a 24-year study on the northern Great Plains, forage utilization was lower in the moderately stocked pasture compared to the heavy stocked pastures (Hart et al. 1988). Higher utilization in heavily stocked pastures has been observed to cause shifts in the botanical composition of peak forage standing crop where forbs and perennial warm-season short grasses increased, and perennial cool-season grasses decreased (Manley et al. 1997). On southern mixed prairies in Texas, mid-grass and bunchgrass species were reduced from 43 to 10% of forage standing crop in pastures that were heavily stocked, while short grasses increased (Ralphs et al. 1990). In the present study, forage utilization by grass, forbs, or grass and forbs combined did not differ by stocking rate or grazing system; instead, increased with each year of grazing and increased each November. I did not classify the percent composition of grass forage standing crop by species but documented the species that comprised grass inside and outside of exclosures each year. Future analyses will investigate if any compositional changes in species richness occurred.

Hypothesis 4.A — The data supported my hypothesis that there would be no difference in percent forage utilization or forage standing crop between on the Coloraditas Grazing Research and Demonstration Area or reference sites. I could only measure differences between the Coloraditas Grazing Research and Demonstration Area and reference sites in 2016 and 2017, and by that time, the grazing was likely impacting the forage standing crop on 2 study sites equally as grazing systems and stocking rates overlapped. The deferment period was likely not long enough to provide any lasting changes between the Coloraditas Grazing Research and Demonstration Area and reference sites. A comprehensive study by Milchunas and Laruenroth (1993) found that grazing history, aboveground net primary production, and grazing intensity were the primary drivers of differences between plant composition response to grazing or rest. Grazing history between the 2 study sites before deferment is similar, and production based on climax communities is likely similar due to the overlap in soil and range types.

Vegetation Structure and composition response

Hypotheses 1.B and 2.B —Contrary to what I hypothesized, grazing system and stocking rate did not create notable variations in the heterogeneity of vegetation structure and composition between grazing treatments. Instead, grass cover, bare ground cover, percent visual obstruction, and bunchgrass density, changed uniformly over grazing treatments on the Coloraditas Grazing Research and Demonstration Area and reference site pastures with annual changes in precipitation over the years. The short duration of this study may not have produced notable differences between the high and moderate stocking rates regarding percent composition, visual obstruction, and bunchgrass density. Manley et al. (1997) associated a decrease in total plant cover within the first 2 years of grazing to the reintroduction of grazing after a 40-year deferment period. Increases in bare ground and decreases in grass cover correlate to the decreases in forage standing crop with decreased precipitation and grazing. However, I expected litter cover to also decrease with increased bare ground and forage utilization and decreased residual forage (Naeth

1988).

There was a treatment by time interaction for both forb cover and species richness, and neither interaction supported my hypothesis that these 2 variables would be highest on the continuous system and high stocked grazing treatments, instead forb cover was more affected by the lack of deferment on the reference sites (see below). Analyzing how species composition rather than total richness changed over the years on individual grazing treatments may provide more insight on grazing effects.

Hypothesis 3.B —The data did not support my hypothesis that bunchgrass density and visual obstruction would be higher on rotational systems compared to continuous systems. Additionally, deferment did not produce more bunchgrass clumps on the Coloraditas Grazing Research and Demonstration Area compared to the reference sites. One of the limiting factors to bobwhite productivity is the availability of nesting suitable nest sites. Bunchgrass density never reached the minimum conditions for nest site selection (>730 nesting clumps/ha; Arredondo et al. 2007) for any treatment or year. Rotational grazing systems are typically touted as being beneficial for upland game birds because deferred or disturbance-free areas are available during the nesting season (Holechek et al. 1982). Bunchgrasses are often palatable to cattle and were found to decrease under heavy grazing rather than between different grazing systems (Rhoades et al. 1964, Sharp et al. 1964). In South Texas, Bareiss et al. (1986) did not find a difference between nesting cover and success of bobwhites between SDG and continuous treatments. Campbell et al. (1984) found that regardless of grazing, clay loam range sites provided more adequate nesting and screening cover for bobwhites compared to sandy range sites. Similarly, Baker and Guthery (1990) found reductions in grazing pressure on sandy soils increased vegetative cover at heights >20 cm. The grazing treatments and reference site pastures lack of clay soils and therefore, bunchgrass density and concealment may be equally susceptible to reductions with grazing pressure in drought periods.

Hypothesis 4.B —The data did support my hypothesis that forb cover would be higher on the reference sites, where no deferment occurred, compared to the grazing treatments. Long-term deferment from grazing has been suggested to hinder the productivity of forb communities (Ruthven 2007), which may have occurred in this study on the Coloraditas Grazing Research and Demonstration Area due to the rapid regrowth of forage standing crop by November 2015. Forb cover remained higher on at least one reference site pasture than the Coloraditas Grazing Research and Demonstration Area treatments each year of the study; however, after grazing treatment implementation, the differences between grazing treatments and pastures were less pronounced. Grazing as a tool to improve vegetation heterogeneity is based on the premise that a reduction in grass and litter cover will provide a competitive advantage for forbs (Fulbright and Ortega-S 2013), many of which provide benefits to bobwhites in terms of foraging and concealment. Ruthven (2007) demonstrated that forb diversity and density of annual forbs were greater on grazed sites under a high intensity low-frequency system compared to sites where no grazing occurred but did not test different grazing systems or stocking rates. Nelson et al. (1997) documented greater forb canopy cover on moderately grazed sites compared to heavily grazed sites, likely because cattle begin to utilize forbs when grazing is too heavy or during the winter months (Jenks et al. 1996). Conversely, Vermeire et al. (2008) documented a greater forb standing crop in severely grazed treatments compared to moderately grazed treatments, but no difference between continuous and rotational systems. After 2 years of grazing, the rotational high pasture was the only grazing treatment in the Coloraditas Grazing Research and Demonstration Area to have a similar forb cover to the reference sites.

Hypothesis 5.B —The data supported my hypothesis that woody cover remained unchanged between grazing systems, stocking rates, and from before to after grazing. While woody encroachment on semiarid grasslands is well documented over the last 200 years (Archer 1989), I did not expect the temporal scale of our sampling to detect these changes or for these changes to occur in the short term. In a 2-year grazing study in South Texas, no differences in brush cover occurred between grazing 3 grazing systems, and brush cover increased seasonally from fall to spring likely due to changes in foliar cover (Hammerquist-Wilson and Crawford 1981).

Bobwhite Density

Hypothesis 1.C — The data supported my hypothesis that with an increase in precipitation in the deferred period, density would increase between 2014 and 2015 on the Coloraditas Grazing Research and Demonstration area and reference sires. However, without deferment, bobwhite densities on the reference site pastures did not increase at the same magnitude of change as the Coloraditas Grazing Research and Demonstration Area with increasing precipitation from 2014 and 2015. Conditions (precipitation and vegetation) were likely more consistent between these 2 years on the reference sites.

Long-term periods of grazing rest and deferment during periods of plant growth has the potential to enhance root and shoot growth of overgrazed plants (Holechek et al. 1999, Holechek et al. 2001, Müller et al. 2007). The deferment period on the Coloraditas Grazing Research and Demonstration Area occurred during a period of increased cumulative annual precipitation across the region increasing the potential of positive vegetation responses to reduced grazing pressure. The larger magnitude of change in bobwhite density after 1.75 years of deferment on the Coloraditas Grazing Research and Demonstration Area compared to the reference sites may indicate that the rest period temporarily ameliorated grazing effects on vegetation. While there were no differences in vegetation response variables between the Coloraditas Grazing Research and Demonstration Area and reference sites at peak forage production in 2015, some aspect of habitat quality may have improved during deferment between 2014 and 2015 on the Coloraditas Grazing Research and Demonstration Area that did not occur on the reference sites. The magnitude of change in bobwhite density was more similar from December 2015 to 2016 on the Coloraditas Grazing Research and Demonstration Area and reference sites when grazing and increased breeding season precipitation occurred on both sampling units.

Hypothesis 2.C —After grazing was implemented, the data did not support my hypothesis that bobwhite density would be highest on the rotational high treatment on the Coloraditas Grazing Research and Demonstration Area as a result of vegetation structure on that treatment (i.e., increase bare ground and forb cover, higher visual obstruction and more nest sites). Consequently, bobwhite density did not fluctuate among individual grazing treatments; however, bobwhite density pooled across all grazing treatments increased from before to after grazing between years of high precipitation (2015–2016) and between years of low precipitation (2014–2017), respectively. This indicated some effect of grazing on the Coloraditas Grazing Research and Demonstration Area. The results from this study were more similar to Baker and Guthery (1990) where bobwhite density did not fluctuate with a specific grazing system after a short period of grazing; instead, grazing system had a collective effect on all grazing treatments over seasons.

An increase in density in response to structural changes in vegetation may have occurred between years of high precipitation 2015–2016. As bare ground increased, and grass cover decreased from 2015 to 2016, bobwhite density increased on the Coloraditas Grazing Research and Demonstration Area and reference sites. Bare ground increases mobility for brood rearing and feeding (Scott and Klimstra 1954) and when interspersed with tall forbs, provides bobwhites with greater availability of seeds and overhead concealment (Kiel 1976, Jackson 1969). This response is similar to what Hammerquist-Wilson and Crawford (1981), Schulz and Guthery (1988), Wilkins and Swank (1992) observed under SDG systems on sites primarily dominated by clay soils and sites that receive greater precipitation. Grazing is more likely to enhance the selection of these habitat attributes where dense stands of residual forage limit bobwhite occupancy (Stoddard 1931) in mesic areas or during periods of above-average precipitation when grazing is light or deferred in semi-arid landscapes. In 2016, grazing reduced residual forage standing crop from peak levels in 2015; this coupled with increased breeding season precipitation may have increased usable space for bobwhites on the Coloraditas Grazing Research and Demonstration Area and reference sites in 2016.

Hypothesis 3.C —In 2016, the data did not support my hypothesis of no differences in density between the Coloraditas Grazing Research and Demonstration Area and reference sites, but the data did support my hypothesis in 2017 after 2 years of grazing and reduced precipitation on the treatments. The largest difference between the Coloraditas Grazing Research and Demonstration Area and the reference sites was the 2 years of grazing deferment. After 2 years of grazing, drought conditions persisting on both sites negated the previous benefits from grazing during increased precipitation after deferment (2015–2016). This result is largely explained by the alternative hypothesis below.

From 2016 to 2017, after 2 years of grazing on the Coloraditas Grazing Research and Demonstration Area, bare ground increased within the estimated selected range (>40–60%) defined by Kopp et al. (1998) on all grazing treatments and pastures. However, while bare ground increased, combined grass and forb cover in 2017 decreased below the 20% suitability threshold determined by Kopp et al. (1998) and the 36% herbaceous cover at nest sites threshold determined by Arredondo et al. (2007). Additionally, percent visual obstruction and bunchgrass density also decreased at 15 cm and 30 cm in height (bobwhite height 15 cm) indicating a potential negation in the benefits of increased mobility for foraging and brooding concealment.

Hypothesis 4.C —The data largely supported my alternative hypothesis that the effects of precipitation would be the driving force in changes to herbaceous forage standing crop, vegetation structure and composition, and bobwhite density. Bobwhite density averaged across Coloraditas Grazing Research and Demonstration Area fluctuated with April–August precipitation within the before period (2014–2015) and within the after period (2016–2017). Bobwhite density on the reference sites only fluctuated from 2015 to 2016 where above average April–August precipitation occurred and decreased from 2016 to 2017 with the onset of a drought.

The influences of precipitation and temperature on bobwhite productivity may have overridden the influences of grazing management on reproduction, survival and the resulting density on the Coloraditas Grazing Research and Demonstration Area. From 2015 to 2016, density on all grazing treatments in the Coloraditas Grazing Research and Demonstration Area increased after 1 year of grazing despite a decrease in cumulative annual precipitation from 68 to 61 cm. However, cumulative precipitation from April to August increased from 25 cm in 2015 to 31 cm in 2016. When April–August precipitation decreased to 20 cm in 2017, bobwhite density returned 2014 levels where April–August precipitation totaled 21 cm. Age ratios, reproduction, and survival are positively correlated with breeding season precipitation in South Texas (Hernández et al. 2005, Tri et al. 2013) as well as growing season length and drought index (Tri et al. 2014). Precipitation has explained 94% and 96% of the variation in bobwhite age ratios in South Texas (Kiel 1976, Tri et al. 2013) and 98% of the variation in California quail (*Callipepla californica*) age ratios in the Sonoran Desert (Raitt and Ohmart 1968). Similar to what I found, precipitation is expected to explain 40% of the variation in bobwhite density (Hanselka and Guthery 1991), precipitation is likely more directly related to age ratios and therefore explains a larger percentage of annual variation. For example, temperatures from 36–39 °C reduce age ratios, survival, production at the landscape scale (Forrester et al. 1998, Guthery et al. 2001, Lusk et al. 2002) resulting in an overall reduction in fall density estimates. While strong positive correlations between spring precipitation and production exist, Guthery et al. (2002) demonstrated the non-linearity of the relationship emphasizing the existence of asymptotes and thresholds to production as well as the complexity of the demographic variables resulting in age ratios. For example, if precipitation can lengthen the breeding season, this can only increase productivity to the biological thresholds of nesting attempts and number of eggs produced (Guthery et al. 2002). More uncertainty is introduced when trying to account for the variation in December density estimates in light of brood survival and predation events. The effects of historically high grazing intensity on the vegetation in the study site pastures coupled with periods of drought and precipitation events during this study likely played a larger role in resulting density estimates than the grazing treatments implemented in 2016.

Stocking Rates

Rangeland ecologists consistently cite proper stocking rate over grazing system as the primary determinant of animal condition and livestock production (Heady 1961, Van Poollen and Lacey 1979, O'Regain and Turner 1992, Holechek et al. 2001). When managing for bobwhites on less productive range sites, light to moderate stocking rates are recommended to preserve adequate cover and condition (Hanselka and Guthery 1991). Light or moderate livestock grazing also typically has little impact on vegetation structure (Holechek et al. 1998). However, grazing at these rates may not be beneficial or practical for most livestock producers (Krausman et al. 2009). Determination of the optimal stocking rate to maintain animal condition and preserve adequate cover is dependent on precipitation and the combined effects of grazing history, soil type, and precipitation (Holechek 1988). The present stocking rates levels were set according to uncited regionally paradigmatic definitions of what was “high” or” moderate” rather than concerning target utilization of the total forage production. As a result, I found fewer differences than I expected in vegetation variables between stocking rates.

Few studies concerning bobwhites have focused on different levels of grazing intensity without short duration grazing as the primary focus, and the ones that have lasted < 1 year (Baker and Guthery 1990). There is still a need for a long-term grazing study measuring the response of bobwhites to a gradient of stocking rates across different soil types and vegetation communities in South Texas.

Conclusions

The benefit of redistributing grazing pressure through grazing systems becomes less critical than stocking rate where precipitation is limiting and unpredictable (Holechek et al. 2001). The influences of weather and stocking rate have been shown to be far more critical to plant and animal production than grazing system in arid and semi-arid environments (Briske et al. 2008). Additionally, the duration of grazing on these treatments was likely not long enough to determine the effects of system and stocking rate on any of the response variables as pastures may be still adjusting to the changes in grazing regimes (Briske et al. 2008). With only 2 years of grazing, the fluctuations in precipitation drove fluctuations in vegetation and density.

Trends between bobwhite densities on the grazing treatments on the Coloraditas Grazing Research and Demonstration Area were not consistent among years, a factor that is likely due to variability in precipitation and corresponding vegetation responses. Variations in forage standing crop, vegetation structure, and composition as well as bobwhite density, changed across years in conjunction with precipitation rather than grazing system and stocking rate. Within the Coloraditas Grazing Research and Demonstration Area, after 2 years of grazing, grazing system or stocking rate had little effect on vegetation response variables and bobwhite density. I observed a difference in forage standing crop between the pastures under a continuous system (continuous high, continuous moderate, Pinto and Agua Dulce) compared to the rotational systems during drought conditions in December 2017. However, forage standing crop values dropped below 1,000 kg/ha within the next 3 months. Grazing treatments on the Coloraditas Grazing Research and Demonstration Area compared to the grazing systems on the reference sites impacted vegetation similarly except for changes in forb cover. Deferment also likely contributed to the more substantial increases in density across the Coloraditas Grazing Research and Demonstration Area when annual precipitation was above average.

The grazing demonstration was halted on all grazing treatments in May of 2018 to prevent further range degradation under prolonged drought conditions. The reference site pastures were also destocked and deferred due to a significant loss in forage and drop in cattle condition. While the original goals of the study were to monitor grazing effects for 8 years, the East Foundation decided to halt the study from an ecological standpoint (preventing further rangeland degradation), and an economic standpoint after the cost of supplemental feeding became prohibitive. Furthermore, the effects of drought on vegetation and bobwhite density on pastures managed under cattle operations that do not evaluate stocking rate according to range condition and annual forage production were evident after only 1 year of grazing. The decision to destock to prevent losses was necessary even where “moderate” stocking rates were maintained indicating that a re-evaluation of what is considered moderate is necessary. Ecologically, from a cattle perspective, the decision to defer in 2014 lead to range recovery after 1.75 years and the decision to destock in 2017 may provide similar range recovery guidance in the future.

The East Foundation will continue to monitor vegetation and bobwhite density on the Coloraditas Grazing Research and Demonstration Area and the reference sites through its next phase. Future studies concerning this dataset should focus on measuring shifts in species composition (i.e. changes in invasive species composition, increasers and decreases, annuals and perennials etc.) under the grazing study. More advanced analyses of the bobwhite density to determine changes by treatment and time with covariates affecting density should be explored using maximum likelihood methods (Oedekoven et al. 2013) and Bayesian methods (Oedekoven et al. 2014).

MANAGEMENT IMPLICATIONS

There are few large-scale studies in South Texas monitoring the effects of grazing system and stocking rate on vegetation and bobwhite density that do not include short duration grazing. Semi-arid environments susceptible to large swings in precipitation with variable timing may negate the effects of grazing systems on any measure of plant or animal productivity. In our study, even moderately stocked pastures exhibited the same fluctuations in vegetation and bobwhite density as high stocked pastures within periods of similar precipitation. Forage standing crop for cattle and vegetation structure associated with bobwhite habitat deteriorated under drought conditions even when grazed at a “moderate” stocking rate. Managers should set stocking rates according to carrying capacity of pastures and adjusted according to precipitation and forage production each year rather than based on regionally assumed definitions of moderate and high. Additionally, flexibility in stocking density allows for greater management of range and wildlife resources. Stable stocking densities are not appropriate for prolonged periods in semi-arid landscapes with high variability in precipitation.

The period of grazing deferment between March of 2014 and December 2015 under periods of increased precipitation increased overall bobwhite density. Deferment during periods of precipitation can be used to increase root and foliar recovery of vegetation and allow residual forage levels to recover. I recommend that managers looking to increase production of cattle and bobwhites in semi-arid regions consider periods of deferment under optimal precipitation conditions, mainly where residual forage is below minimum residue levels needed to support growth. Additionally, Bobwhite hunters and managers should be cognizant of fluctuations in breeding season precipitation when planning management activities.

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CHAPTER IV.

USING DENSITY SURFACE MODELS TO MONITOR POPULATION DENSITY AND SPATIAL RELATIONSHIPS OF NORTHERN BOBWHITES IN SOUTH TEXAS RANGELANDS

ABSTRACT

Monitoring the population density of a terrestrial vertebrate species over large areas is an important component in assessing ecological impacts and the natural variability of populations through time. Distance sampling has improved the way researchers can analyze count data by incorporating a detection probability for calculating density estimates. Density surface modeling is an extension of distance sampling where the distribution of density across the surveyed landscape can be assessed and evaluated in relation to environmental covariates (i.e., water depth, vegetation cover, and distance to anthropogenic structures). Additionally, the density estimates derived from density surface models are less sensitive to low numbers of detections and low spatial coverage in sub-strata. In this study, I used density surface modeling to monitor the changes in the spatial distribution of northern bobwhite (*Colinus virginianus*) density from before grazing deferment to after grazing implementation on 4 different grazing treatments within the Coloraditas Grazing Research and Demonstration Area, a large-scale grazing demonstration project on the East Foundation San Antonio Viejo Ranch in Jim Hogg County, Texas. I also monitored 3 pastures as reference sites where grazing deferment did not occur. I included environmental covariates related to woody cover in density surface models due to their importance in meeting bobwhite life history requirements and their ability to provide thermal refuge during drought or on heavily grazed landscapes where herbaceous cover is limiting. On the grazing treatments in the Coloraditas Grazing Research and Demonstration Area and

reference sites, the Coefficient of Variation (CV) was 0.02–13.56 % and 0.0–7.30 % lower when estimated using density surface modeling compared to conventional distance sampling. The density surface model resulted in similar confidence intervals compared to estimates from conventional distance sampling in all occasions. The brush metrics I modeled did not explain a high amount of variation in density on the study sites in any year of the study (<15%). Bobwhites did not seek refuge in areas with higher woody cover in the presence of grazing. Grazing did not influence the distribution of bobwhites when precipitation was above average on the Coloraditas Grazing Research and Demonstration Area (2016). When precipitation was below average, and grazing was present (2017), bobwhites density was concentrated in the southern portion of the Coloraditas Grazing Research and demonstration Area in pastures with deep sandy soils and moderately disaggregated (small dispersed patches) brush patches. Bobwhite distribution did not follow a pattern on the reference sites but tended to be higher in areas associated with sandy soils. There is a great potential for the use of density surface models to assess bobwhite density response to impacts and management actions.

INTRODUCTION

Density surface models have expanded use of the location data collected during distance sampling surveys (Miller et al. 2013, Schroeder et al. 2014). Density surface models provide researchers with a way to explain spatial distributions of abundance and analyze the relationships between environmental covariates and abundance with the inclusion of an offset for detectability (Miller et al. 2013). This provides an improvement on spatial mapping by using distance sampling data within the prediction of per cell density. For example, Valente et al. (2016) were able to determine that roe deer (*Capreolus capreolus*) densities increased with increasing distance from roads and Katsanevakis (2007) provided dispersion information related to the water depth in habitats used by the endangered fan mussel (*Pinna nobilis*). Therefore, there is a great potential amount of ancillary information related to density, distribution, and spatial relationships that can be derived from a distance sampling survey, particularly where covariates change in relation to a specified management activity or impact.

Also, density surface models use model-based methods to estimate density, rather than the design-based approach used with conventional distance sampling (Miller et al. 2013). Density surface modeling has provided researchers with an option for obtaining density estimates that are less susceptible to biases in survey designs (i.e., non-uniform or nonrandom coverage) or small sample sizes in sub strata (Hedley and Buckland 2004, Miller et al. 2013). In situations where large areas are subdivided into treatments or management blocks, researchers are often unable to meet the minimum sample size required for detection function modeling. As a result, lower level density estimates are penalized with analyses from conventional distance sampling (Hedley et al. 2004).

Monitoring Environmental Impacts with Density Surface Models

The environmental covariates used in density surface models can help assess population response to meaningful landscape features with the inclusion of an offset term for detection. For example, brush cover and configuration are an important component for northern bobwhite (*Colinus virginianus*; hereafter bobwhite) habitat use, particularly in rangeland areas (Rice et al. 1993). Woody cover is especially important in providing midday refuge during high temperatures in South Texas (Johnson and Guthery 1988, Guthery et al. 2005) as well as escape cover from predators (Perkins et al. 2014).

While the bounds of useable brush cover for bobwhites have been documented to be larger (20–60%; Kopp et al. 1998) than previously thought (5–15%; Guthery 1986), large-scale brush clearings are still a common management practice, particularly for cattle (Davis and Winkler 1968). However, the amount of brush cover recommended for bobwhite management on grazed lands corresponds to the level and intensity of grazing that results in a decline of herbaceous cover. In cases where herbaceous cover diminishes with heavy grazing and drought, woody cover is hypothesized to provide bobwhites the structural cover needs (Parent et al. 2016). Hernández and Guthery (2012) recommend more brush cover for heavily grazed lands with sparse grass cover and less brush cover where grazing maintains tall herbaceous vegetation. These recommendations are supported by Guthery's (1999) concept of "slack" where different configurations of vegetation can be interchangeable regarding the functions they provide for bobwhites (Guthery 1997; DeMaso et al. 2014).

Grazing intensity, history, precipitation, and soil type play a significant role in the determination of herbaceous cover in semi-arid rangelands. Where herbaceous cover is high, Bobwhite populations have been shown to respond positively to the creation and dispersion of bare ground as a byproduct of residual forage removal by cattle (Hammerquist-Wilson and Crawford 1981, Campbell-Kissock et al. 1984, Wilkins and Swank 1992). Therefore, in years of above average precipitation and light grazing, bobwhites may be distributed in areas with a higher proportion of bare ground. There are thresholds at either end of the bobwhite selection/avoidance curves for woody cover and bare ground as documented previously (Kopp et al. 1998). Measuring the response of density to vegetation parameters related to woody cover during periods of grazing and fluctuations in precipitation may further clarify the importance of heterogeneity in a South Texas landscape for bobwhite productivity and survival under a range of conditions and management types.

In 2014, the East Foundation initiated a large-scale grazing study with a monitoring program for several wildlife species, including bobwhites. This project was conducted on the East Foundation's San Antonio Viejo Ranch in Jim Hogg County, Texas on a 7,689-ha pasture complex called the Coloraditas Grazing Research and Demonstration Area and 3 reference sites (1,200−1,600 ha) for comparison. The project included 2 years (2014, 2015) of monitoring pastures under deferment from grazing and 2 years (2016, 2017) of post-grazing treatment under 4 grazing systems. Because grazing pressure is not uniformly distributed throughout a pasture, the density surface model may help explain where management or disturbance has caused an impact on abundance as well as provide lower level density estimates on each treatment with better precision.

I collected bobwhite density data through distance sampling from a helicopter platform; this method has been demonstrated to improve the precision of bobwhite density estimates over methods using index data due to the inclusion of detection probability (Shupe et al. 1987, Rusk et al. 2007). I used distance and location data collected during distance sampling surveys to map the spatial distribution and abundance of bobwhite distributions based on environmental covariates relating to woody cover and structure as well as the Normalized Difference Vegetation Index (NDVI). NDVI can be used to determine areas on a gradient of sparse herbaceous cover to dense herbaceous and shrub cover (Guthery et al. 2005).

Based on the density surface models, my objectives were to (1) compare bobwhite density and precision estimates from substrata (i.e., lower level grazing treatment and reference site pasture) derived from the density surface model to estimates derived from conventional distance sampling, (2) evaluate the relationship between bobwhites and woody cover and NDVI from before to after grazing from 2014–2017 using single covariate generalized additive models, and (3) evaluate the spatial distribution of bobwhites across Coloraditas Grazing Research and Demonstration Area and reference sites.

The following research hypotheses were related my objectives:

Hypothesis 1. —For the hypothesis related to objective 1, I expected the precision of the measurements would be greater in the estimates from the density surface models compared to conventional distance sampling, however, I expected density estimates to be similar.

Hypothesis 2. —After grazing implementation on the Coloraditas Grazing Research and Demonstration Area and throughout the study on the reference sites, I expected bobwhite density would increase with increasing woody cover up to a threshold higher than the average reported values of 30%, but not exceeding 60% (Kopp et al. 1998), with the removal of herbaceous cover. Spatially, bobwhite density would be distributed in a higher concentration where these conditions occurred.

Alternatively, if precipitation was not limiting during grazing or grazing did not reduce herbaceous cover below the needs of bobwhite requirements, bobwhite density would be higher at lower levels of NDVI corresponding to bare ground and higher woody cover values closer to the average reported values of 30% (Kopp et al. 1998, Guthery et al. 2005, Hiller et al. 2007, Ransom et al. 2008), but decreasing thereafter. Spatially, bobwhite density would be distributed in a higher concentration where these conditions occurred.

Hypothesis 3. —The distribution of bobwhite density on the Coloraditas Grazing Research and Demonstration Area and reference sites would be uniform in years where precipitation was above average but reflect a gradient in years where precipitation was below average. Bobwhite density was not impacted by grazing treatment on the Coloraditas Grazing Research and Demonstration Area but did fluctuate yearly with annual precipitation and differed from the reference areas after 1 year of deferment (Chapter III). Therefore, I did not make predictions concerning the distribution of density related to treatments.

STUDY SITE

My study was conducted in 2 areas on the East Foundation, San Antonio Viejo Ranch (SAV; 60,298 ha) in Jim Hogg County, Texas: (1) Coloraditas Grazing Research and Demonstration Area 7,689 ha treatment pasture), and (2) 3 pastures ranging in size from 1,200 to 1,600 ha south of the Coloraditas Grazing Research and Demonstration Area (reference sites; see Chapter II and III). The Coloraditas Grazing Research and Demonstration Area was divided into 4 grazing treatments beginning in December 2015: continuous system at moderate stocking rate (1 Animal Unit [AU] /20 ha), continuous high (1 AU/14 ha), rotational moderate, and rotational high) ranging in size from 1,400 to 2,100 ha). The San Antonio Viejo ranch is located 32 km South of Hebbronville, Texas and was part of the collection of properties that make up the East Foundation. The property was previously a family owned ranch with a history of intense grazing and ranching activity dating back to the early 1900s; prior to the initiation of this study in 2014, the Coloraditas Grazing Research and Demonstration Area was grazed at a stocking rate of 1 AU/12 ha. This ranch lies within the South Texas Plains Ecoregion (Gould 1960). The 30-year average annual precipitation on the ranch was 53.6 cm (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 April 2018). Based on 30-year normal, average temperatures were between 12–13 °C in January and 27–30 °C in July (PRISM 2018). Elevation ranges from 52 m on the eastern edge to 64 m on the western edge of the ranch. The Coloraditas Grazing Research and Demonstration Area and reference sites lie within the Coastal Sand Plain and Texas-Tamaulipan Thorn scrub ecoregions (Omernik 1987). There were 6 different ecological sites on the Coloraditas Grazing Research and Demonstration Area of which 3 (Sandy PE 25-44, Loamy Sand PE 19-31, Red Sand Loam PE 19-31) make up 95% of the area. The same 3 range sites comprised 83% of the reference sites. Woody plant communities on the study areas was dominated by honey mesquite (*Prosopis glandulosa*), huisache (*Acacia farnesiana*), brasil (*Condalia hookeri*), granjeno (*Celtis pallida*), and prickly pear (*Opuntia* spp.). Seacoast bluestem (*Schizachyrium scoparium var. littorale*), purple threeawn (*Aristida purpurea*), Lehman lovegrass (*Eragrostis lehmanniana*), spotted beebalm (*Monarda fruticulosa*), and woolly croton (*Croton capitatus*) dominate the herbaceous plant community. Tanglehead (*Heteropogon contortus*) was only present on <3% of the total area in 2014.

Defining the bobwhite population.—The South Texas region is approximately 8,080,000 ha where more than 4,7000,000 ha of rangeland has been classified as habitat that will support a wild bobwhite population (Brennan 2014). I define the bobwhite population in this study as the sample population of bobwhites in South Texas within the Coloraditas Grazing Research and Demonstration Area and reference site pasture boundaries on the San Antonio Viejo Ranch from 2014 to 2017.

METHODS

Study Design

My study design goal was to monitor the impact of an environmental disturbance (in this case cattle grazing) on annual bobwhite density. I took bobwhite measurements before and after the disturbance on 2 types of study plots: (1) the Coloraditas Grazing Research and Demonstration Area which contained 4 grazing treatments, and (2) 3 reference sites. The Coloraditas Grazing Research and Demonstration Area pastures were a part of a before-after (B-A) study comparing vegetation and bobwhite density before and after implementation of 4 different grazing treatments (continuous high and moderate stocking rate, rotational high and moderate stocking rate, defined below). The Coloraditas Grazing Research and Demonstration Area was historically grazed at high stocking rates prior to the initiation of this grazing study. Due to the inability to prohibit grazing on the San Antonio Viejo, I was unable to include any areas of no grazing control plots to monitor before and after the impact occurred on Coloraditas Grazing Research and Demonstration Area treatments. Reference sites represented changes outside of the controlled treatment area and changes where no grazing deferment took place (see Reference sites below). The reason for selecting these reference sites was to have a baseline for comparison that represented management outside the grazing treatments on the Coloraditas Grazing Research and Demonstration Area.

For the purposes of this chapter, I designed hypothesis not to test specific grazing treatment effects (addressed in Chapter III), rather analyzed 2 density surface models (Coloraditas Grazing Research and Demonstration Area and reference sites) for each year of the study in order to test efficacy of using density surface models for density, modeling the relationship with density to landscape covariates, and analyzing the distribution of density throughout the study. The Coloraditas Grazing Research and Demonstration Area and reference sites density surface models were built and analyzed separately because they represent two spatially distinct areas with different grazing management practices.

Aerial Surveys

I conducted aerial surveys using an R-44 helicopter to estimate bobwhite density using line-transect distance sampling methods each December 2014–2017. I used the same transect design and protocol described in Chapter II.

Covariates for Density Surface Models

I built 5 class level covariate raster files for brush configuration and composition in FRAGSTATS and a Normalized Difference Vegetation Index (NDVI) raster in ArcMap (Table 4.1). I created a set of 6 raster files for the Coloraditas Grazing Research and Demonstration Area and reference sites, respectively, to use in a Density Surface Model (density surface model) analysis. I downloaded 2014, 2015, and 2016 NAIP (1-m resolution, NC and CIR) imagery for each orthophoto quarter quadrant on SAV from the USDA through Texas Natural Resources Information System (TNRIS). I built a separate aerial image of SAV vegetation mosaics for 2014, 2015, and 2016 using NAIP images. For each aerial image by year, I calculated NDVI using the image analysis tool in ArcMap. I resampled each image to a 10m resolution and calculated NDVI using the red band (band 3) and NIR band in the following equation:

$$NDVI = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

To build the environmental covariate raster files, I obtained a 2014 NAIP aerial image classified into brush, herbaceous vegetation, and bare ground using an unsupervised classification method (Perotto-Baldivieso et al. 2009) in ERDAS Imagine 8.5 (Lecia

Table 4.1. Covariates used to model the spatial variation of northern bobwhite density in relation to spatial covariates through density surface models.

Name	Units	Description
Aggregation Index (AI)	% of class type	Number of like adjacencies of brush patches divided by the maximum possible number of like adjacencies × 100 to convert to a percentage. A value of 0 represents maximally disaggregated brush patches and 100 represents a maximally aggregated patch (i.e., single patch).
Edge Density (ED)	Meters\ha	Sum of the lengths (m) of all edge segments of brush divided by the total landscape area (m^2) ×10,000 to convert to meters per ha.
Euclidean Nearest Neighbor Distance (ENN)	Meters	Distance (m) to the nearest neighboring patch of the same type.
Normalized difference vegetation Index (NDVI)	-1 to 1	Relative vegetation biomass based on differential reflectance of plants in the red and near infrared band. Values of 0.1 and below represents bare ground, 0.2 to 0.3 represent shrub and grasslands, and 0.6 to 0.8 forests.
Patch Density (PD)	Number/100 ha	Number of brush patches divided by total landscape area)×10,000 and 100 to convert to per 100 ha.
Percentage of Landscape (PLAND)	% of class type	Sum of areas (m^2) of all brush patches divided by total landscape area ×100 to convert to a percentage.

Geosystems, Atlanta, GE) from Dr. H. Perotto-Baldivieso at Texas A&M University-Kingsville. An accuracy assessment of the image was conducted using a confusion matrix (Congalton 1991, Foody 2009) and reclassified until an accuracy of >85% was obtained (Jensen 1995). I resampled the image to 10 m resolution and imported the classified image into FRAGSTATS for analysis. I selected 5 class level metrics for brush cover after an exploration of potential metrics. I created 5 raster files for each metric in the brush class using a 400-m square moving window analysis. The moving window size corresponded to the scale I predicted density at in the density surface model (16 ha), roughly the size of a bobwhites home range during the hunting season in South Texas (Haines et al. 2004). To keep raster resolution consistent, I recalculated the mean per cell NDVI value within a 400 m square using the focal statistics tool in ArcMap.

Analyses

All analyses focused on data collected during aerial surveys each December (Fig. 4.1). Density surface models were built in a two-stage process: (1) estimate the detection function; and (2) model density response using spatial covariates and project model onto surface. The detection functions were also used to estimate density (global and stratum level) through conventional distance sampling, which I compared to estimates derived from density surface models (Fig. 4.1).

Conventional distance sampling. — I estimated the detection function for each year of the study (2014–2017) from detections pooled across the Coloraditas Grazing Research and Demonstration Area and reference sites, respectively, through conventional distance sampling methods in Program Distance, version 7.0, Release 1 (Thomas et al. 2010). I used the same data exploration and model selection process for conventional distance sampling described in Chapter II. For each analysis (year × study site), I selected the best fit models based on Akaike's

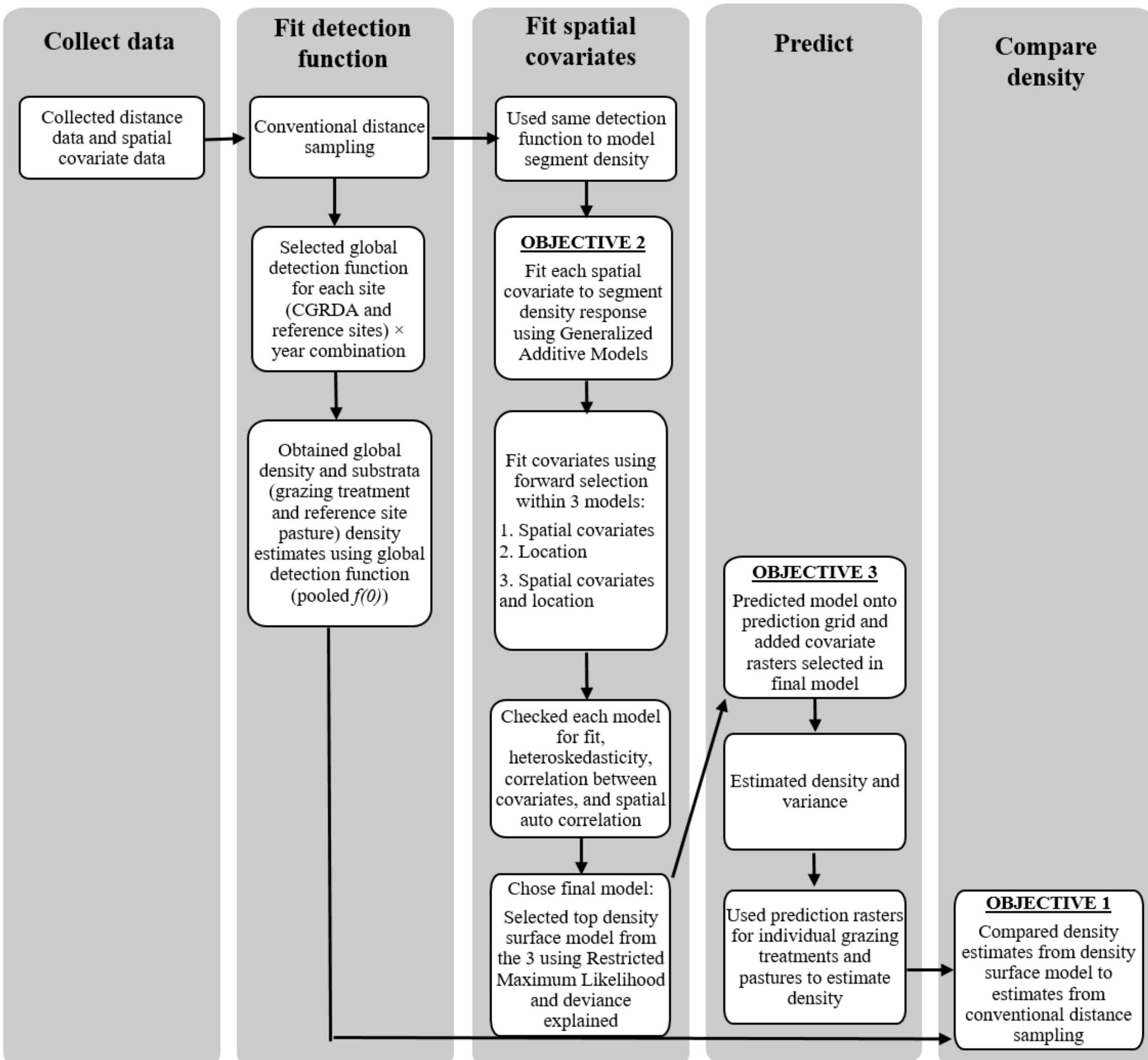

Figure 4.1. Analytic pathway for analyses involving northern bobwhite distance data related to (1) creating density surface models, (2) comparing density estimates from density surface models to density estimates from conventional distance sampling, and (3) evaluating the individual relationships between density and spatial covariates for northern bobwhites. CGRDA = Coloraditas Grazing Research and Demonstration Area.

Information Criterion (AIC) where ΔAIC values were <2.00. I used the detection function from the top model in each analysis to estimate density in the density surface model. I estimated sub strata, treatment and pasture, density estimates for each year, using a pooled $\hat{f}(0)$ for each site × year (i.e., Coloraditas Grazing Research and Demonstration Area 2014, Reference sites 2014) using conventional distance sampling in order to directly compare to the estimates predicted by the density surface model.

The reference site boundaries were changed from 2014 to 2015 for the purpose of monitoring density within an entire pasture boundary rather than across multiple pastures. The data collected from the 2014 surveys were readjusted so that covey locations fell completely inside the designated pasture boundaries from the 2015–2017 surveys. I included the detection function and density estimates from the 2014 original survey in each analysis to compare to the adjusted 2014 model. I also created a density surface model for the original survey in 2014 (described below).

Density surface modeling. — I created a separate density surface model for the Coloraditas Grazing Research and Demonstration Area and reference sites, respectively, for each year of the study resulting in 9 models (1 additional for the original 2014 reference site boundaries). Building a density surface model requires a two-stage process: (1) estimating the detection function and summarizing counts per segment, and (2) using a generalized additive model (GAM) to predict the per segment density as a function of the smoothed spatial covariates (Wood 2006). To model per segment density, I divided the transects into segments where density and the chosen covariates were not expected to vary (Miller et al. 2013). Miller et al. (2013) suggested selecting segment size by doubling the truncation distance used to estimate the detection function. I created several density surface models' using this suggested size, which resulted in a segment size of roughly 90 to 150 m depending on the year. Dividing 200 to 400 km of transects into 100 m segments created a highly zero inflated model that made the model selection process difficult (J. Edwards unpublished data). Increasing segment size to 400 allowed the spatial covariates to vary at a scale relevant to the bobwhite and reduce zero inflation. I segmented transects and extracted the environmental covariate values for each segment mid-point in ArcMap. I created a 1-ha constant raster for the Coloraditas Grazing Research and Demonstration Area and reference sites to be used as the prediction grid. The chosen covariate raster files were resampled to this grid size using bilinear interpolation creating a final density surface model at 1-ha resolution.

I used the dsm package version 2.2.15 (Miller al. 2017) in program RStudio version 3.4.4 (R Development Core Team 2013) to model the count or abundance per segment as a function of environmental covariates. I modeled the response variable of count (*n*) per segment (*j*) using a GAM (Hastie and Tibshirani 1990) from the following equation in Miller et al (2013):

$$E(n_j) = \hat{p}_j A_j \exp\left[\beta_0 + \sum_k f_k(z_{jk})\right]$$

Where $\hat{p}_j$ was the estimated detection probability by segment area (A_j), β_0 was the intercept, and f_k were the smoothed functions of the covariates (z_{jk}) with *k* indexing each covariate at the segment level. Smooths allow for flexibility in the response variable as a function of the covariates (Wood 2006). I explored a quasi-Poisson, negative binomial, and Tweedie distributions response to model count per segment with the GAM. The Tweedie distribution provided the best model fit based on an evaluation of Q-Q plots. The Tweedie distribution is particularly useful with zero inflated models (Peel et al. 2012).

I modeled the response of count for each single covariate model and evaluated the resulting model fit and term plot (Hypothesis 2: relationship between covariates and bobwhite density). These single covariate responses were used to evaluate density response to each of the environmental covariates (shown in Table 4.1) for each year. I followed the model selection methodology outlined by J. Edwards (unpublished data). Using the top covariate as a starting point, I created a density surface model with only environmental covariates using forward selection (dsm.hab). I selected the covariates to include based on the highest percent of model deviance explained and lowest restricted maximum likelihood (REML) score. I also evaluated the significance of each added covariate ($P < 0.05$) and kept significant terms in the model that improved deviance explained. I evaluated the concurvity, or correlation, at each covariate addition and removed any terms > 0.6. I evaluated the final model based on model fit (Q-Q residual plot, histogram of residuals) and evidence of heteroscedasticity (residual vs. linear predictors). I evaluated spatial autocorrelation between the segments and transects in the final model through a lag plot created by 'dsm.cor'. I created a second density surface model (dsm.xy) incorporated a bivariate smooth of the interaction between latitude (x) and longitude (y) to account for a more robust estimate of density (Valente et al. 2016). In a third model (dsm.xy.hab), I incorporated environmental covariates into the model with geographic information model using the methods described above.

A REML score was generated for each of the 3 models (dsm.hab, dsm.xy, and dsm.xy.hab). I selected one of the 3 models by selecting the lowest REML score and percent deviance explained (Miller et al. 2013) among the top models from each analysis.

The final model was used to predict the response of count with cell size as an offset on the 1-ha covariate raster, or raster stack if more than 1 covariate was selected, created in the previous steps resulting in a density of bobwhites/ha/cell. To estimate variance, I modeled the % CV per segment and predicted % CV values per cell on the prediction grid using the variance propagation method from Williams et al. (2011).

A density estimates and % CV for the total area is derived from a mean per cell value of the density surface model and variance raster. I also calculated standard error (SE) and 95% confidence intervals (CI) for each estimate. I derived grazing treatment and reference site pasture level density estimates by clipping the covariate rasters to the extent of each area and predicting the final model from the Coloraditas Grazing Research and Demonstration Area or reference sites to the spatial extent of each treatment or pasture. I compared the density surface model estimates of density by year for the Coloraditas Grazing Research and Demonstration Area, reference sites, and their respective treatments to the conventional distance sampling estimates of density for each area derived from a global detection function. I reported all density estimates as $\widehat{D}$ ± SE.

RESULTS

A total of 2,333 bobwhite coveys were detected from 2014–2017. I used a detection function from the best fitting conventional distance sampling model where detections were pooled over treatment on the Coloraditas Grazing Research and Demonstration Area and pooled over pasture on the reference sites for each year of the study (Table 4.2). The top model selected in each year exhibited good fit (K-S >0.05 and CvM >0.05; Table 4.2). A half normal key function was selected in the top model for each year with the exception of the reference site estimates from 2015. The total number of detections pooled across treatments within the Coloraditas Grazing Research and Demonstration Area and pooled across pastures in the reference sites were above the recommended 60–80 minimum each year (Buckland et al. 2001).

Table 4.2. Top models with for the fitted global detection function (Key function + no adjustments) using conventional distance sampling, truncation distance, goodness of fit tests (K-S and CvM unif), estimated detection probability (*p*), and number of northern bobwhite coveys after truncation (*n*) for the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, 2014–2017. Goodness of fit tests: CvM = Cramer VonMises (uniform); K-S =Kolmorogov-Smirnov.

Region[a]	Year	Key functions[b]	Truncation (m)	K-S	CvM (unif)	*p*	*n*
CGRDA	2014	HN	50	0.96	1.00	0.58	131
	2015	HN	60	0.95	1.00	0.67	405
	2016	HN	30	0.73	0.80	0.57	346
	2017	HN	50	0.71	0.90	0.61	271
REF	2014	HN	56	0.98	1.00	0.61	69
	2014 original	HN	65	0.96	1.00	0.52	82
	2015	HZ	50	0.47	0.70	0.88	143
	2016	HN	32	0.99	1.00	0.58	115
	2017	HN	45	0.93	0.90	0.58	120

[a]Region: CGRDA = Coloraditas Grazing Research and Demonstration Area; REF = Reference sites

[b]Key functions: HN = Half-normal; HZ = Hazard-rate.

Density Surface Models

The inclusion of covariate terms and associated significance for the Coloraditas Grazing Research and Demonstration Area models varied by year (Table 4.3). In 2014, 2015, and 2016, NDVI was included in each model, while the aggregation index was included in 2016 and 2017. The smoothing of the covariate terms in each top model were significant with the exception of NDVI in 2014 and edge density in 2015. The percent deviance explained in these models ranged from 1.19 to 4.93%.

The inclusion of covariate terms and associated significance for the reference sites models varied by year (Table 4.4). None of the covariates selected were significant in the 2014, 2015, and 2017 reference site models. The smoothing of the location covariate terms for the 2014 original survey and 2016 were significant; the only other significant term in all years was patch density for 2016. The percent deviance explained in these models ranged from 2.27 to 13.19%. There were no issues in the model fit or spatial auto correlation between segments and transects for each of the top models by year on the Coloraditas Grazing Research and Demonstration Area (Fig. 4.2–4.3) or reference sites (Fig. 4.4–4.6).

Density surface models reflect the spatial relationships described by the covariates in the top models for the Coloraditas Grazing Research and Demonstration Area and reference sites from 2014–2017 (Fig. 4.7–4.10). On the Coloraditas Grazing Research and Demonstration Area in 2014, bobwhites were distributed on the southern portion of the large pasture complex, with the highest densities (0.82–1.23 bobwhites/ha) toward the southwestern corner (Fig. 4.7). In 2015, bobwhites were more widely distributed throughout the pasture complex with the highest densities (1.23–2.47 bobwhites/ha) in the northern portion. Bobwhites densities were lowest in the southwestern corner where they were previously the highest (Fig. 4.8). In 2016, bobwhites

Table 4.3. Top density surface model with terms, significance of terms (*p*), and percent deviance explained fitted for each year of survey for northern bobwhites on the Coloraditas Grazing Research and Demonstration Area, in Jim Hogg County, Texas, USA, 2014–2017.

Year	Model	Response	Terms[a]	*p*	Deviance explained (%)
2014	dsm.xy.hab	Tweedie(p=1.224)	s(x,y)	0.065	1.49%
			s(NDVI)	0.313	
2015	dsm.xy.hab	Tweedie (p=1.26)	s(x,y)	0.001	4.63%
			s(NDVI)	0.003	
			s(ED)	0.346	
2016	dsm.hab	Tweedie(p=1.217)	s(NDVI)	0.001	2.25%
			s(AI)	0.001	
2017	dsm.xy.hab	Tweedie(p=1.227)	s(x,y)	0.772	1.19%
			s(AI)	0.024	

[a]s(x,y) = bivariate smooth of covey location (easting and northing); s(NDVI) = smooth of Normalized Difference Vegetation Index; s (ED) = smooth of edge density (m/ha); s(AI) = Aggregation index (%).

Table 4.4. Top density surface model with terms, significance of terms (*p*), and percent deviance explained fitted for each year of surveys for northern bobwhites on the reference sites in Jim Hogg County, Texas, USA, 2014–2017.

Year	Model	Response	Terms[a]	*p*	Deviance explained
2014	dsm.xy.hab	Tweedie(p=1.218)	s(x,y)	0.133	7.57%
			s(AI)	0.569	
			s(ED)	0.260	
2014_original	dsm.xy.hab	Tweedie(p=1.214)	s(x,y)	0.004	6.98%
			s(ED)	0.232	
			s(PLAND)	0.284	
2015	dsm.hab	Tweedie(p=1.269)	s(PLAND)	0.068	2.27%
			s(PD)	0.865	
			s(NDVI)	0.051	
2016	dsm.xy.hab	Tweedie(p=1.209)	s(x,y)	0.078	13.19%
			s(PD)	0.026	
			s(ED)	0.142	
2017	dsm.xy.hab	Tweedie(p=1.209)	s(x,y),	0.038	7.77%
			s(AI)	0.403	
			s(PLAND)	0.011	

[a]s(x,y) = bivariate smooth of covey location (easting and northing); s(ED) = smooth of edge density of brush (m/ha); s(PLAND) = smooth of percent of brush cover (%); s(AI) = smooth of Aggregation index of brush (%); s(PD) = smooth of patch density of brush (patches/100 ha) s(NDVI) = smooth of Normalized Difference Vegetation Index.

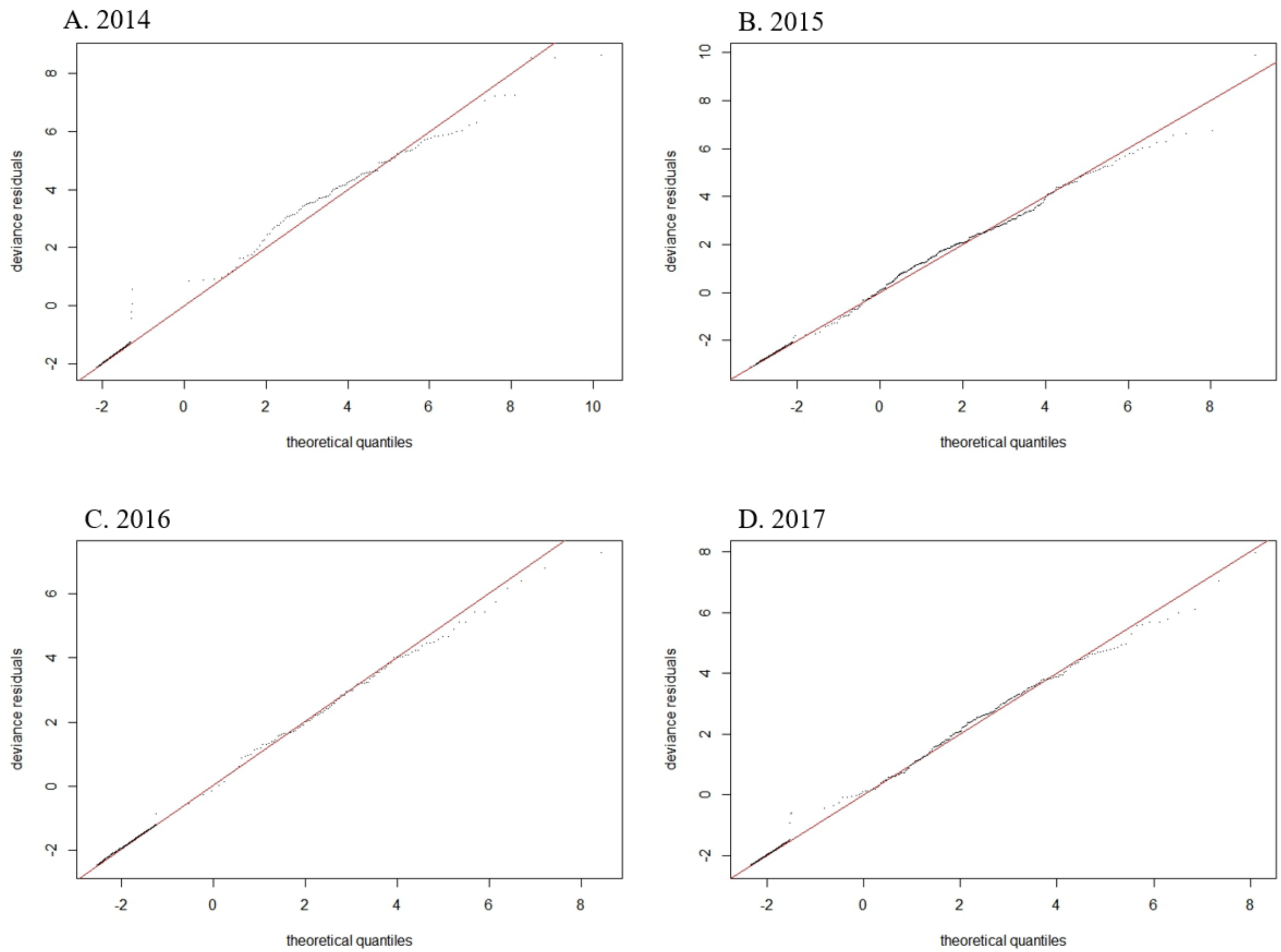

Fig 4.2. Quantile-Quantile (Q-Q) plots for each individual density surface model by year on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA, (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

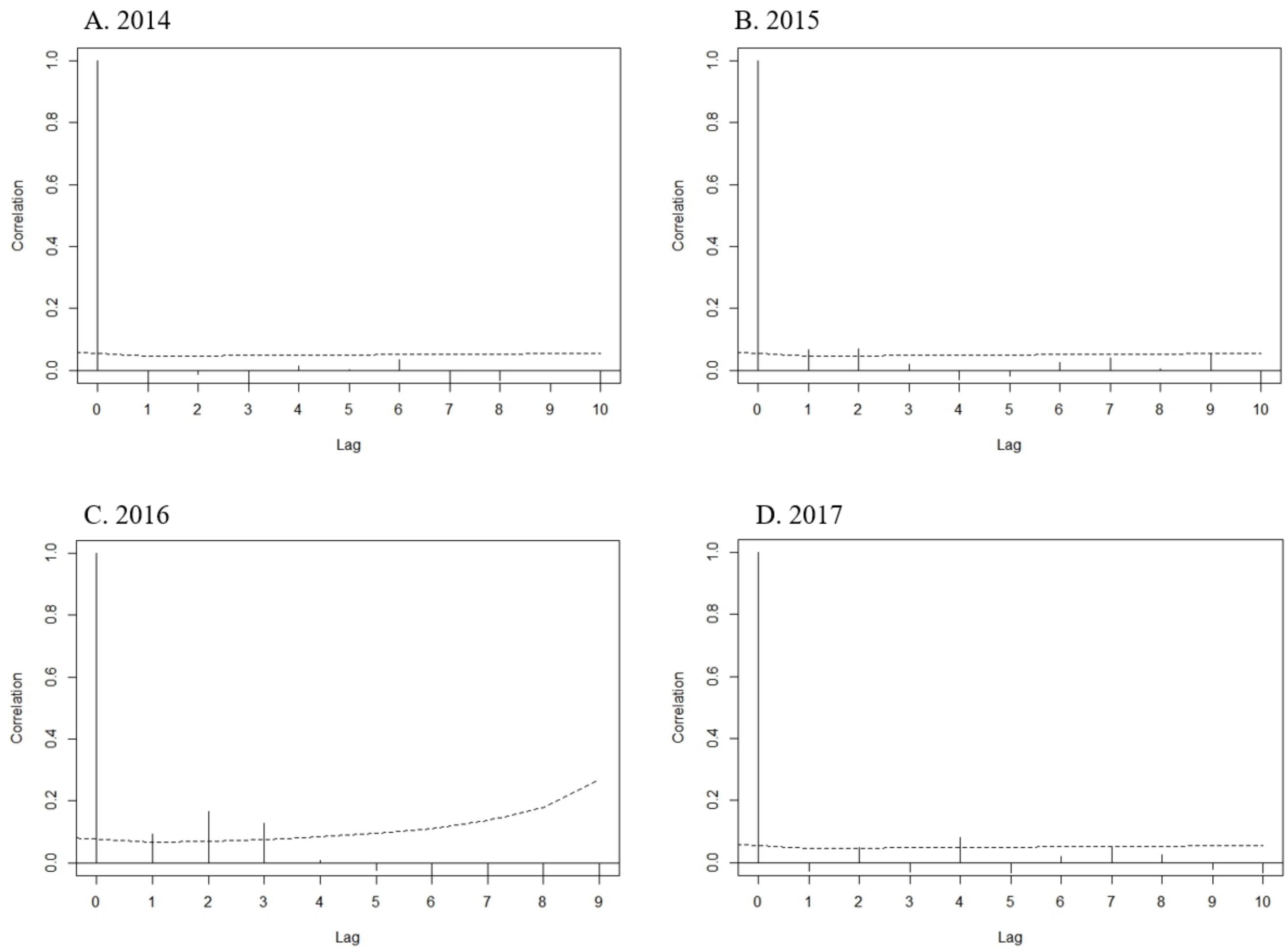

Fig 4.3. Lag plots describing the relationship between spatial autocorrelation between segments and transects for each top model of the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

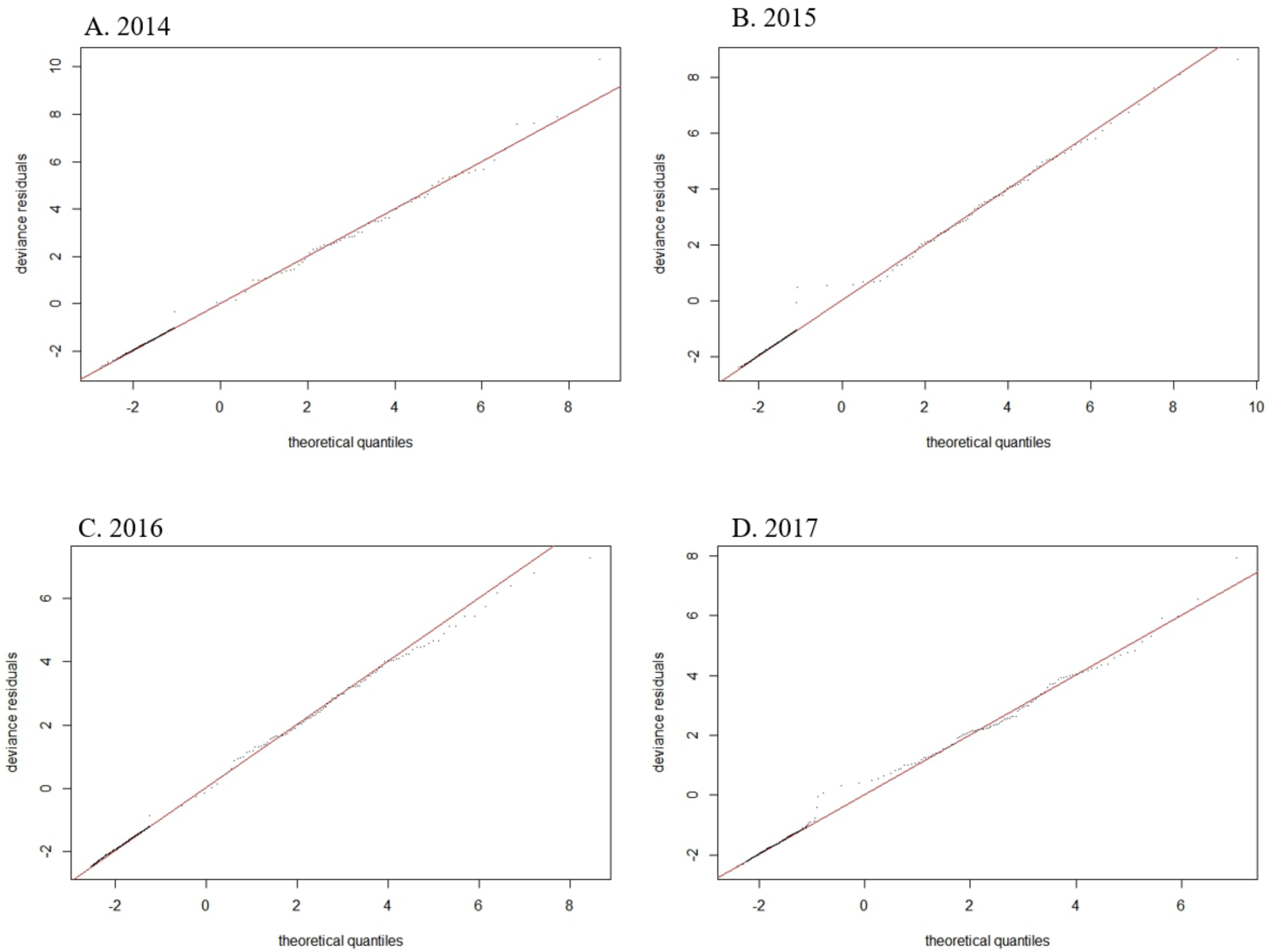

Figure 4.4. Quantile-Quantile (Q-Q) plots for each individual density surface model by year pooled over the reference site pastures in Jim Hogg County, Texas, USA (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

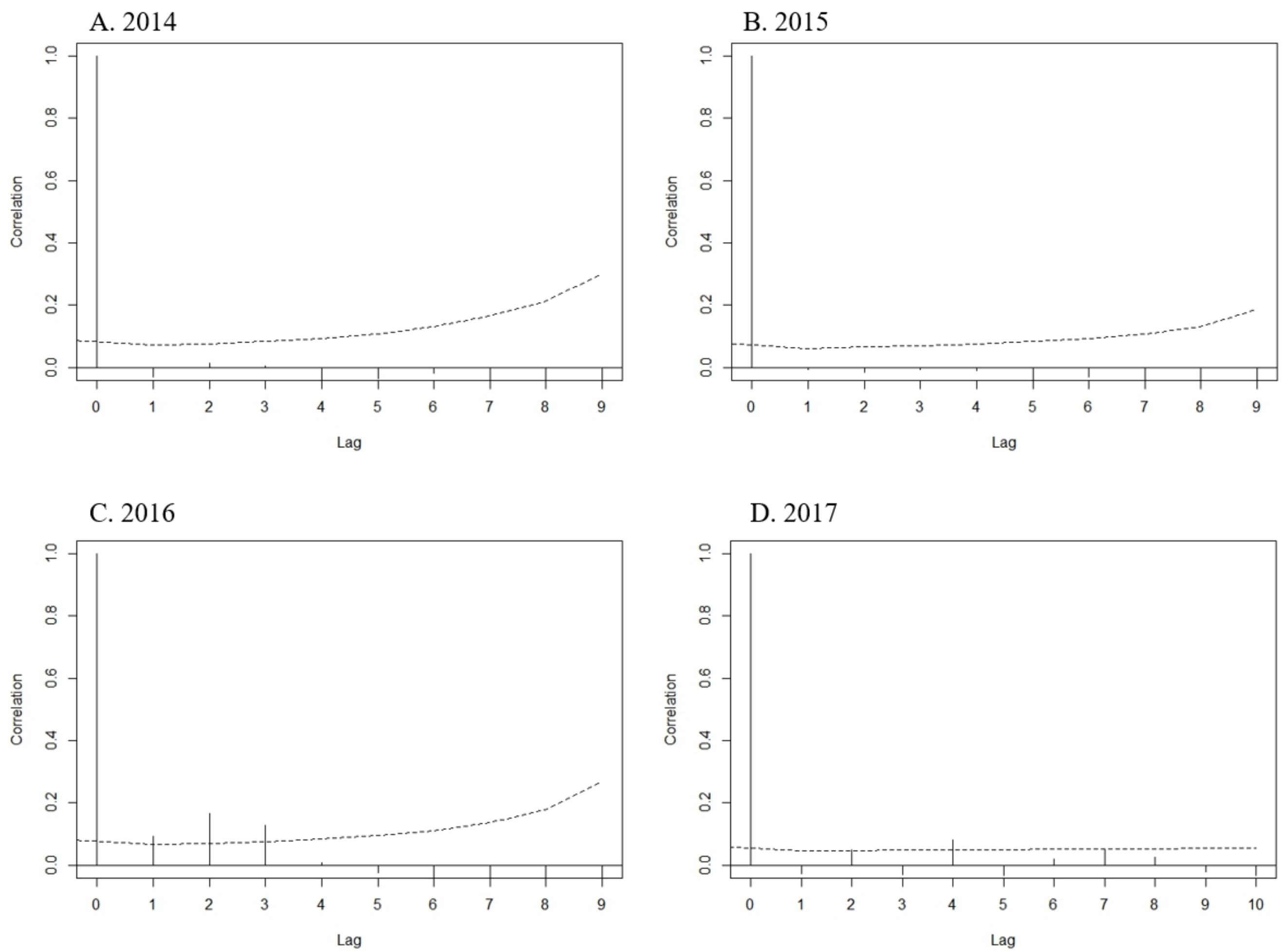

Figure 4.5. Lag plots describing the relationship between spatial autocorrelation between segments and transects for each top model of the reference sites in Jim Hogg County, Texas, USA (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

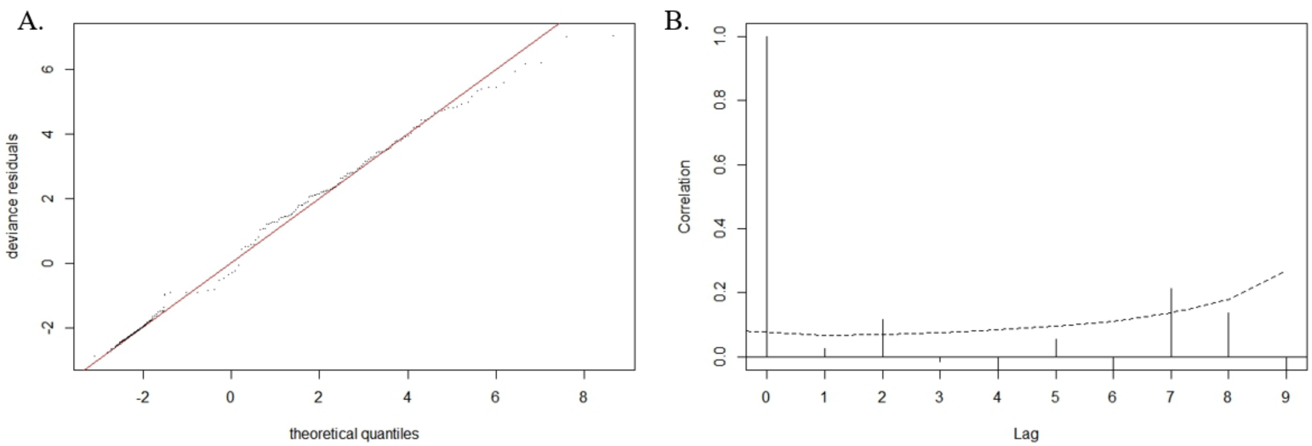

Figure 4.6. (A) Quantile-Quantile (Q-Q) plots and (B) lag plot for a density surface model fitted to the original pooled reference sites in Jim Hogg County, Texas, USA, 2014.

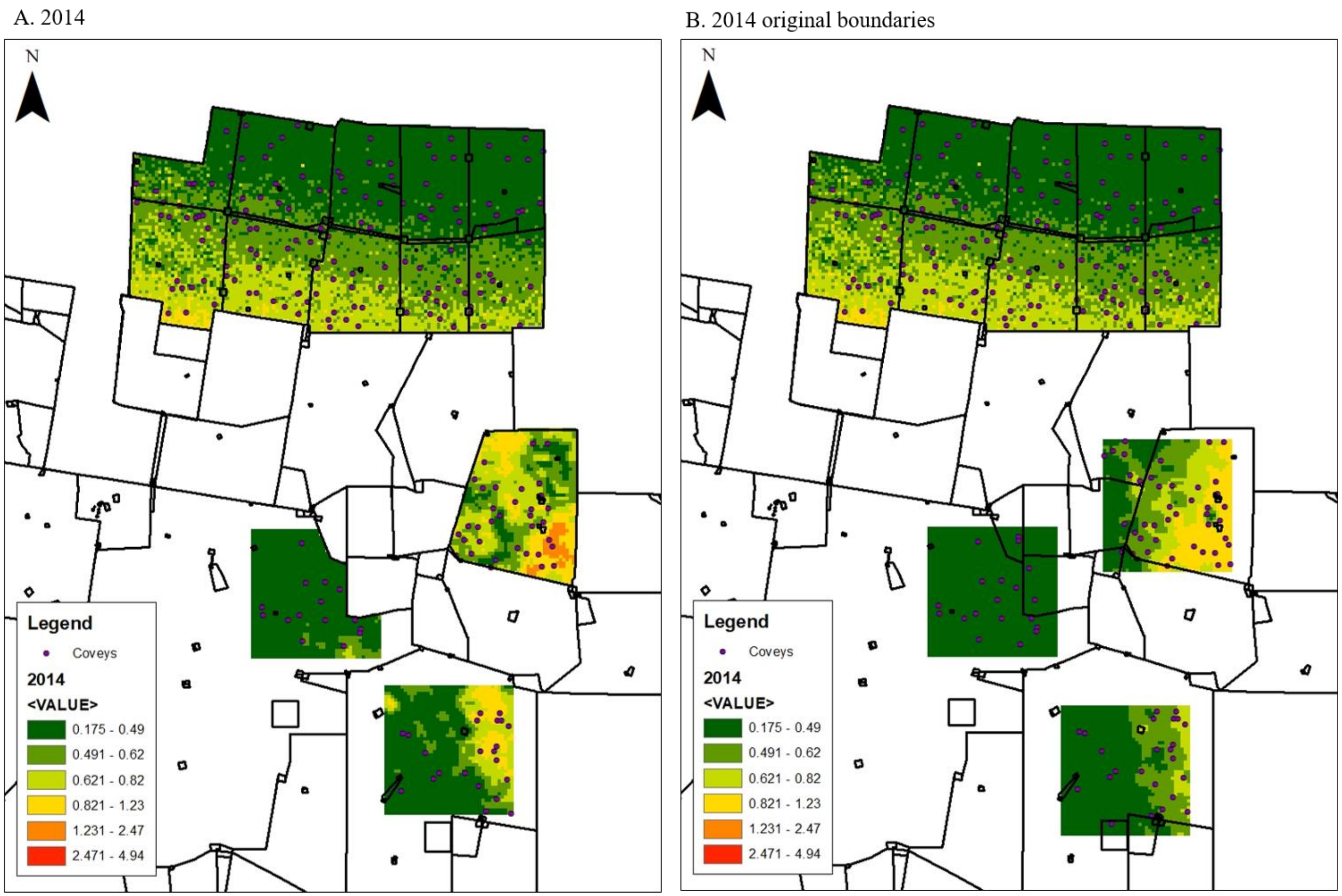

Figure 4.7. Density surface models for northern bobwhite density at 1-ha resolution and northern bobwhite covey locations on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, respectively for (A) 2014 with new reference site boundaries (B) 2014 with original reference site boundaries. Scale reflects groupings of bobwhites per ha converted into 0.5-acre intervals: 2.47105 ha = 1 acre.

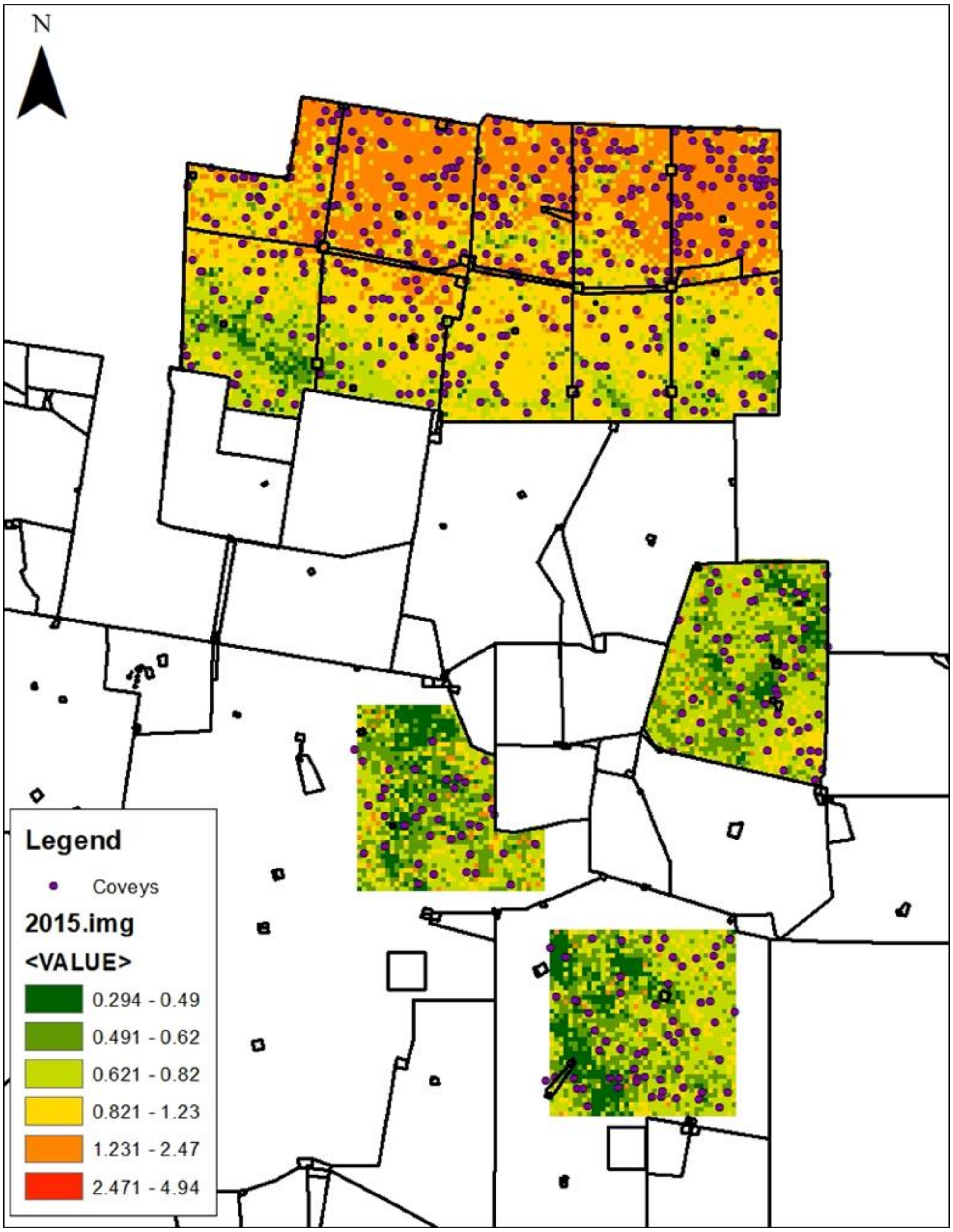

Figure 4.8. Density surface models for northern bobwhite density at 1-ha resolution and northern bobwhite covey locations on the Coloraditas Grazing Research and Demonstration Area and reference sites, in Jim Hogg County, Texas, USA, respectively for 2015 survey 1 (Coloraditas Grazing Research and Demonstration Area) and survey 2 (reference sites). Scale reflects groupings of bobwhites per ha converted into 0.5-acre intervals: 2.47105 ha = 1 acre.

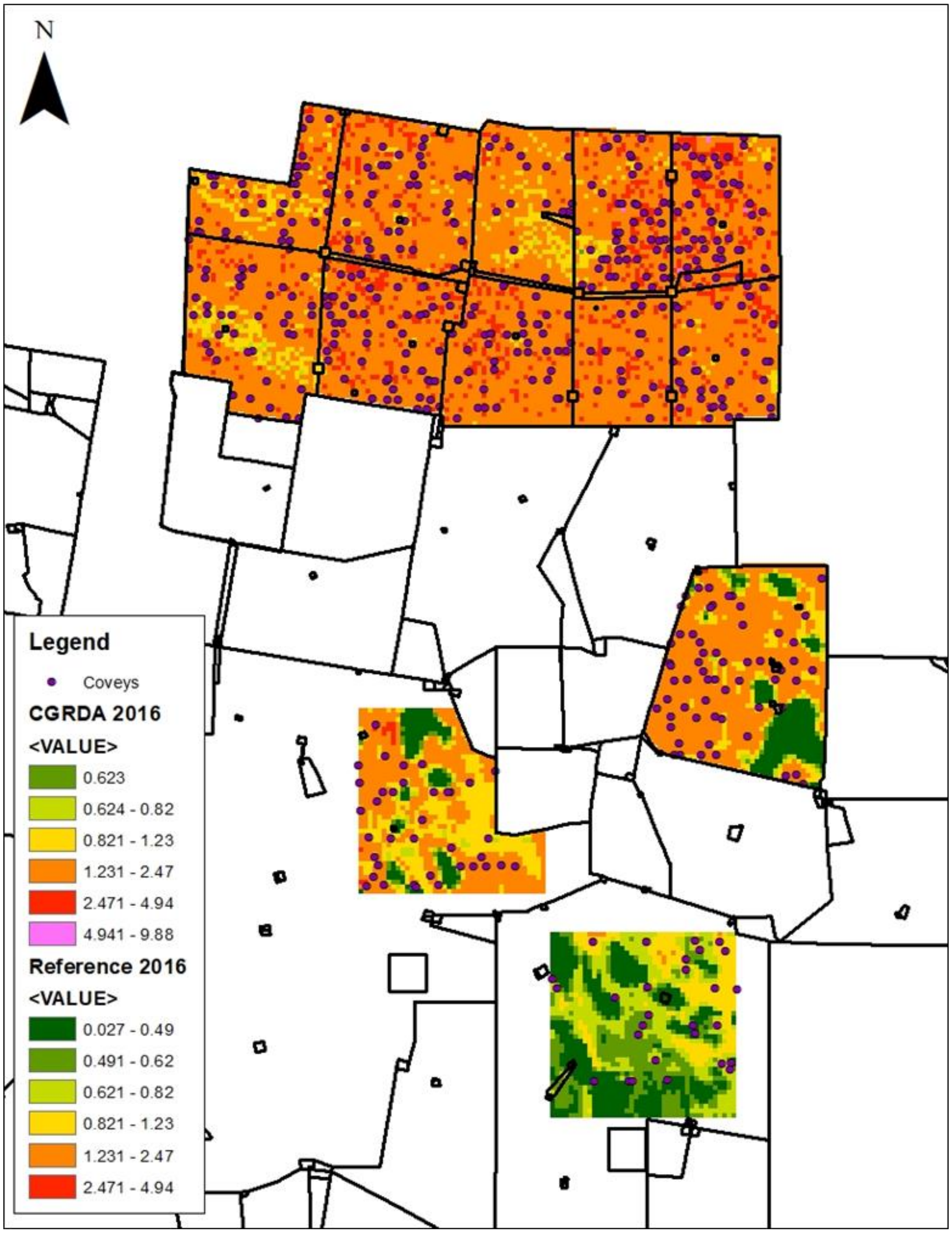

Figure 4.9. Density surface models for northern bobwhite density at 1-ha resolution and northern bobwhite covey locations on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, respectively for 2016, pooled across surveys. Scale reflects groupings of bobwhites per ha converted into 0.5-acre intervals: 2.47105 ha = 1 acre.

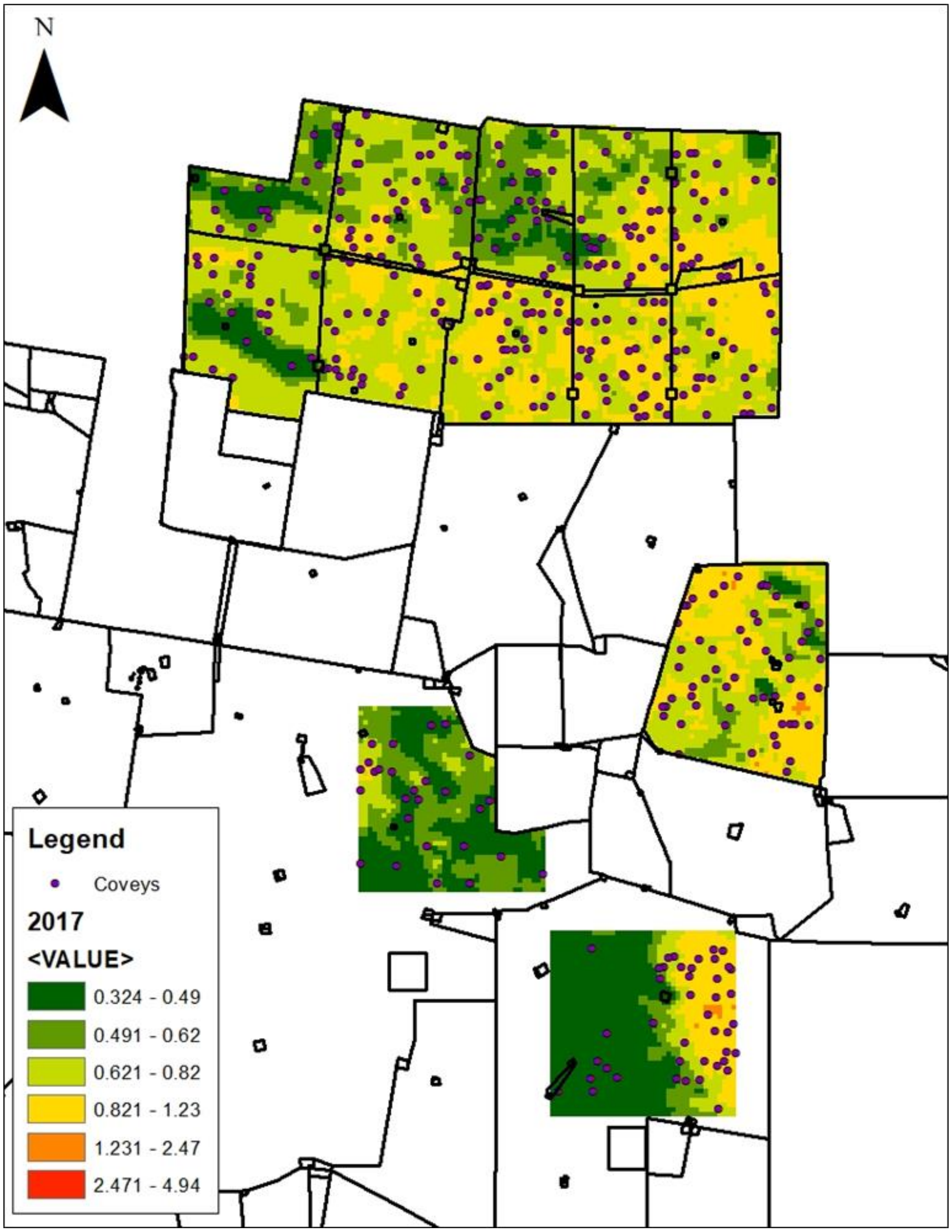

Figure 4.10. Density surface models for northern bobwhite density at 1-ha resolution and northern bobwhite covey locations on the Coloraditas Grazing Research and Demonstration Area and reference sites in Jim Hogg County, Texas, USA, respectively for 2017, pooled across surveys. Scale reflects groupings of bobwhites per ha converted into 0.5-acre intervals: 2.47105 ha = 1 acre.

were uniformly distributed across the pasture complex at densities of 2.47–4.94 bobwhites/ha (Fig. 4.9). In 2017, bobwhites were distributed across the large pasture complex at lower densities (0.62–0.82 bobwhites/ha) with higher densities (0.82–1.23 bobwhites/ha) toward the eastern part of the complex (Fig. 4.10). Bobwhites avoided areas associated with large dense brush patches (Fig. 4.10).

On the reference sites, artificially changing the reference site pasture boundaries in 2014 biased densities high in area that were not surveyed (Fig. 4.7). Comparing the density surface models with the reference sites in 2014 from the new (Fig. 4.7A) to the original (Fig. 4.7B) boundaries shows an artificial increase in density in the southeastern portion of the Atole pasture and the western portion of the Auga Dulce pasture. Therefore, I will discuss distribution on the reference sites in 2014 referring to the original surveyed boundaries (Fig. 4.7B).

Density was highest on the Atole pasture (northern pasture) and increased from the northeast to the south western corner of the pasture (Fig. 4.7B). Density was uniformly low (0.17–0.49 bobwhites/ha) across the Pinto pasture (western pasture Fig. 4.7B). In the Agua Dulce pasture (southern pasture), bobwhites density was uniformly low (< 0.82 bobwhites/ha) but increased from west to the eastern periphery (Fig. 4.7B). In 2015, bobwhites were more widely distributed at higher densities across all 3 pastures (Fig. 4.8). Patchy areas of low density (0.29–0.49 bobwhites/ha) occurred in each pasture. In 2016, bobwhite density was uniformly high (1.23–2.47 bobwhites/ha) across the Atole and Pinto pastures with patchy areas of low density (0.03–0.49) on the southwestern corner of the Atole and central portion of the pinto (Fig. 4.9). Bobwhites were aggregated in low densities (0.03–0.49) across the Agua Dulce pasture with higher densities toward the northwestern corner (Fig. 4.9). In 2017, the distribution of bobwhite density was similar to 2014 (Fig. 4.10). Density was higher (0.82–1.23 bobwhites/ha) toward the northwest and southeast corners of the Atole pasture (Fig. 4.10). Density was uniformly low on the Pinto pasture, but bands of 0.49–1.23 bobwhites/ha occurred toward the west. On the Agua Dulce pasture, bobwhite density increased from 0.32–0.49 bobwhites/ha on the east and were concentrated at 0.82–1.23 bobwhites/ha on the west.

Comparisons of Density Estimates

Density estimates derived from the density surface model were similar to those from conventional distance sampling in both the Coloraditas Grazing Research and Demonstration Area (Table 4.5, Fig. 4.11) and reference sites (Table 4.6, Fig. 4.12). The density surface model resulted in similar confidence intervals compared to estimates from conventional distance sampling in all occasions. The average absolute difference between the conventional distance sampling and density surface model estimates on the Coloraditas Grazing Research and Demonstration Area was 0.19 bobwhites/ha (range 0–0.59). The differences occurred between the conventional distance sampling and density surface model estimates on the continuous moderate treatment in 2015 (+0.54 bobwhites/ha) and 2016 (+0.59 bobwhites/ha), on the on the rotational high treatment in 2015 (+0.36 bobwhites/ha) and 2016 (+0.40 bobwhites/ha), and on the rotational moderate treatment in 2016 (0.40 bobwhites/ha). All other differences were between 0.0 and 0.22 bobwhites/ha.

The average difference between the conventional distance sampling and density surface model estimates on the reference sites was 0.09 bobwhites/ha (range 0.0–0.37). The largest differences occurred between the conventional distance sampling and density surface model estimates in 2016 on the Atole (+0.17 bobwhites/ha), Pinto (+0.37 bobwhites/ha), Agua Dulce (+0.34 bobwhites/ha) and the total combined estimate (+0.31 bobwhites/ha). All other differences were between 0.0 and 0.11 bobwhites/ha.

Table 4.5. Northern bobwhite density (bobwhites/ha [$\widehat{D}$ ± SE]), 95% confidence intervals (95% CL), and coefficient of variation (CV[$\hat{D}$]%) pooled across the Coloraditas Grazing Research and Demonstration Area grazing treatments and for each treatment in Jim Hogg County, Texas, USA, 2014–2017 estimated using density surface models with percent deviance explained and conventional distance sampling.

			DSM[b]			CDS[c]		
Year	Model[a]	Deviance explained (%)	$\hat{D}$ ± SE	95% CI	% CV ($\hat{D}$)	$\hat{D}$ ± SE	95% CI	% CV ($\hat{D}$)
2014	s(x,y),s(NDVI)	1.5	0.51 ± 0.06	(0.40–0.65)	12.40	0.48 ± 0.06	(0.37–0.62)	12.75
	Continuous Moderate		0.55 ± 0.08	(0.41–0.74)	14.97	0.68 ± 0.16	(0.42–1.10)	24.03
	Continuous High		0.53 ± 0.09	(0.39–0.73)	16.12	0.46 ± 0.11	(0.28–0.73)	23.57
	Rotational Moderate		0.54 ± 0.07	(0.41–0.70)	13.75	0.53 ± 0.09	(0.38–0.75)	17.34
	Rotational High		0.43 ± 0.08	(0.30–0.61)	17.96	0.35 ± 0.08	(0.22–0.56)	24.04
2015_2	s(x,y), s(NDVI), s(ED)	4.63	1.13 ± 0.08	(0.98–1.30)	7.29	1.33 ± 0.09	(1.15–1.53)	7.17
	Continuous Moderate		1.07 ± 0.11	(0.88–1.30)	9.97	1.61 ± 0.22	(1.23–2.11)	13.61
	Continuous High		1.10 ± 0.11	0.91–1.33)	9.72	0.97 ± 0.12	(0.76–1.23)	12.28
	Rotational Moderate		1.09 ± 0.10	(0.91–1.30)	9.2	1.25 ± 0.15	(0.98–1.60)	12.29
	Rotational High		1.24 ± 0.13	(1.01–1.53)	10.49	1.60 ± 0.17	(1.3–1.96)	10.51
2016	s(NDVI), s(AI)	2.25	1.91 ± 0.15	(1.65–2.22)	2.25	2.05 ± 0.15	(1.77–2.37)	7.46
	Continuous Moderate		1.85 ± 0.14	(1.59–2.14)	7.63	2.44 ± 0.32	(1.87–3.17)	14.52

Table 4.5. continued

			DSM[b]			CDS[c]		
Year	Model[a]	Deviance explained (%)	$\hat{D} \pm SE$	95% CI	% CV ($\hat{D}$)	$\hat{D} \pm SE$	95% CI	% CV ($\hat{D}$)
	Continuous High		1.71 ± 0.14	(1.46–2.00)	8.08	1.81 ± 0.26	(1.36–2.41)	13.29
	Rotational Moderate		2.03 ± 0.16	(1.74–2.36)	7.73	1.63 ± 0.25	(1.18–2.22)	10.17
	Rotational High		2.05 ± 0.16	(1.76–2.40)	7.97	2.45 ± 0.25	(2.00–2.99)	15.68
2017	s(x,y), s(AI)	1.2	0.72 ± 0.06	(0.61–0.85)	8.65	0.77 ± 0.07	(0.63–0.92)	9.61
	Continuous Moderate		0.69 ± 0.06	(0.58–0.82)	8.68	0.55 ± 0.13	(0.35–0.85)	22.24
	Continuous High		0.66 ± 0.06	(0.55–0.79)	9.05	0.85 ± 0.14	(0.62–1.16)	15.69
	Rotational Moderate		0.74 ± 0.06	(0.63–0.88)	8.71	0.90 ± 0.13	(0.68–1.19)	14.20
	Rotational High		0.76 ± 0.07	(0.64–0.91)	8.98	0.75 ± 0.13	(0.53–1.06)	17.46

[a]s(x,y) = bivariate smooth of covey location (easting and northing); s(NDVI) = smooth of Normalized Difference Vegetation Index; s (ED) = smooth of edge density (m/ha); s(AI) = Aggregation index (%).

[b]DSM = Density Surface Model

[c]CDS = Conventional Distance Sampling

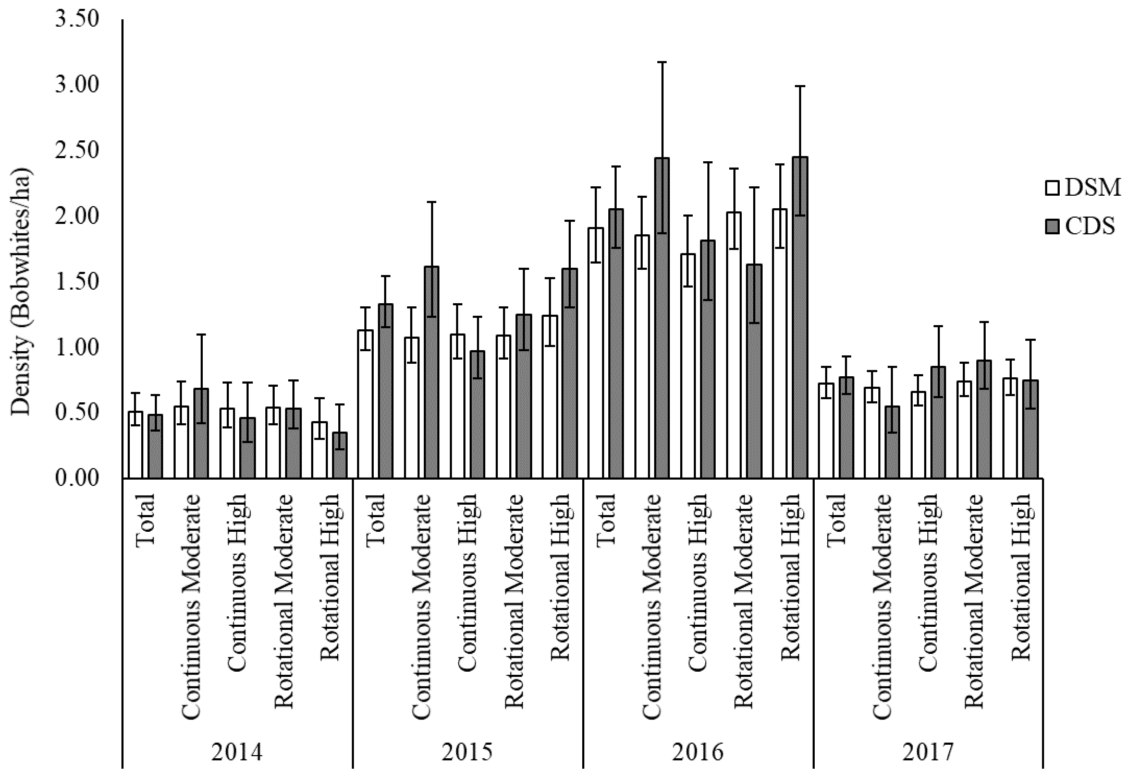

Figure 4.11. Northern bobwhite density (bobwhite/ha [D̂] ± SE) and 95% confidence intervals (95% CI) pooled across the Coloraditas Grazing Research and Demonstration Area grazing treatments and for each treatment Jim Hogg County, Texas, USA, 2014–2017 estimated using density surface models' deviance explained and conventional distance sampling. DSM = Density Surface Model; CDS = Conventional Distance Sampling.

Table 4.6. Northern bobwhite density (quail/ha [$\hat{D}$] ± SE), 95% CI , and coefficient of variation (CV[$\hat{D}$]%) pooled across the reference site pastures and for each reference site pasture Jim Hogg County, Texas, USA, 2014–2017 estimated using density surface models with percent deviance explained and conventional distance sampling.

			DSM			CDS		
Year	Modela	Deviance explained (%)	$\hat{D}$±SE	95% CI	% CV ($\hat{D}$)	$\hat{D}$±SE	95% CI	% CV ($\hat{D}$)
2014_original	s(x,y), s(ED), s(PLAND)	6.98	0.44 ± 0.07	(0.33–0.58)	15.2	0.44 ± 0.07	(0.33–0.60)	15.21
	Atole		0.66 ± 0.13	(0.45–0.96)	19.6	0.65 ± 0.13	(0.43–0.97)	20.8
	Pinto		0.23 ± 0.06	(0.14–0.39)	26.4	0.30 ± 0.08	(0.18–0.52)	26.74
	Agua Dulce		0.43 ± 0.10	(0.27–0.65)	22.7	0.39 ± 0.09	(0.25–0.62)	23.16
2014	s(x,y), s(AI), s(ED)	7.57	0.54 ± 0.10	(0.38–0.76)	17.9	0.52 ± 0.09	(0.37–0.72)	16.89
	Atole		0.81 ± 0.19	(0.51–1.29)	23.9	0.77 ± 0.17	(0.50–1.20)	21.87
	Pinto		0.23 ±0.23	(0.13–0.41)	30.8	0.34 ± 0.11	(0.18–0.65)	32.42
	Agua Dulce		0.52 ± 0.12	(0.33–0.82)	23.4	0.44 ± 0.11	(0.27–0.72)	24.52
2015_1	s(PLAND), s(PD), s(NDVI)	2.27	0.65 ± 0.08	(0.52–0.83)	12.1	0.70 ± 0.09	(0.54–0.91)	13.26
	Atole		0.67 ± 0.09	(0.51–0.87)	13.5	0.71 ± 0.15	(0.47–1.05)	20.23
	Pinto		0.64 ± 0.09	(0.50–0.83)	13.3	0.66 ± 0.12	(0.44–0.99)	20.62
	Agua Dulce		0.65 ± 0.08	(0.51–0.83)	12.5	0.74 ± 0.13	(0.50–1.08)	19.36
2016	s(x,y), s(PD), s(ED)	13.19	1.03 ± 0.13	(0.80–1.33)	13.1	1.34 ± 0.19	(1.00–1.79)	14.67
	Atole		1.41 ± 0.24	(1.01–1.96)	17.2	1.58 ± 0.28	(1.10–2.27)	18.15
	Pinto		1.15 ± 0.23	(0.78–1.68)	19.7	1.52 ± 0.37	(0.92–2.50)	24.82
	Agua Dulce		0.59 ± 0.13	(0.38–0.90)	22.1	0.93 ± 0.25	(0.55–1.58)	26.46

2017	s(x,y), s(AI), s(PLAND)	7.77	0.61 ± 0.08	(0.47–0.78)	12.7	0.62 ± 0.08	(0.48–0.80)	12.9
	Atole		0.78 ± 0.13	(0.56–1.09)	16.9	0.78 ± 0.13	(0.55–1.09)	17.1
	Pinto		0.49 ± 0.10	(0.33–0.74)	21.2	0.54 ± 0.12	(0.33–0.86)	23.42
	Agua Dulce		0.53 ± 0.10	(0.37–0.77)	19.1	0.55 ± 0.11	(0.37–0.82)	19.68

[a]s(x,y) = bivariate smooth of covey location (easting and northing); s(ED) = smooth of edge density of brush (m/ha); s(PLAND) = smooth of percent of brush cover (%); s(AI) = smooth of Aggregation index of brush (%); s(PD) = smooth of patch density of brush (patches/100 ha) s(NDVI) = smooth of Normalized Difference Vegetation Index.

[b]DSM = Density Surface Model

[c]CDS = Conventional Distance Sampling

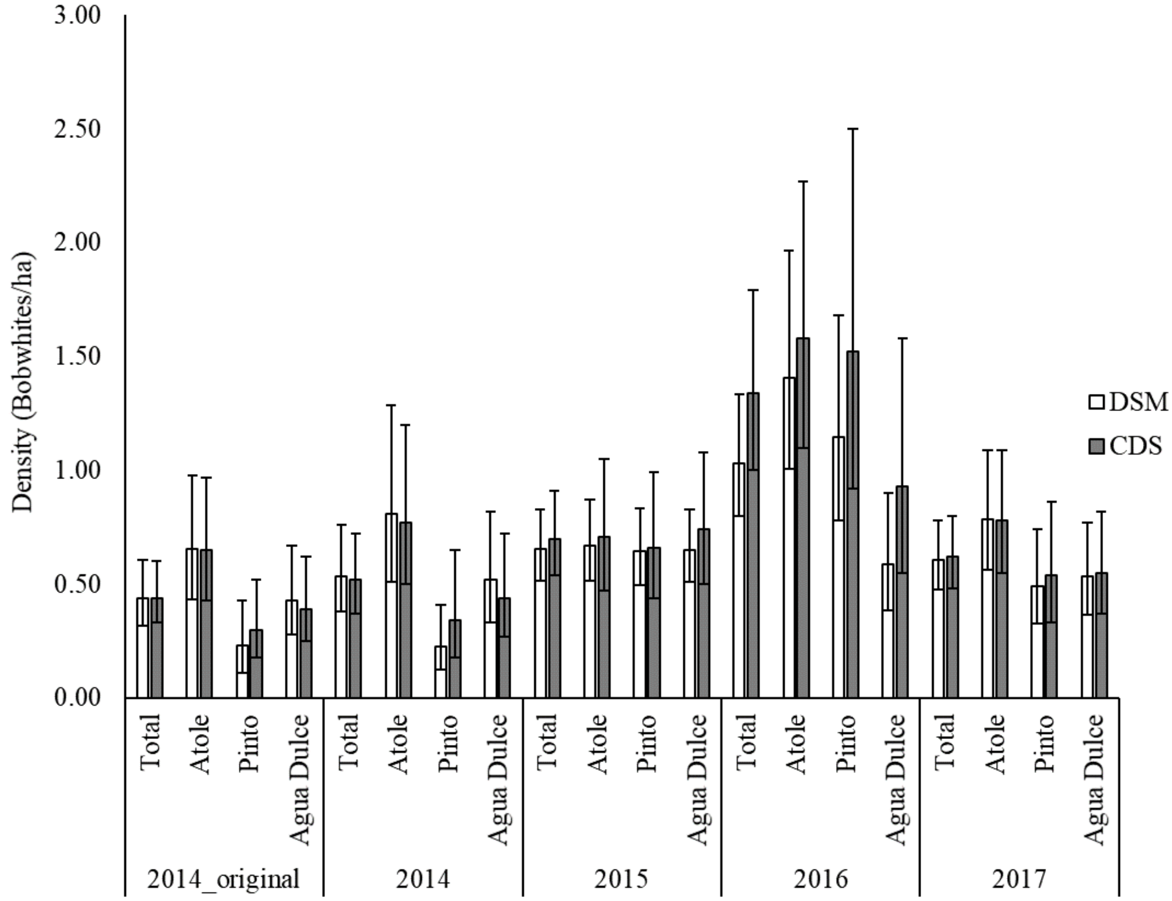

Figure 4.12. Northern bobwhite density (quail/ha [$\hat{D}$] ± SE) and 95% CI pooled across the reference site pastures and for each reference site pasture Jim Hogg County, Texas, USA, 2014–2017 estimated using density surface models and conventional distance sampling. DSM = Density Surface Model; CDS = Conventional Distance Sampling.

Density estimates from the density surface model had lower SE and CV, particularly when estimating at the treatment or pasture level in all years except on the reference sites in 2014 (Fig. 4.11, Fig. 4.12). The CV was less sensitive to a low number of detections when estimating density from the density surface model on both the Coloraditas Grazing Research and Demonstration Area (Fig. 4.13) and reference sites (Fig. 4.14).

Relationships to Environmental Covariates

Coloraditas grazing research and demonstration area. — On the Coloraditas Grazing Research and Demonstration Area, the individual relationships between bobwhite density and the 6 environmental covariates differed by year (Fig. 4.15–4.20). The aggregation index showed linear trends in 2014, 2016, and 2017 where density decreased with increasing aggregation of brush patches (Fig. 4.15A; C; D).

In 2015, density increased up to an aggregation index of 45% and decreased thereafter (Fig. 4.15B). Edge density had negative linear relationships to bobwhite density in 2014 and 2017, but quadratic relationships in 2015 and 2016 where density increased to ~500 m/ha leveling off in 2015 and sharply decreasing in 2016 (Fig. 4.16). The relationship between density and the Euclidean nearest neighbor distance between patches of similar types could not be correctly interpreted for any year of the study (Fig. 4.17). The rug ticks at the bottom of the plot indicate the range of average nearest neighbor distances between brush patches spanned from 20 to 30 m on the Coloraditas Grazing Research and Demonstration Area and density did not seem to fluctuate within that range.

There was a negative linear relationship between bobwhite density and NDVI for 2014, 2015, and 2017 (Fig. 4.18A; B; D). The range of NDVI values was wider prior to grazing (2014 and 2015). Low values (i.e., bare ground) of NDVI in 2014 are likely due to the construction of

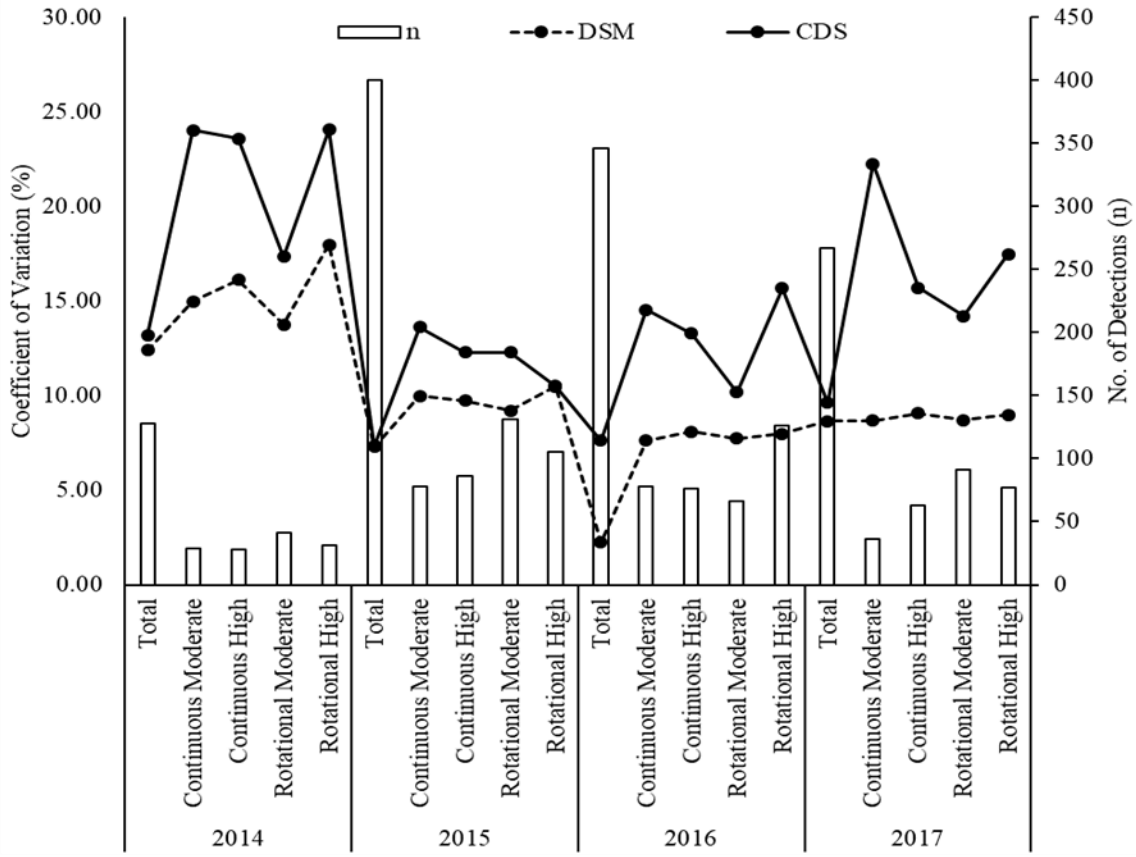

Figure 4.13. The relationship between coefficient of variation (CV[D̂]%) (lines) and number of detections (n; white bars) for each northern bobwhite density estimate (quail/ha [D̂]) pooled across the Coloraditas Grazing Research and Demonstration Area grazing treatments and for each treatment Jim Hogg County, Texas, USA, 2014–2017 estimated using density surface models and conventional distance sampling. DSM = Density Surface Model; CDS = Conventional Distance Sampling.

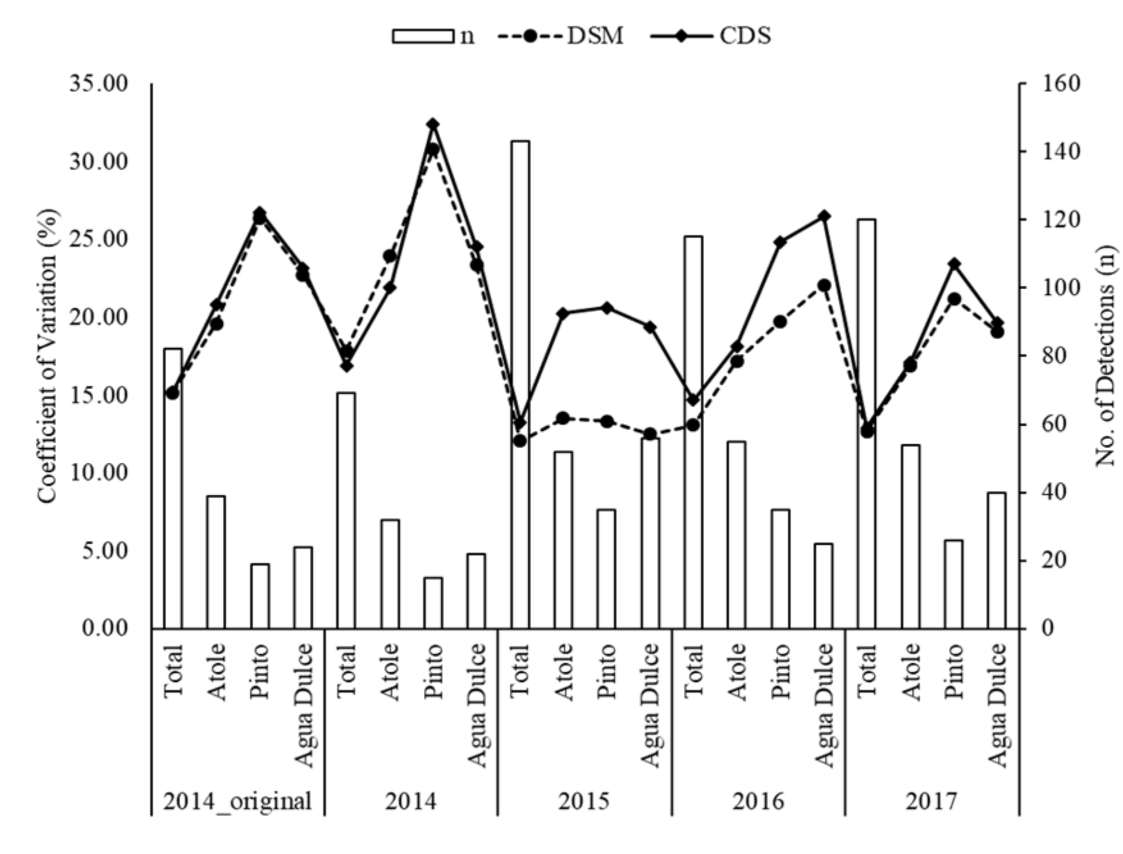

Figure 4.14. The relationship between coefficient of variation (CV[D̂]%) (lines) and number of detections (n; white bars) for each northern bobwhite density estimate (bobwhite/ha [D̂]) pooled across the reference sites and for each reference site pasture Jim Hogg County, Texas, USA, 2014–2017 estimated using density surface models and conventional distance sampling. DSM = Density Surface Model; CDS = Conventional Distance Sampling.

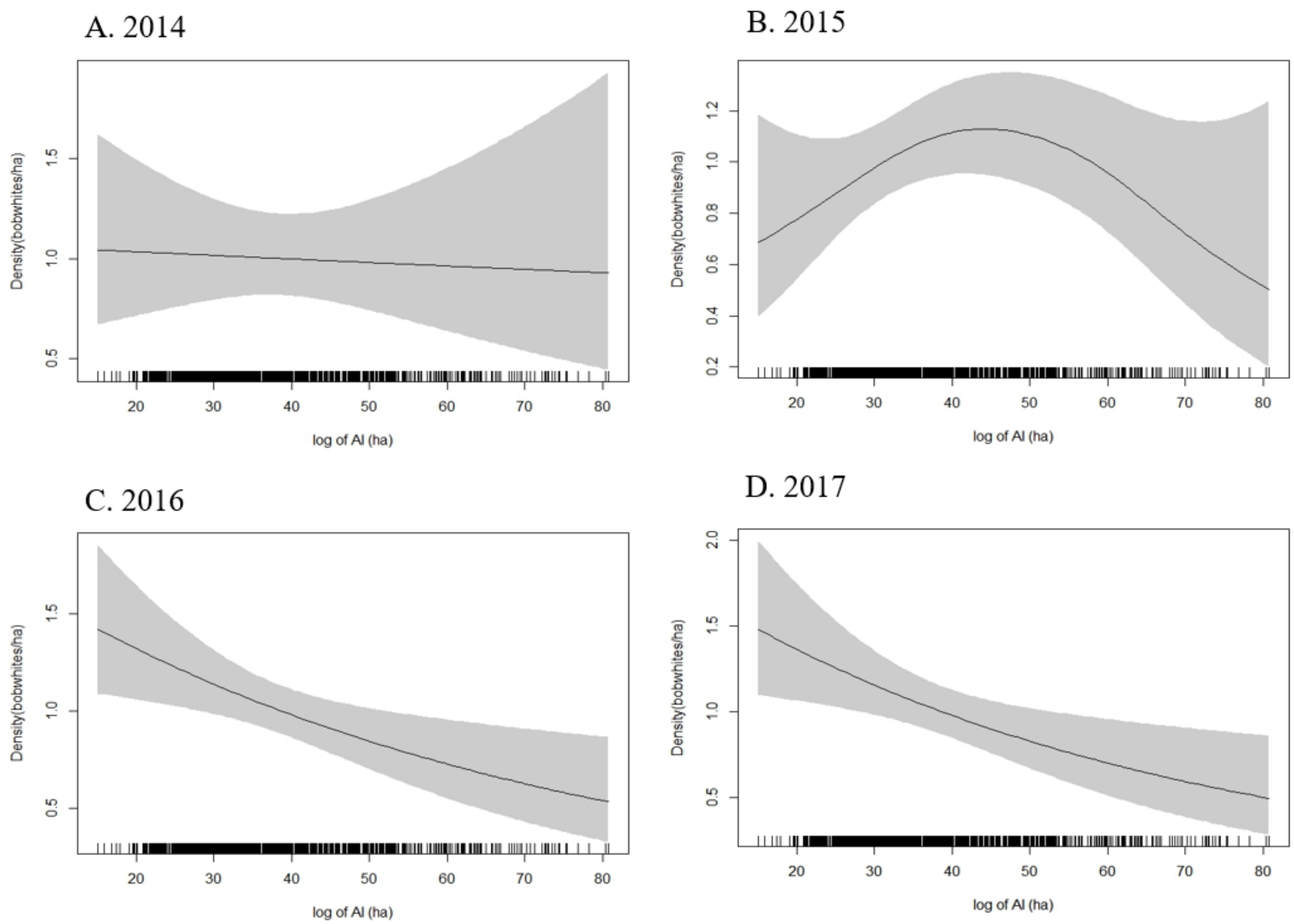

Figure 4.15. Relationship between northern bobwhite density (bobwhite/ha [D̂]) on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA and the aggregation index (AI) of brush for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

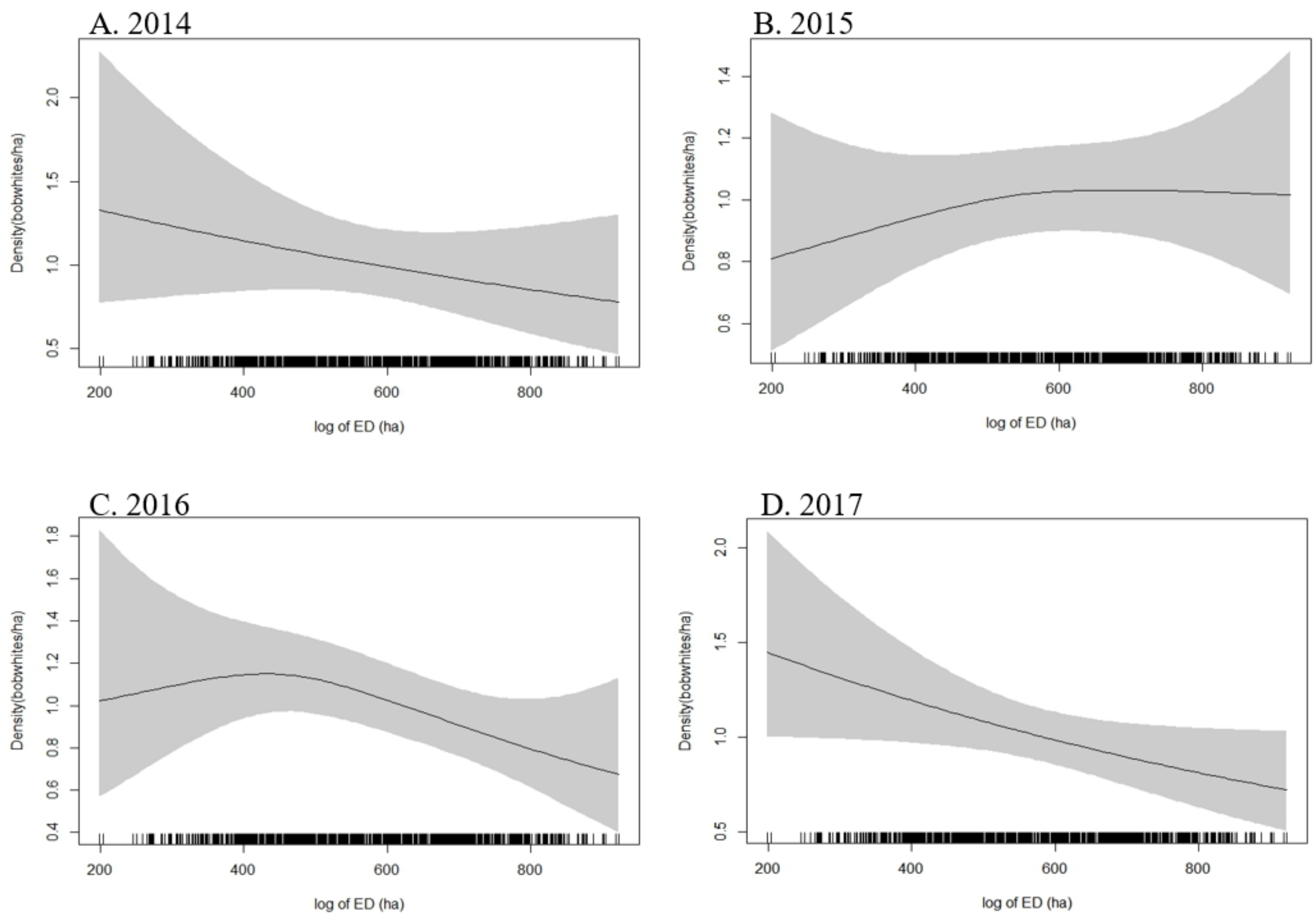

Figure 4.16. Relationship between northern bobwhite density (bobwhite/ha [$\hat{D}$]) on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA and the edge density (ED) of brush for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

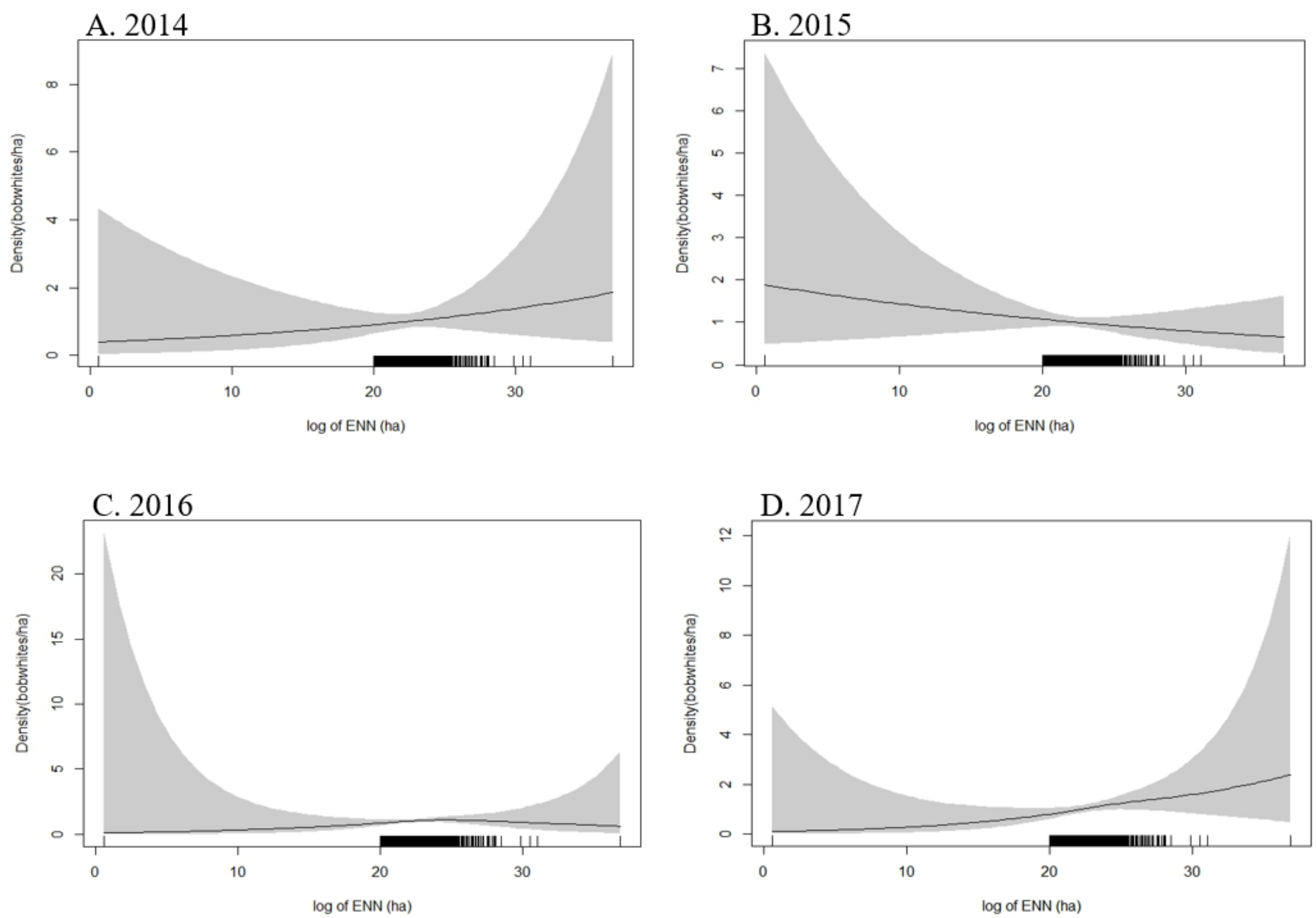

Figure 4.17. Relationship between northern bobwhite density (bobwhite/ha [D̂]) on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA and the Euclidian nearest neighbor distance (ENN) between brush patches for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

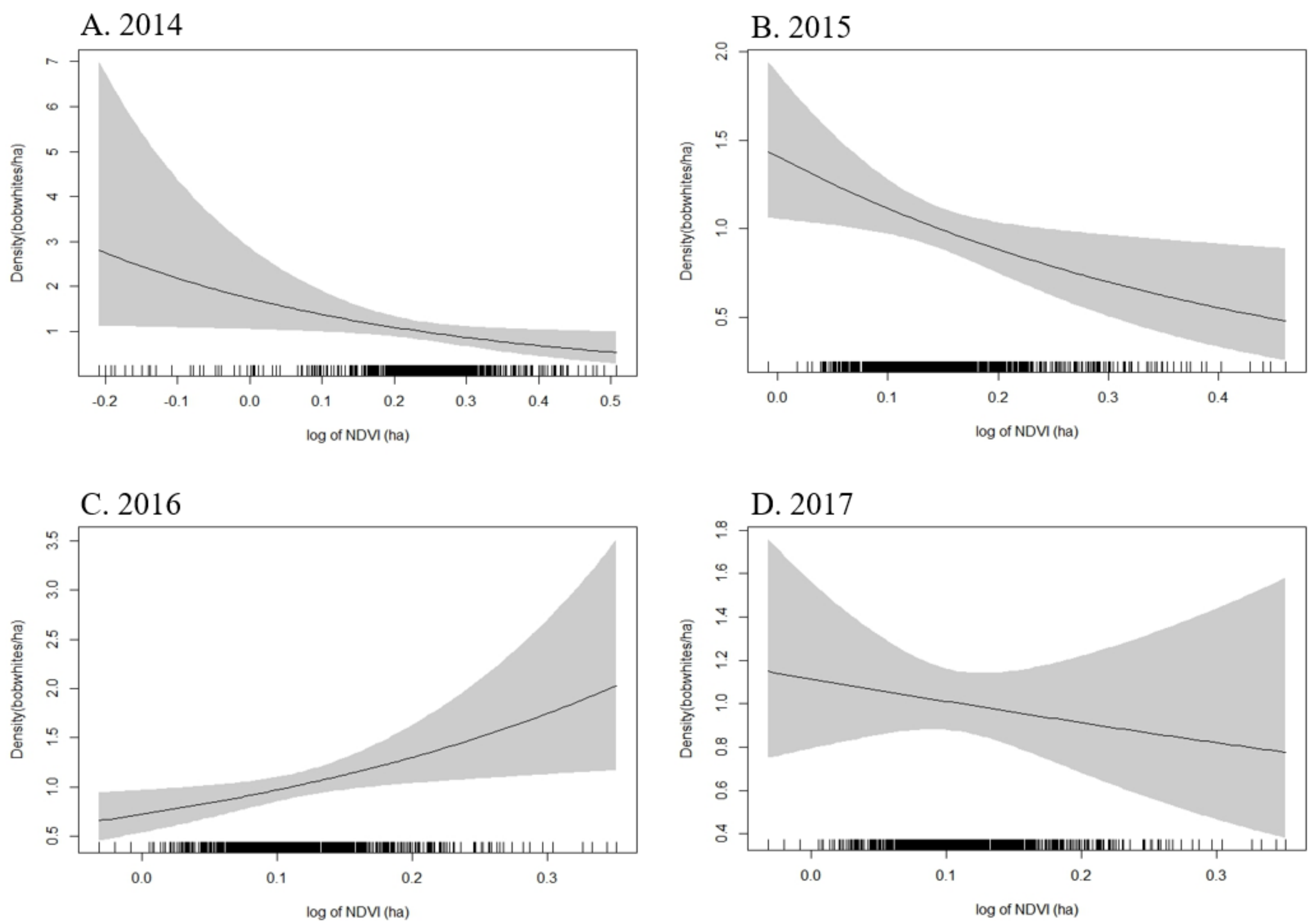

Figure 4.18. Relationship between northern bobwhite density (bobwhite/ha [$\hat{D}$]) on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA and the Normalized Difference Vegetation Index (NDVI) for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

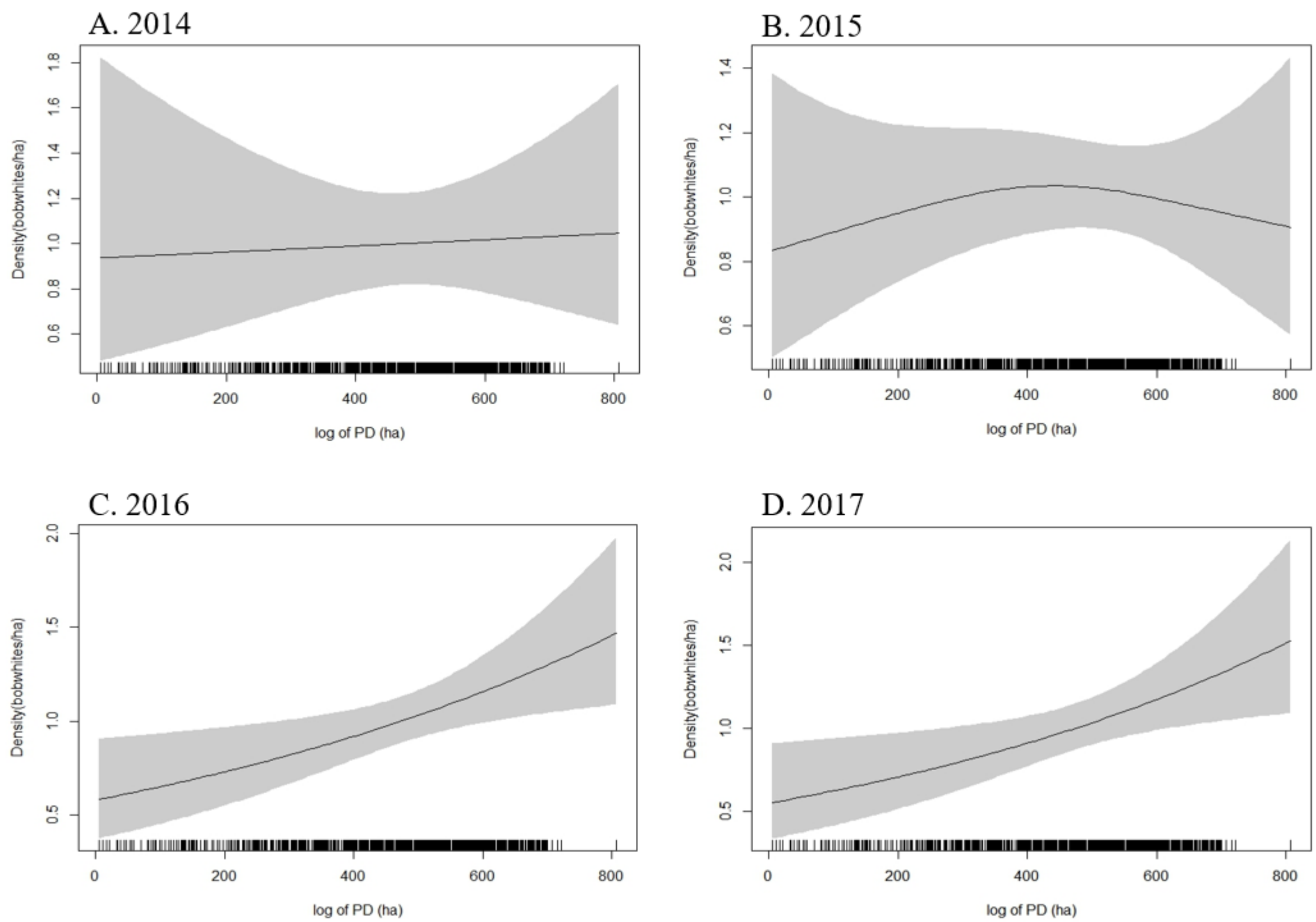

Figure 4.19. Relationship between northern bobwhite density (bobwhite/ha [$\hat{D}$]) on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA and the patch density of brush (PD) for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

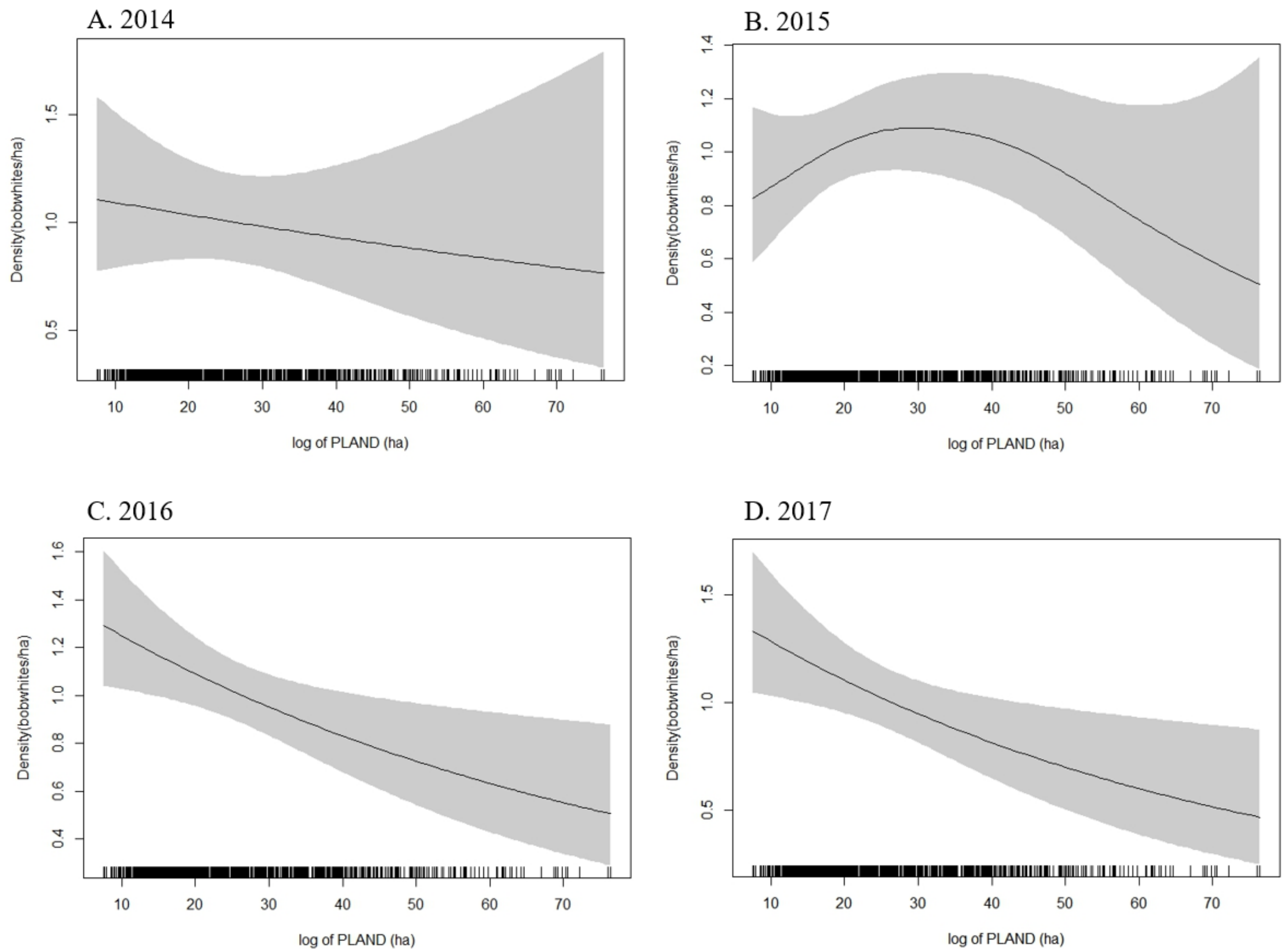

Figure 4.20. Relationship between northern bobwhite density (bobwhite/ha [$\hat{D}$]) on the Coloraditas Grazing Research and Demonstration Area in Jim Hogg County, Texas, USA and the percentage of landscape (PLAND) of brush for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

water lots, fences, traps, and lanes for cattle. Bobwhite density was highest in these areas, and weakly decreased with increasing NDVI (woody and herbaceous cover). In 2015, bobwhite density decreased as NDVI values increased from bare ground (<0.1) to herbaceous (0.1 to 0.2) to woody vegetation (>0.2; Fig. 4.18B). In 2016, bobwhite density increased with increasing NDVI value likely corresponding to the relationship in increasing bobwhite density with brush patch density (Fig. 4.18C). In 2017, density steadily decreased with increasing NDVI (Fig. 4.18D).

The relationship between brush patch density and percent brush and bobwhite density varied from before (2014 and 2015) to after grazing (2016 and 2017). There was an inverse relationship between patch density and the percentage of landscape made up by brush within years. In 2014, as bobwhite density increased linearly with brush patch density, percent brush cover decreased (Fig. 4.19A and Fig. 4.20A). The relationship was quadratic in 2015 where bobwhite density increased up to a density of 500 brush patches/ha and decreased thereafter (Fig. 4.19B and Fig. 4.20B). This corresponded to an increase bobwhite density with percent brush cover up to 35%, decreasing thereafter. In 2016 and 2017, there was a positive linear relationship between bobwhite density and brush patch density and a negative linear relationship between bobwhite density and percent brush cover (Fig. 4.19C; D and Fig. 4.20C; D). The linear trend in 2014 was weaker than in 2016 and 2017.

Reference sites—The term plots displayed for 2014 in the reference sites are from the original pasture boundaries surveyed (Fig. 4.21A–4.26A). Because I altered the pasture boundaries from the original 2014 survey to match the current boundaries, the spatial relationships may have been biased in that year; therefore, I excluded the covariate relationships from the altered 2014 surveys.

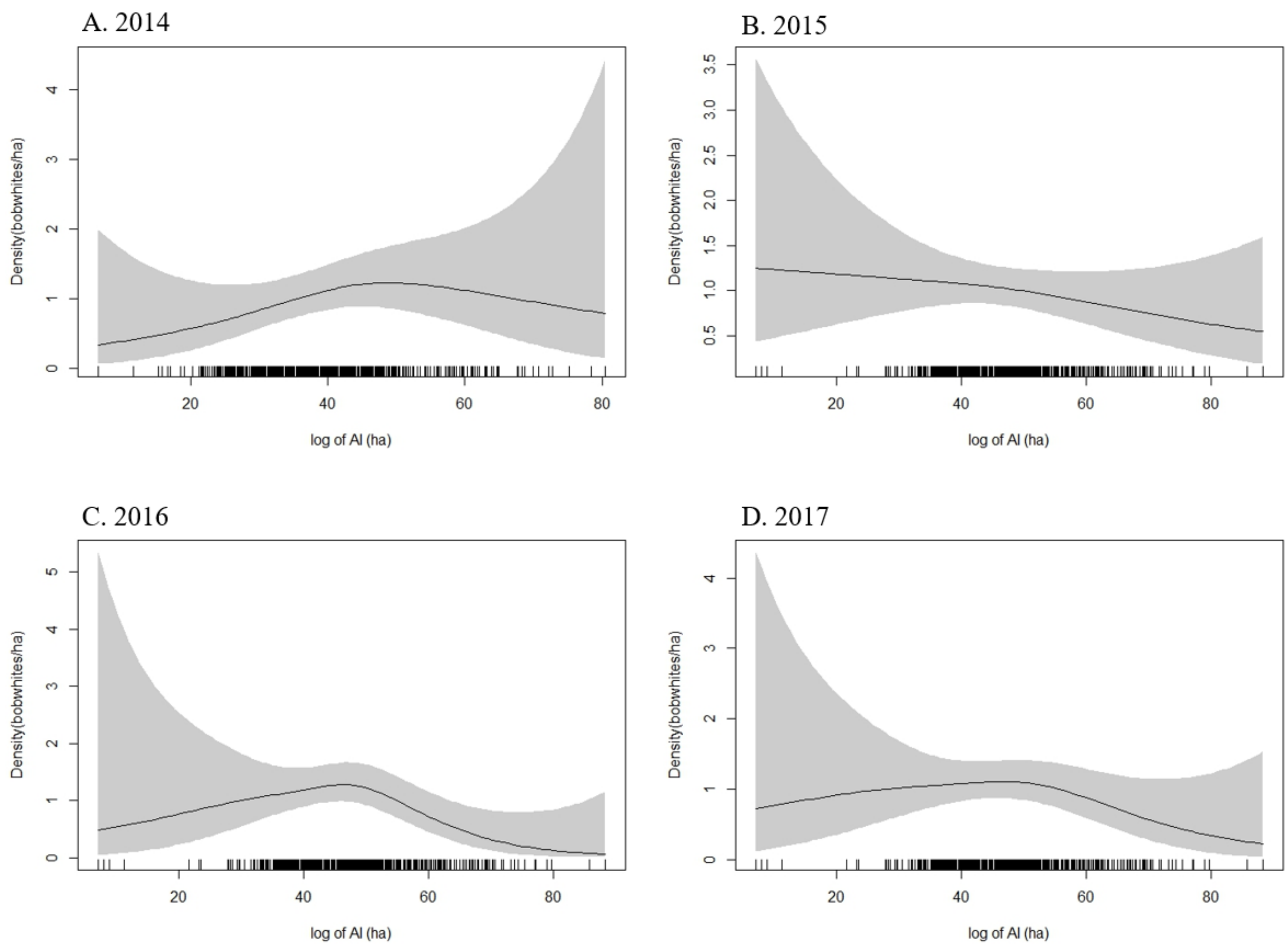

Figure 4.21. Relationship between northern bobwhite density (bobwhite/ha [D̂]) on the pooled reference sites in Jim Hogg County, Texas, USA and the aggregation index (AI) of brush for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

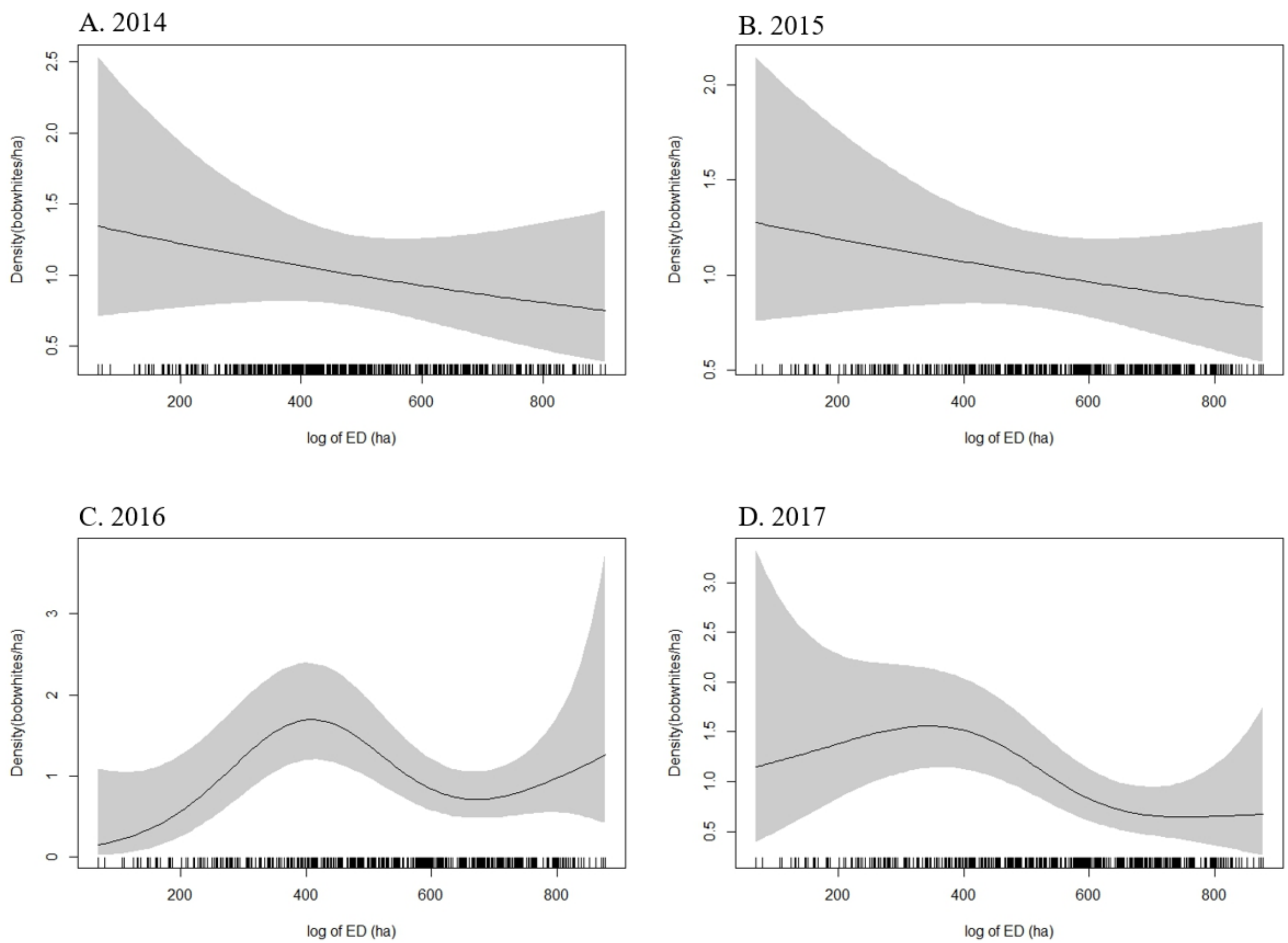

Figure 4.22. Relationship between northern bobwhite density (bobwhite/ha [$\hat{D}$]) on the pooled reference sites in Jim Hogg County, Texas, USA and the edge density (ED) of brush for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

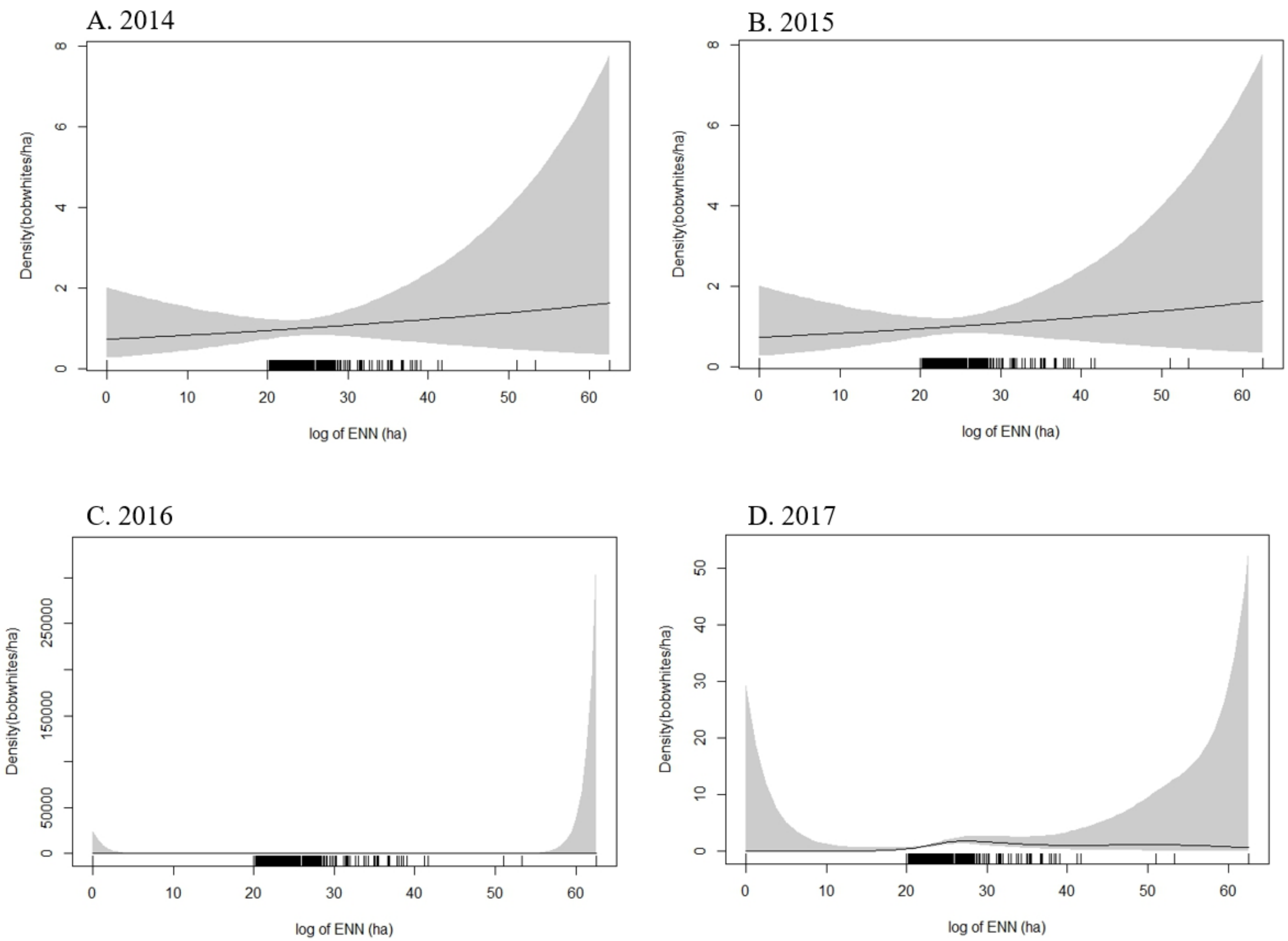

Figure 4.23. Relationship between northern bobwhite density (bobwhite/ha [$\hat{D}$]) on the pooled reference sites in Jim Hogg County, Texas, USA and the Euclidian nearest neighbor distance (ENN) between brush patches for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

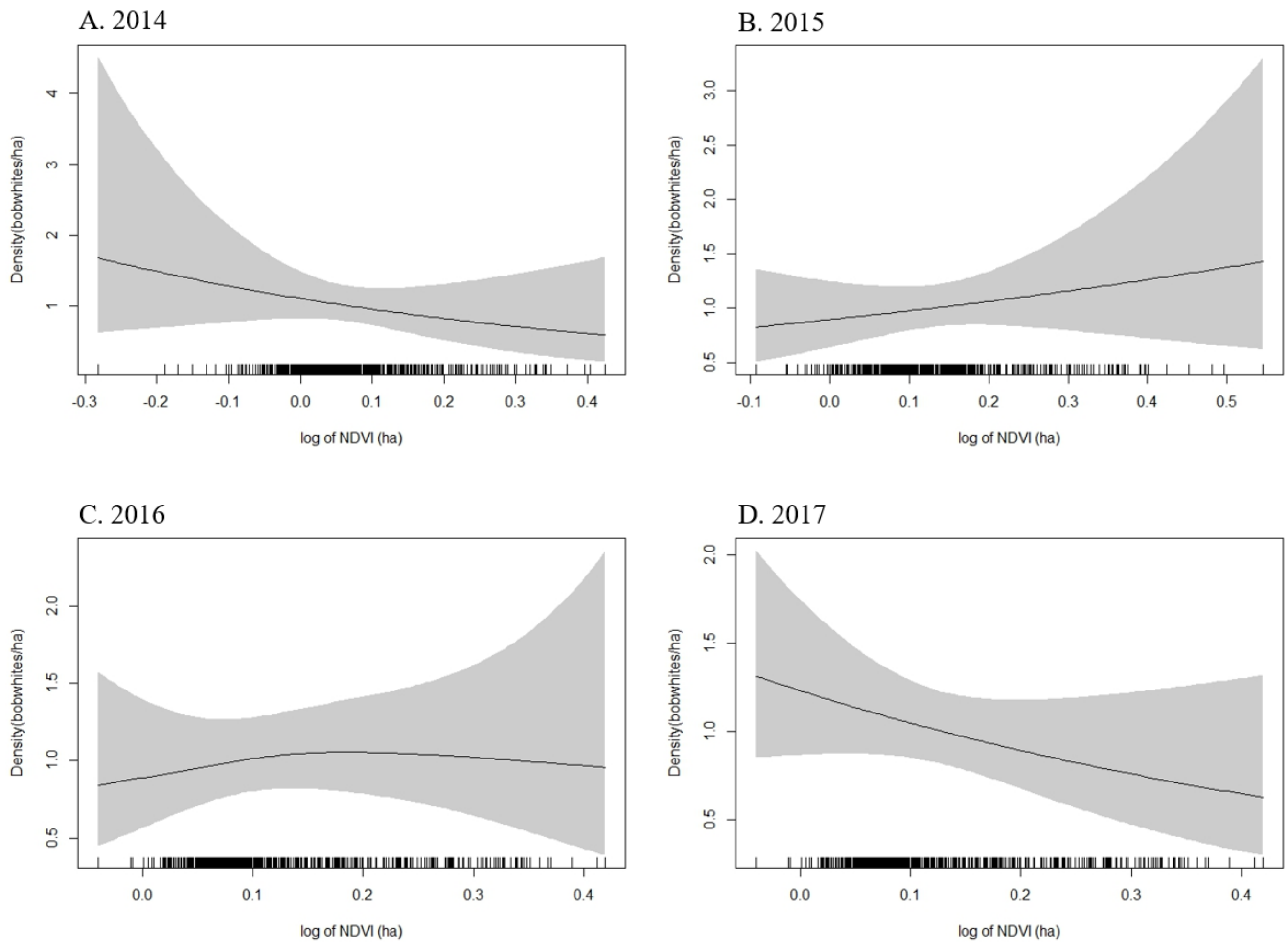

Figure 4.24. Relationship between northern bobwhite density (bobwhite/ha [$\hat{D}$]) on the pooled reference sites in Jim Hogg County, Texas, USA and the Normalized Difference Vegetation Index (NDVI) for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

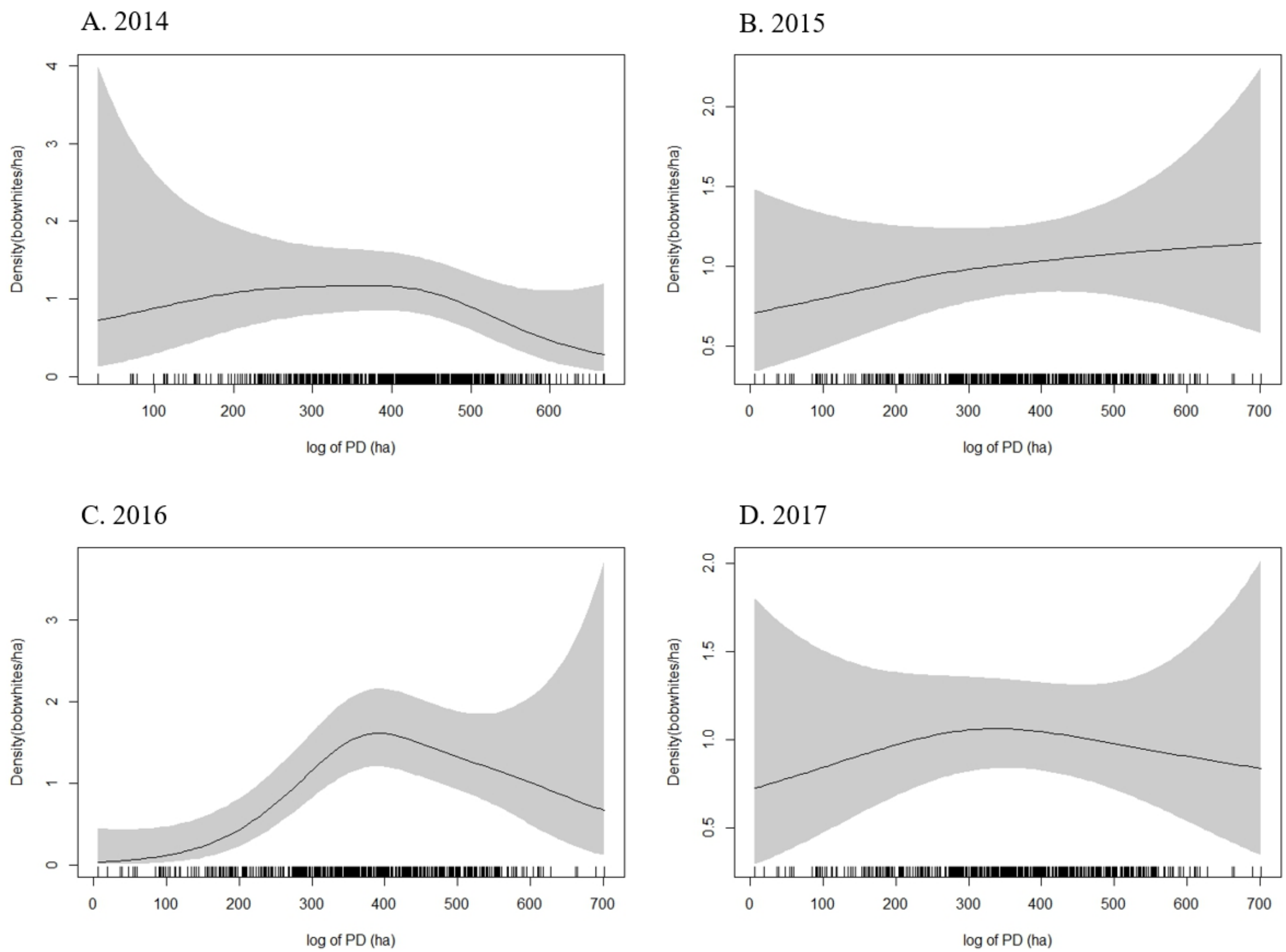

Figure 4.25. Relationship between northern bobwhite density (bobwhite/ha [D̂]) on the pooled reference sites in Jim Hogg County, Texas, USA and the patch density of brush (PD) for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

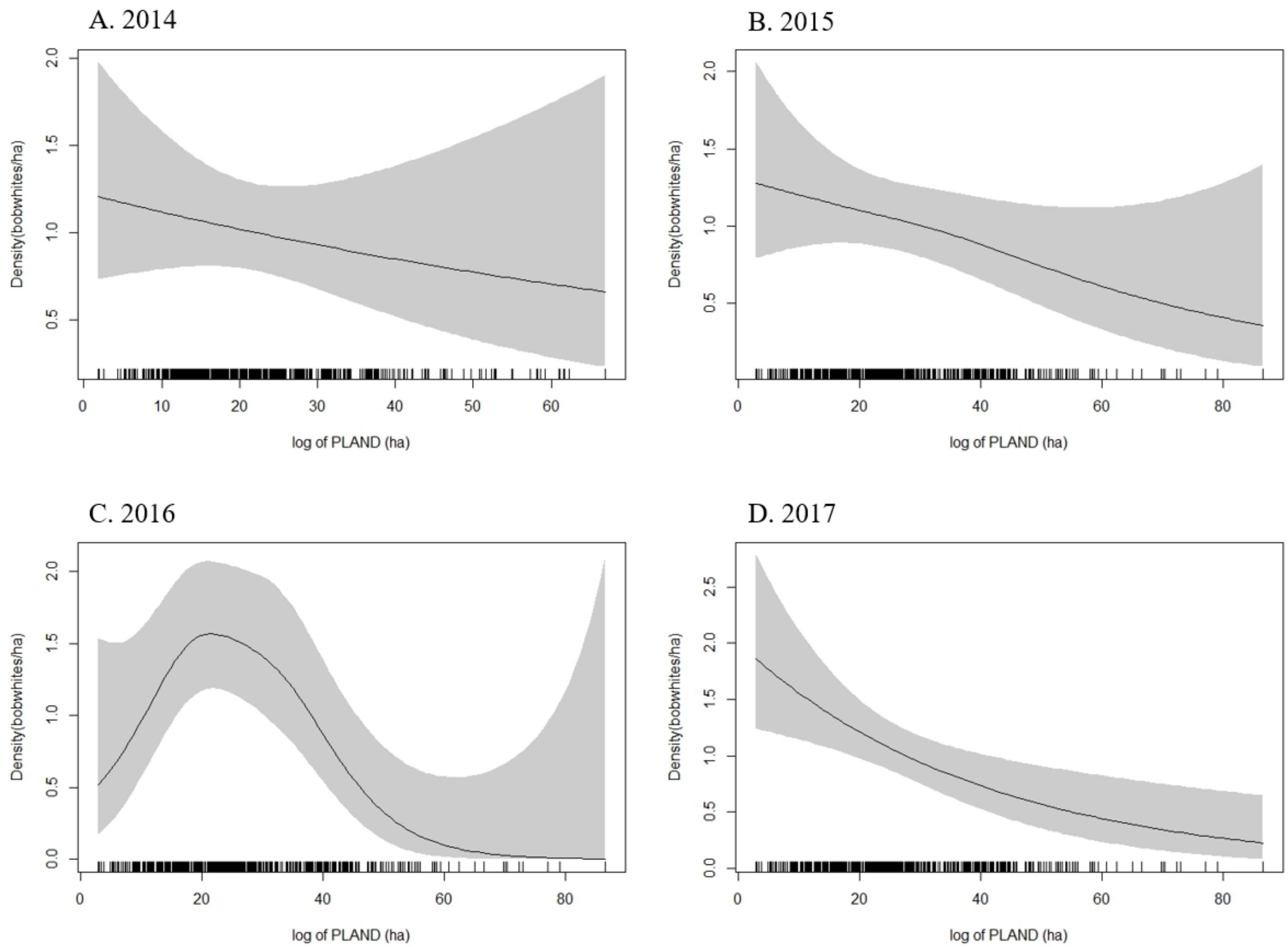

Figure 4.26. Relationship between northern bobwhite density (bobwhite/ha [$\hat{D}$]) on the pooled reference sites in Jim Hogg County, Texas, USA and the percentage of landscape (PLAND) of brush for each year of survey (A) 2014, (B) 2015, (C) 2016, and (D) 2017.

There was a similar quadratic relationship between density and aggregation index across years. Density increased to 45% and decreased thereafter, the relationship was more linear in 2015 steadily decreasing from 30 to 80% (Fig. 4.21). There was a negative linear relationship between bobwhite density and edge density in the 2014 and 2015. In 2016 and 2017, there was a quadratic relationship where density increased to 400 m and then decreased (Fig. 4.22). The relationship between the mean nearest neighbor distance to similar patches could not be determined due to the same distribution issues described above (Fig. 4.23). There was a negative linear relationship between bobwhite density and NDVI in 2014 and 2017 corresponding higher densities to NDVI values between 0.0 and 0.1 (Fig. 4.24A; D). In 2015 and 2016, there was a positive relationship between density and NDVI (Fig. 4.24B; C). Bobwhite density in 2015 increased linearly with NDVI while density in 2016 increased to 0.15 and steadily decreased. The relationship between bobwhite density and patch density was quadratic and peaked between 300 and 400 patches/100 ha in 2014, 2016, and 2017 (Fig. 4.25A; C; D). Density steadily increased as patch density increased in 2015 (Fig. 3.21B). Bobwhite density decreased with an increase in percent brush cover in 2014, 2015, and 2017 (Fig. 4.26A; B; D). In 2016, bobwhite density was highest between 20 and 30% brush cover and decreased sharply after (Fig. 4.26C).

There was a wider range in average woody cover on the 3 reference sites (13.11–37.56%) compared to the Coloraditas Grazing Research and Demonstration Area treatments (18.54–32.32%). As a result, relationships between bobwhite density and woody cover were slightly more quadratic on the reference sites compared to the Coloraditas Grazing Research and Demonstration Area. Density on the reference sites peaked at moderate (50%) brush aggregation and moderate (400 patches/100 ha) patch density in each year of the survey. In 2014, 2015 and 2017, density was highest where brush cover was lowest, however, in 2016, density peaked with

25% brush cover. The relationship between edge density and bobwhite density was negative in 2014 and 2015 but peaked with 400 meters per ha in 2016 and 2017.

Values of NDVI reflected greenness and density of herbaceous and woody vegetation across the landscape. On average bobwhite density decreased as NDVI value increased on the Coloraditas Grazing Research and Demonstration Area and reference sites indicating preference for bare ground or use of bare ground due to increased availability. In years where precipitation was higher density on average increased with increasing NDVI peaking around 0.2 to 0.3 which may be related to availability.

DISCUSSION

Evaluating Density Estimation and Model Performance

Hypothesis 1. —The data supported my hypothesis that the precision of estimates from density surface models would be higher than estimates from conventional distance sampling, and also that density estimates would be similar. The resulting density estimates derived from density surface modeling provide an adequate method for estimating density at lower levels with good precision. Estimates derived from density surface models are expected to improve upon conventional distance sampling methods because the model accounts for spatial heterogeneity over strata (Burt and Paxton 2006). The similarity between estimates derived from both methods has been confirmed in several studies on marine mammals (Gómez de Segure et al. 2007, Best et al. 2015). Additionally, Best et al. (2015) documented that density surface model estimates provided narrower confidence intervals than conventional distance sampling methods for 11 cetacean species of conservation concern.

Where surveys cannot be designed with uniform coverage or small stratum level density estimates are required, density surface models performed well in improving upon the precision of sub level density estimates in this study. Using density surface models to estimate density may provide relief in design constraints situations where bobwhite surveys are below 100% coverage. For terrestrial species, estimates from simulated surveys analyzed using conventional distance sampling were negatively biased and less precise than estimates using density surface models when survey effort was below optimum (La Morgia et al. 2015). Conducting field surveys at large scales for terrestrial species is cost prohibitive for many researchers and density surface models allow for the reduction in survey effort as well as inference within portions of the study area not surveyed (La Morgia et al. 2015).

Because density surface modeling methods are model-based, the reliability of these estimates is dependent upon correctly fitting the detection function model in the first stage as well as the proper selection of environmental covariates (Hedley and Buckland 2004). I modeled the detection functions used in the density surface models in this study with conventional distance sampling, with density as a function of distance alone. These models can be improved upon in future analyses by fitting density surface models with detection functions modeled with covariates affecting detectability.

Despite the identification of relationships between chosen covariates and bobwhite density, few of the covariates selected for the top model were significant and furthermore, did not adequately explain the spatial variations in density. Lack of significance is likely related to slack or flexibility in configurations of vegetation metrics that can provide bobwhites with their cover requirements (Guthrey 1999). Furthermore, the woody cover may not have explained the heterogeneity in the model because the woody cover had less of an effect on bobwhite distribution during the time of our surveys in December. The bobwhite relationship to woody cover is primarily determined by the thermal intensity across the landscape from open to shaded areas (Guthery et al. 2005). The average temperature in December from 2014 to 2017 was 20 C, which may not have been high enough to elicit a strong response to woody cover.

Future analyses may benefit from the inclusion of covariates that extend beyond woody cover metrics. Because the herbaceous vegetation in this study was directly impacted by grazing and precipitation, using more covariates, such as NDVI, related to ground cover and structure may have provided a better explanatory model. On the Coloraditas Grazing Research and Demonstration Area, NDVI was selected in the top model 3 out of the 4 years; however, other vegetation indices such as the Optimized Soil Adjusted Vegetation Index (OSAVI), may be more accurate in predicting the current state of vegetation health than NDVI. OSAVI is less susceptible to high reflectance values by dry sandy soils and was found to better predict changes in bare ground, herbaceous, and woody cover than NDVI when compared to ground truth data on the Coloraditas Grazing Research and Demonstration Area (Fern et al. 2018).

The deviations explained for all Coloraditas Grazing Research and Demonstration Area and reference site models were low compared to density surface models created for species with larger home ranges. Cetaceans are sensitive to changes in covariates relating to water depth, temperature, and distance from the shoreline. These relationships tend to be less complicated whereby there is a clear preference for depth and temperature. For example, in density surface models for 12 species of marine mammals, depth and distance to coastline were significant covariates in each model and explained 11–52% of the deviance in the models (Best et al. 2015). Distance to human settlements explained approximately 28–51% of the variation in ungulates (Schroeder et al. 2014) and elevation and distance to settlements explained 51–71% of the variation in ungulates (Harihar et al. 2014).

A more in-depth analysis of proper segment size and environmental covariates are needed. The segment size initially used corresponded to twice the truncation distance or 100 m. This segment size created a highly zero inflated model where determining covariate relationships and selecting covariates was difficult. Increasing the segment size to 400 m helped with model selection but may not adequately address the relationship between density and environmental covariates across large areas. Additionally, these models may have benefitted by using detection functions fitted with covariates affecting detectability as well as the inclusion of covariate interactions in the GAM. Spatial covariates related to precipitation and herbaceous vegetation productivity may reduce some of the unmodeled heterogeneity in density surface model. I did not use precipitation in these models because it is currently not available at the scale at which I can predict changes in bobwhite density (i.e., PRISM 400-km2).

Relationship of Density to Grazing and Environmental Covariates

Hypothesis 2. —The data did not support my hypothesis that after grazing implementation, bobwhite density would increase with increasing woody cover on the Coloraditas Grazing Research and Demonstration Area. Additionally, bobwhite density was not consistently higher in areas with high brush cover on the reference sites throughout all 4 years of the study. I expected this to occur with the reduction of herbaceous cover. In 2015 (before grazing), on the Coloraditas Grazing Research and Demonstration Area, the data supported the alternative hypothesis that bobwhite density would be highest where there were low values of NDVI associated with the bare ground and when precipitation was not limiting. In 2016 and 2017 (after grazing), bobwhite density on the Coloraditas Grazing Research and Demonstration Area were highest where the woody cover was <10%. Precipitation, rather than grazing likely influenced these results.

In 2016, breeding season precipitation (31 cm) was the highest recorded over the 4 years, and bobwhites density averaged 2.0 bobwhites/ha across the Coloraditas Grazing Research and Demonstration Area. Without a measure of productivity and survival, I cannot attribute the increase in density to an increase in habitat quality in 2016 (Van Horne 1983); however, bobwhites were distributed across the Coloraditas Grazing Research and Demonstration Area potentially indicating saturation of usable space at the time of survey (Guthrey 1997). The effects of grazing on bobwhite distribution were likely masked by precipitation on the Coloraditas Grazing Research and Demonstration Area.

In 2017, bobwhites did not seem to seek refuge in areas of higher woody cover, despite a decrease in cumulative annual (45 cm) and breeding season precipitation (20 cm), an increase in bare ground, and a decrease in herbaceous cover during fall vegetation surveys (Chapter III). This result is contrary to what is expected where herbaceous cover is limiting (Hernández and Guthery 2012) and within range of brush cover that bobwhites were predicted to avoid (<20%; Kopp et al. 1998). However, bobwhite density increased linearly with patch density, decreased linearly with increasing aggregation and edge density indicating bobwhites were using dense patches of disaggregated brush. These results agree with landscape level analyses of bobwhites and woody cover across the Rio Grande Plains (Parent et al. 2016). Parent et al. (2016) reported areas with high bobwhite counts, even during drought, had woody cover that made up 11% of the landscape existing in a patchy and moderately interspersed configuration. I might have seen more of a selection for woody cover attributes if I analyzed habitat relationships at lower levels (treatments or pastures). Alternatively, the configuration of brush patches where percent woody cover was highest on the Coloraditas Grazing Research and Demonstration Area may not have provided the heterogeneity in structure preferred for different requirements (foraging, roosting, loafing).

The data did not support my hypothesis that bobwhites would select for greater woody cover on the reference sites throughout the study due to lack of grazing deferment. Bobwhites only showed a preference for woody cover higher than 10% in 2016, when density was highest on all 3 pastures. Parent et al. (2016) concluded that bobwhite density on landscapes with adequate woody cover fluctuated independently with precipitation at a landscape scale. The response of bobwhite density to brush configuration was more consistent on the reference sites compared to the Coloraditas Grazing Research and Demonstration Area across all four years of the study. Additionally, densities on the reference sites were reasonably consistent all four years of the study regardless of drought or increased precipitation. Density may have been less susceptible to fluctuations in precipitation because the variation in brush configuration was higher across the 3 reference site pastures allowing bobwhites greater selection in drought buffering coverts.

Hypothesis 3. —On the Coloraditas Grazing Research and Demonstration Area, the data supported my hypothesis that bobwhite density would be uniformly distributed in years of above average precipitation in 2016, but there was a gradient in distribution of density in 2015. On the reference sites, Density was more uniformly distributed in 2015 and in 2016 on the Atole and Pinto pastures, but a gradient was present on the Agua Dulce pasture. The spatial distribution of bobwhites during years with low and high cumulative precipitation on the Coloraditas Grazing Research and Demonstration Area could be related to the North to South gradient in soil type and texture across the pasture.

Out of the 4 years, the grazing treatments were in near normal conditions in 2015 (1.69 Palmer Drought Severity Index), and 2016 (-0.59 Palmers Drought Severity Index) and cumulative annual precipitation were the highest in 2015 (68.03 cm) and 2016 (61.06 cm;

PRISM 2018; see Chapter III). The southern pastures on the Coloraditas Grazing Research and Demonstration Area are dominated by Sandy and Sand Hills ecological sites associated with deep, well to moderately drained sandy soils (Soil Survey Staff 2018). The northern pastures are dominated by red loams and loamy sand ecological sites (Soil Survey Staff 2018). The inverse texture hypothesis states that when precipitation is <37 cm/year, sandy soils with low water holding capacity would be more productive than loamy soils (Sala et al. 1988), and vice versa when precipitation is >37cm/year. With an increase in cumulative annual precipitation and herbaceous forage standing crop from 2014–2015, bobwhite concentrations shifted from the southern Sandy pastures to the northern loamy pastures on the Coloraditas Grazing Research and Demonstration Area where brush cover and brush patch density are higher and moderately aggregated. A shift in density to the northern pastures may represent a shift to the vegetation structure and composition provided by the shallow soils under above average precipitation conditions in the north compared to the deep sandy soils in the south. Preferences for woody cover, patchiness, and edge increased up to a threshold in 2015 indicating the use of more diverse cover types across the landscape when precipitation was not limiting.

Similarly, high bobwhite density in 2014 and 2017 in areas of low woody cover the southern portion of the pasture may reflect an interaction between precipitation and soil type. Out of the 4 years, the grazing treatments were in mild drought conditions in 2014 (-1.75 Palmer Drought Severity Index), and 2017 (-1.15 Palmers Drought Severity Index) and cumulative annual precipitation were the lowest in 2014 (55 cm) and 2017 (45 cm; PRISM 2018; see Chapter III). While precipitation was not <37 cm, the forage quantity and quality on loamy sands in 2014 and 2017 may have been recovering at a slower rate from intense grazing and drought than forage in the deeper sands. While brush cover was higher in the north, some aspect of usable space in the herbaceous component of the of the pastures was likely missing.

Bobwhite distribution on the reference sites did not follow a pattern according to any discernable soil features within years, but distribution was more uniform across pastures in years of high precipitation (2015 and 2016) compared to low precipitation (2014 and 2017). On the Atole and Agua Dulce pasture, some of the higher concentrations of density were associated with areas where deep sandy soils occurred (Dune, Sandy, and Sand Hills ecological sites; Soil Survey Staff 2018) in years of low precipitation. Sandy soils are typically associated as being beneficial to bobwhites due to increased foraging opportunities and increased presence of bunchgrasses (Rice et al. 1993).

The results from covariate relationships to density across a large scale demonstrate how density surface models may be used in future research and management projects. Quantifying habitat relationships with density surface models is more cost and time effective than radio marking birds to determine selection and avoidance curves. While a great amount of potential exists for the use of density surface models in impact management, exploration of the best segment size and covariate selection need more attention. Care should be taken to select covariates that explain the variation of density across the landscape so more meaningful habitat relationships can be constructed and interpreted. Future research should focus on improving the model selection process as it relates to northern bobwhites and then modeling covariates that directly relate to impacts or management goals.

MANAGEMENT IMPLICATIONS

This is the first study to apply density surface models to explain the distribution and density response of upland game birds to management actions. Distance sampling data is often already being collected for bobwhites on many ranches in South Texas. Density surface modeling provides an opportunity to obtain density estimates at large scales with the inclusion of a detection probability while mapping the spatial distribution of bobwhites and relating that distribution to differences in vegetation structure and composition across a landscape. Density surface models also provide a cost-effective alternative to obtaining density estimates in substrata (i.e., smaller pastures or delineated vegetation communities) without increasing sampling effort.

Mapping the spatial distribution of bobwhites on grazed areas presents an interesting method to evaluate the co-management of cattle and bobwhites. While the models I created did not provide specific responses to herbaceous cover, I was able to evaluate and determine where bobwhites were concentrated and relate concentrations to range types, vegetation configurations, and herbaceous forage standing crop outside of the models. Information of bobwhite distribution will help the East Foundation plan future grazing specifics (i.e., increase grazing pressure where bobwhite density is low and herbaceous cover is high). Incorporating metrics related to herbaceous cover, percent sand in soil, and distance to water may further the amount and usefulness of information gained from relating bobwhite density to grazing management. Furthermore, incorporating the spatial distribution of cattle into density surface models may provide information on the overlap in space and resource use of both species on the landscape.

In operations where bobwhites provide income from hunting leases, density surface models can help inform managers on what types of vegetation cover are most important to manage for and provide a specific location for management focus on their property. Modeling the spatial distribution will help managers plan where to focus or suspend hunting pressure to better manage potential additive effects of harvest. Brush management for both cattle and bobwhites is common in South Texas. The spatial distribution of both bobwhites and cattle can be mapped using density surface models and evaluated to determine if reconfiguring or removing large brush patches would be beneficial. Distance to feeders or energy exploration activity may also help managers evaluate the impacts of management activity on bobwhites across their property. Knowledge of the distribution and concentration of bobwhite density is particularly important for operations that are focused on producing and maintaining high densities of bobwhites for private recreation.

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APPENDICES

APPENDIX A

Reference Site Selection

I chose reference sites based on the visual similarity of characteristics to the treatment area (size, location, soils, vegetation cover type, and woody cover; Morrison et al. 2008: 241). I conducted a retrospective analysis to determine if the pastures I selected out of the 47 potential pastures (>100 ha) were similar to the Coloraditas Grazing Research and Demonstration Area pastures in (1) percent composition of brush, herbaceous, bare ground, and (2) landscape metrics by class (brush, herbaceous vegetation, and bare ground). I used the following metrics from FRAGSTATS (Version 4.2; University of Massachusetts, Amherst, MA): Percentage of Landscape (PLAND), Patch Density (PD), Edge Density (ED), Largest Patch Index (LPI), Mean Patch Area (MPA), Mean Patch Shape (AREA_SHAPE), Cohesion (connectedness), and Interspersion and Juxtaposition (IJI). I completed a supervised image classification of the SAV ranch in ENVI version 5.2 (Exelis Visual Information Solutions, Boulder, CO). I downloaded 1-m resolution National Agriculture Imagery Program (NAIP) (natural color [NC] and color-infrared [CIR]) aerial imagery for each orthophoto quarter quadrant on SAV from the United States Department of Agriculture Farm Service Agency (USDA-FSA) from the Texas Natural Resources Information System (TNRIS) database. I imported a mosaicked image of SAV into ENVI and displayed it as a CIR image using the red, green, and Near-infrared (NIR) bands. Based on my knowledge of the area, I defined 3 land cover classes: woody, herbaceous (live and residual), and bare ground. I used the ROI tool to draw polygons to define the training regions for these land cover types (using multiple training sites per polygon). I identified 47 pastures on the ranch > 100 ha (i.e., excluding all water lots, fence depots, housing units, and cattle traps and including the 10 pastures on the Coloraditas Grazing Research and Demonstration Area) and split the supervised image by each pasture. I imported a GeoTIFF of the classified image into FRAGSTATS and used a 10-m square moving window analysis to obtain values for the 8-class metrics each by class (brush, herbaceous vegetation, and bare ground) for each pasture

Analyses Reference site selection. —I determined similarity in 4 separate analyses (1) percent cover (PLAND) of brush, herbaceous vegetation, and bare ground and (2) landscape metrics in the brush class, (3) herbaceous vegetation class, and (4) bare ground class. I used a K-means cluster analysis in R to group each pasture into the optimal number of clusters predicted by the silhouette method (Kaufman and Rousseeuw 1990). Plot centroids were graphed using the 1st and 2nd discriminant functions. Clusters were generated using the 1st and 2nd principle components. I verified the variability among and within clusters by comparing the dispersion of the Euclidean distance between all plots for each cluster. I used $P > 0.05$ to indicate no difference in dispersion among groups in either set of clusters. I displayed pastures according to cluster assignment for each analysis in ArcMap. Pastures displayed in similar colors are alike.

Reference Site Similarity to Treatment Sites

The variability among pastures within grazing treatments in the Coloraditas Grazing Research and Demonstration Area was intentionally designed so that each treatment represented a range of conditions (i.e., the dominant range site differed between 1 or more pastures within a treatment). I considered a reference site acceptable if it fell within the same cluster as at least 1 of the Coloraditas Grazing Research and Demonstration Area pastures. The percentage of the landscape (PLAND) comprised of brush, herbaceous vegetation, and bare ground was best described by 3 clusters (Fig. 3.5). Percent composition on the 4 western and 1 central pastures in the Coloraditas Grazing Research and Demonstration Area is similar to the selected reference sites, but the eastern pastures in the Coloraditas Grazing Research and Demonstration Area fell into a separate cluster, which did not include any of the selected reference sites. Metrics for brush configuration were best described by 2 clusters (Fig. 3.6). The 5 southern and 1 northern pasture on the

Coloraditas Grazing Research and Demonstration Area were similar to brush configuration to the selected reference sites. The 4 northern pastures were divided into a separate cluster, which did not include any of the selected reference sites. Metrics for herbaceous vegetation configuration were best described by 3 clusters (Fig. 3.7). The pastures on the Coloraditas Grazing Research and Demonstration Area were grouped into the same cluster patterns as the percent composition similarities (Fig. 3.5). The eastern pastures and the Agua Dulce reference site pasture were grouped into the same cluster while the western pastures and the Atole reference pasture were grouped into another cluster. The Pinto pasture was separated into its own single pasture cluster. Two clusters best-described metrics for bare ground configuration (Fig. 3.8). Bare ground configuration was similar throughout the ranch except for 3 pastures in the western part of the Coloraditas Grazing Research and Demonstration Area, which were separated into a different cluster.

The selected reference sites did not adequately represent the range of conditions in percent composition of bare ground, herbaceous, and woody cover on the eastern half of the Coloraditas Grazing Research and Demonstration Area or brush composition and configuration on the northern half of the Coloraditas Grazing Research and Demonstration Area. Future measurements may benefit from including reference sites closer in distance where landscape metrics encompass the range of conditions on the Coloraditas Grazing Research and Demonstration Area.

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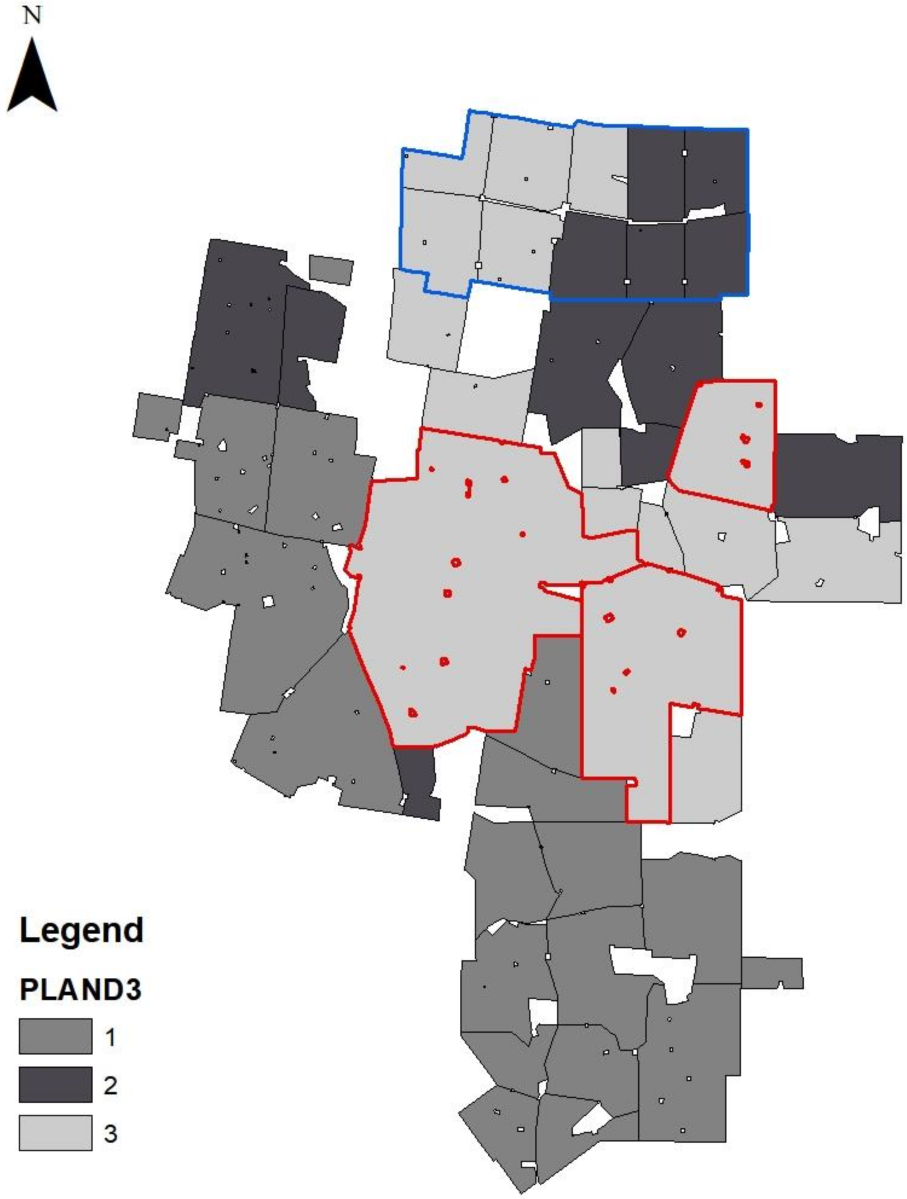

Figure 3.5. A K-means cluster analysis on the similarity between the percentage of landscape (PLAND) or brush, herbaceous vegetation, and bare ground within 47 pastures on the San Antonio Viejo Ranch, Jim Hogg County, Texas, USA. Pastures with the same color are similar. The Coloraditas Grazing Research and Demonstration Area are shown in blue and the selected reference site pastures are shown in red.

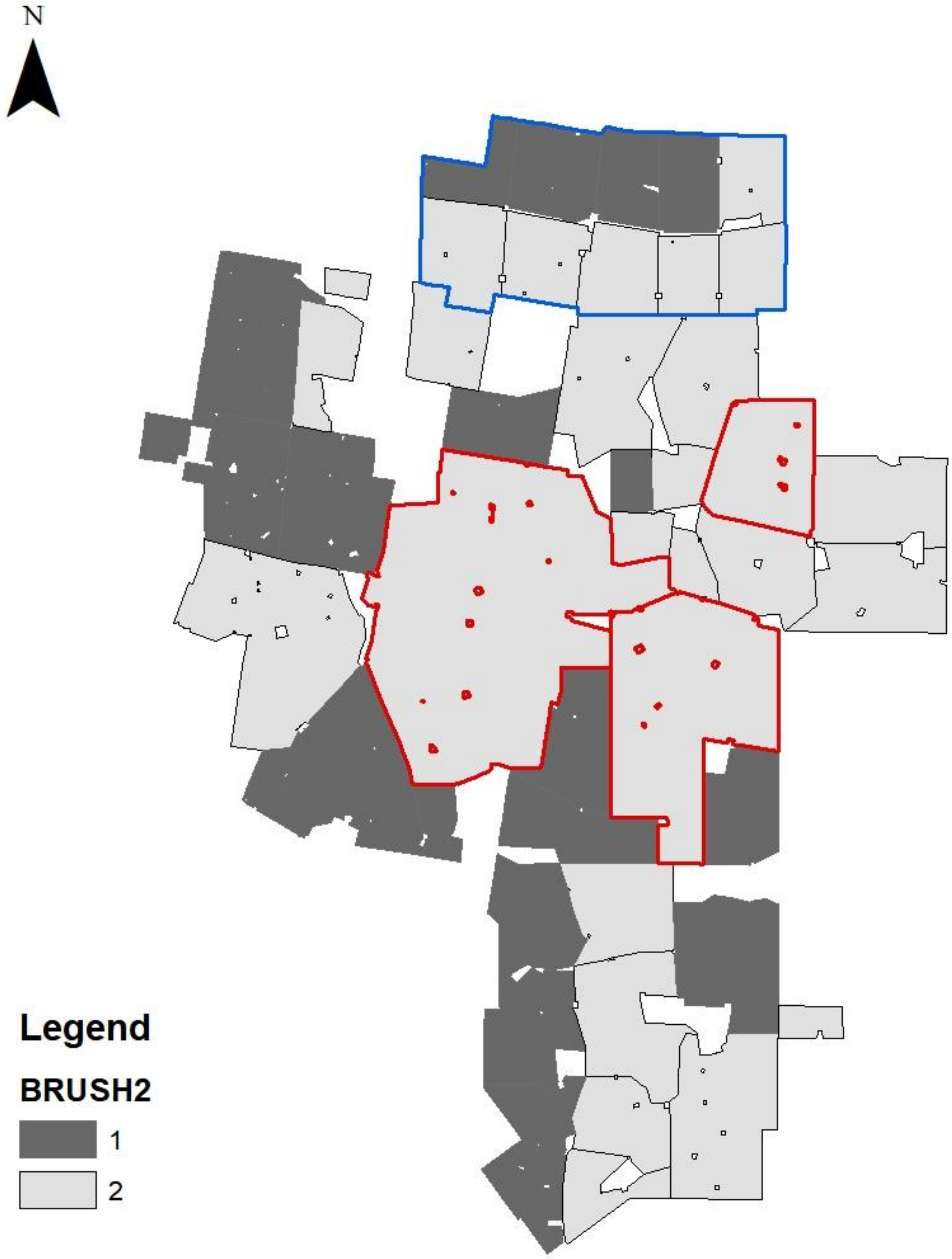

Figure 3.6. A K-means cluster analysis on the similarity between the composition and configuration of brush within 47 pastures on the San Antonio Viejo Ranch, Jim Hogg County, Texas, USA. Pastures with the same color are similar. The Coloraditas Grazing Research and Demonstration Area are shown in blue and the selected reference site pastures are shown in red.

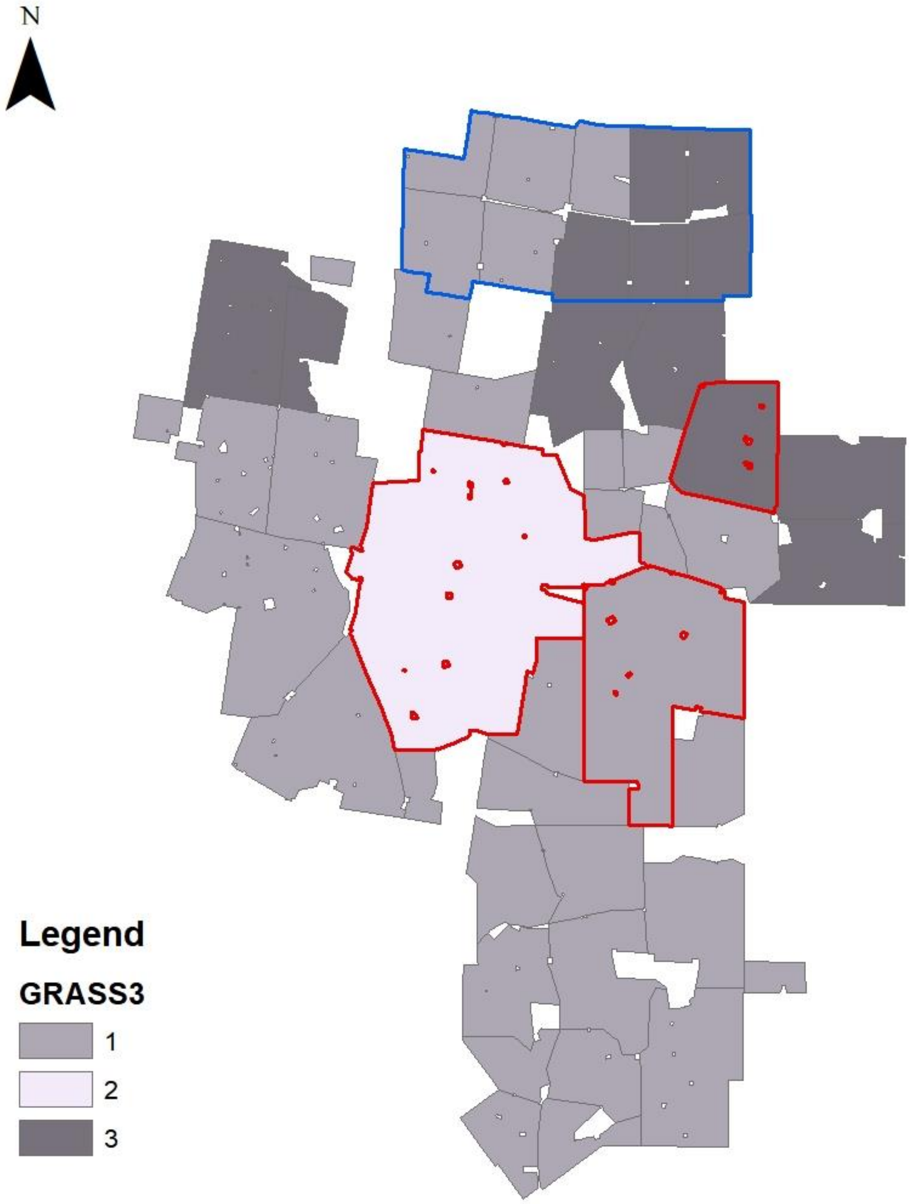

Figure 3.7. A K-means cluster analysis on the similarity between composition and configuration of herbaceous vegetation within 47 pastures on the San Antonio Viejo Ranch, Jim Hogg County, Texas, USA. Pastures with the same color are similar. The Coloraditas Grazing Research and Demonstration Area are shown in blue and the selected reference site pastures are shown in red.

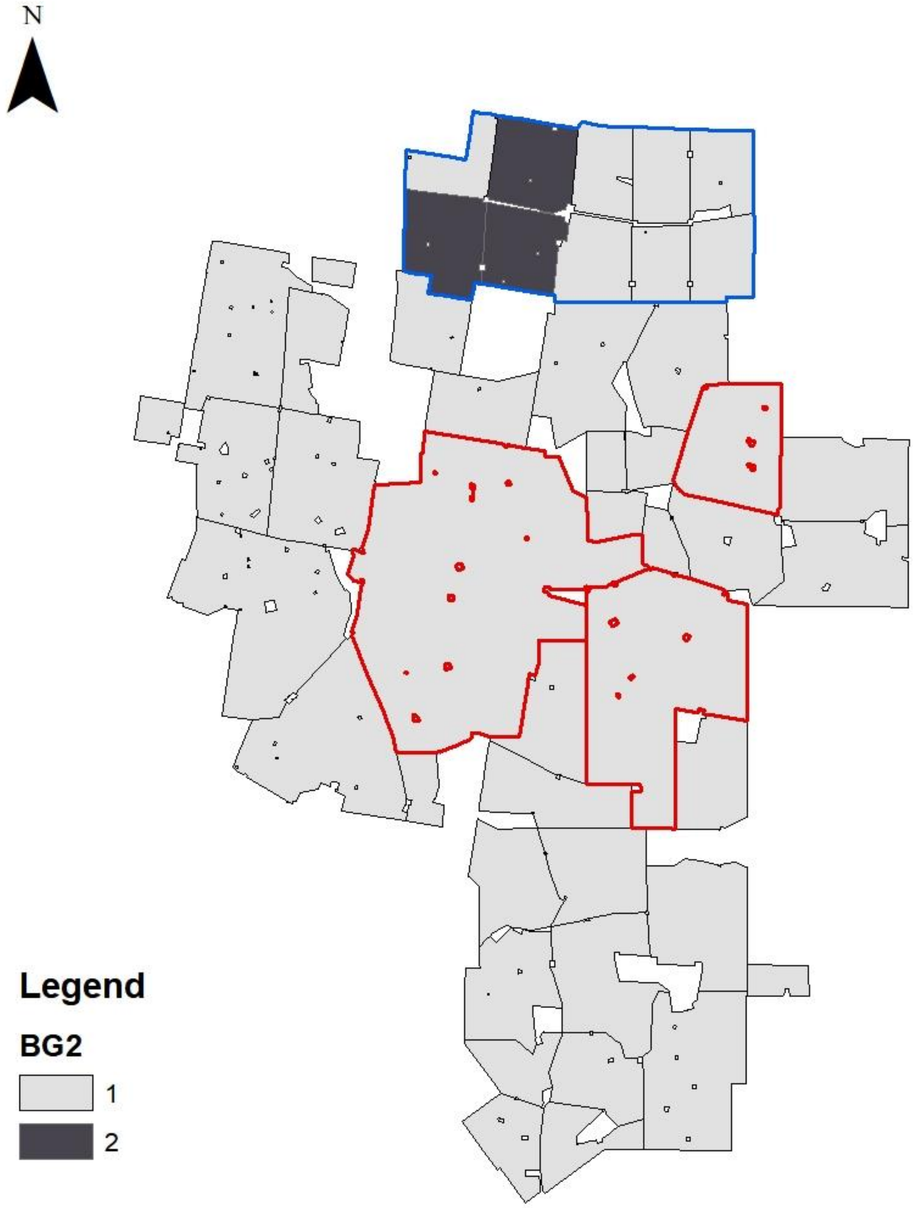

Figure 3.8. A K-means cluster analysis on the similarity between the composition and configuration of bare ground within 47 pastures on the San Antonio Viejo Ranch, Jim Hogg County, Texas, USA. Pastures with the same color are similar. The Coloraditas Grazing Research and Demonstration Area are shown in blue and the selected reference site pastures are shown in red.

APPENDIX B

Distribution of Vegetation Sampling Locations

Appendix B. Breakdown of the number of vegetation sampling units (enclosures and transects) across ecological sites and placed in each respective study pasture on the San Antonio Viejo Ranch, in Jim Hogg County, TX, USA. Samples were randomly stratified according to pasture size and ecological site within each treatment.

Treatment	Stocking density	Area (ha)		Pasture	Ecological Site	Grazing exclosure (*n*)		Transect (*n*)	
				Label		Range site (*n*)	Total (*n*)	Range site (*n*)	Total (*n*)
Continuous	Moderate	580	1	Rodeo	Loamy Sand PE 19-31	3		6	
					Red Sandy Loam PE 19-31	3		8	
					Total		10		14
Continuous	Moderate	821	2	Tia Nena	Loamy Sand PE 19-31	2		3	
					Sand Hills PE 31-44	1		2	
					Sandy PE 25-44	3		7	
					Total		10		12
Continuous	High	939	1	Calichera	Loamy Sand PE 19-31	4		6	
					Red Sandy Loam PE 19-31	5		1	
					Sandy PE 25-44	1		8	
					Ramadero	-		1	
					Total		10		16
Continuous	High	988	2	San Juan	Loamy Sand PE 19-31	4		12	
					Sand Hills PE 31-44	1		-	
					Sandy PE 25-44	1		3	
					Total		10		15
Rotational	Moderate	729	1	San Rafael	Loamy Sand PE 19-31	6		10	

Appendix B continued

Treatment	Stocking density	Area (ha)	Pasture		Ecological Site	Grazing exclosure (*n*)		Transect (*n*)	
				Label		Range site (*n*)	Total (*n*)	Range site (*n*)	Total (*n*)
					Red Sandy Loam PE 19-31	1		-	
					Sandy PE 25-44	4		5	
					Total		10		15
Rotational	Moderate	681	2	Coloraditas	Loamy Sand PE 19-31	4		6	
					Red Sandy Loam PE 19-31	6		9	
					Total		10		15
Rotational	Moderate	804	3	Desiderio	Sand Hills PE 31-44	1		2	
					Sandy PE 25-44	9		12	
					Total		10		14
Rotational	High	585	1	Guadalupe	Loamy Sand PE 19-31	1		2	
					Sand Hills PE 31-44	1		-	
					Sandy PE 25-44		8		12
					Total	10		14	
Rotational	High	689	2	Tequilero	Loamy Sand PE 19-31	3		5	
					Sand Hills PE 31-44	1		1	
					Sandy PE 25-44	7		9	
					Total		10		15
Rotational	High	690	3	Loma	Loamy Sand PE 19-31	3		4	
					Sandy PE 25-44	8		10	
					Total		10		14

Appendix B continued

Treatment	Stocking density	Area (ha)		Pasture	Ecological Site	Grazing exclosure (*n*)		Transect (*n*)	
				Label		Range site (*n*)	Total (*n*)	Range site (*n*)	Total (*n*)
Reference	Variable	1511	1	Atole	Loamy Sand PE 19-31	1		2	
					Sand Hills PE 31-44	6		6	
					Sandy PE 25-44	6		7	
					Total		10		15
Reference	Variable	1262	2	Pinto	Loamy Sand PE 19-31	3		4	
					Red Sandy Loam PE 19-31	2		2	
					Sandy PE 25-44	7		9	
					Shallow Sandy Loam	1		1	
					Total		10		15
Reference	Variable	1593	3	Agua Dulce	Loamy Sand PE 19-31	2		3	
					Red Sandy Loam PE 19-31	4		5	
					Sand Hills PE 31-44	2		2	
					Sandy PE 25-44	5		6	
					Total		10		15
Total		11872					130		189

APPENDIX C

Statistical Tables

Appendix C1. Results from model selection to survey data using conventional distance sampling with a pooled detection function, conventional distance sampling with a fully stratified detection function, and multiple-covariates distance sampling to estimate annual northern bobwhite density by treatment for the Coloraditas Grazing Research and Demonstration Area or December 2014–2017. Results for each model include covariate, key function + adjustment terms, number of parameters, Akaike's Information Criterion (AIC), and differences in AIC (ΔAIC), and goodness of fit tests (GOF): CvM = Cramer VonMises (cosine and uniform); K-S =Kolmorogov-Smirnov.

Analysis[a]	Covariate[b]	Key function[c]	# parameters	ΔAIC	AIC	CvM (cos)	CvM (unif)	K-S
MCDS	Year + Survey	HN	5	0.00	7607.31	0.70	0.80	0.48
MCDS	Year + Survey + Condition	HN	6	0.03	7607.35	0.70	0.80	0.50
MCDS	Year + Survey + Temperature	HN	6	1.63	7608.94	0.70	0.80	0.47
MCDS	Year + Survey + Hour	HZ	6	1.69	7609.00	0.70	0.80	0.47
MCDS	Year + Survey + Condition F	HZ	8	3.57	7610.89	0.70	0.80	0.46
MCDS	Year + PLAND	HN	5	4.04	7611.35	0.70	0.80	0.59
MCDS	Year + Experience	HN	5	4.58	7611.89	0.50	0.60	0.51
MCDS	Year	HN	4	5.85	7613.17	0.60	0.70	0.52
MCDS	Year + Wind	HN	5	6.41	7613.72	0.60	0.80	0.56
MCDS	Year + Temperature	HN	5	7.13	7614.44	0.60	0.70	0.60
MCDS	Year + Hour	HN	5	7.77	7615.09	0.70	0.80	0.57
MCDS	Year + Condition	HN	5	7.78	7615.10	0.60	0.70	0.56
MCDS	Year + Treatment	HN	7	8.65	7615.97	0.60	0.80	0.69
MCDS	Experience	HN	2	16.40	7623.72	0.15	0.15	0.24
CDS	Stratified f(0)	HN+cos	18	21.47	7628.78	-	-	-

Appendix C1 continued

Analysis[a]	Covariate[b]	Key function[c]	# parameters	ΔAIC	AIC	CvM (cos)	CvM (unif)	K-S p
MCDS	Stratum	HN	16	23.95	7631.26	0.70	0.80	0.75
CDS	Stratified f(0)	HN	16	24.35	7631.67	-	-	-
MCDS	Condition	HN	2	54.12	7661.43	0.40	0.50	0.42
MCDS	Condition F	HN	4	57.78	7665.10	0.40	0.50	0.42
MCDS	Year + Hour	HZ	6	63.91	7671.23	0.40	0.15	0.14
MCDS	Temperature F	HN	4	64.97	7672.29	0.30	0.40	0.27
MCDS	Experience F	HN	3	65.18	7672.49	0.30	0.40	0.33
MCDS	Year + Survey + Hour	HZ	7	65.19	7672.51	0.40	0.15	0.15
MCDS	Year + Temperature	HZ	6	65.35	7672.67	0.40	0.20	0.17
MCDS	Year + Survey + Temperature	HZ	7	66.70	7674.02	0.40	0.15	0.16
MCDS	Year + Wind	HZ	6	66.86	7674.17	0.40	0.20	0.16
MCDS	Year	HZ	5	67.16	7674.47	0.40	0.30	0.22
MCDS	Year + PLAND	HZ	6	67.38	7674.69	0.40	0.20	0.19
MCDS	Year + Experience F	HZ	7	68.00	7675.31	0.40	0.20	0.17
MCDS	Year + Treatment	HZ	8	68.00	7675.32	0.40	0.20	0.12
MCDS	Year + Condition	HZ	6	68.71	7676.02	0.40	0.20	0.20
MCDS	Year + Survey + Condition	HZ	7	69.56	7676.88	0.40	0.20	0.22
MCDS	Year + Survey	HZ	6	69.73	7677.05	0.40	0.20	0.23
MCDS	Hour	HN	2	71.35	7678.66	0.30	0.40	0.38
MCDS	Temperature	HN	2	72.05	7679.36	0.30	0.40	0.40
CDS	-	HN+cos	2	72.78	7680.09	0.90	1.00	0.80
CDS	-	Unif+cos	1	73.97	7681.28	0.50	0.70	0.43

Appendix C1 continued

Analysis[a]	Covariate[b]	Key function[c]	# parameters	ΔAIC	AIC	CvM (cos)	CvM (unif)	K-S p
MCDS	PLAND HN	HN	2	74.03	7681.34	0.30	0.40	0.37
CDS	-	HN	1	74.08	7681.39	0.30	0.40	0.27
CDS	-	HN+hp	3	74.54	7681.85	0.90	1.00	0.86
CDS	-	HZ+sp	3	75.35	7682.66	0.90	0.90	0.80
MCDS	Wind	HN	2	75.36	7682.67	0.30	0.40	0.29
MCDS	Survey	HN	2	75.36	7682.68	0.30	0.40	0.26
MCDS	Stratum	HZ	17	76.75	7684.06	0.30	0.15	0.10
MCDS	Treatment	HN	4	78.79	7686.10	0.30	0.40	0.29
CDS	-	HZ+sp	2	79.15	7686.46	0.70	0.60	0.64
MCDS	Condition F	HZ	5	79.44	7686.75	0.50	0.30	0.24
MCDS	Hour	HZ	3	81.65	7688.96	0.60	0.50	0.54
MCDS	Temperature	HZ	3	81.69	7689.00	0.60	0.50	0.51
MCDS	Wind	HZ	3	82.18	7689.49	0.50	0.50	0.57
MCDS	PLAND	HZ	3	83.06	7690.37	0.50	0.50	0.54
MCDS	Survey	HZ	3	83.29	7690.60	0.50	0.40	0.52
MCDS	Experience	HZ	3	83.62	7690.94	0.50	0.40	0.39
MCDS	Condition	HZ	3	83.71	7691.02	0.50	0.40	0.49
MCDS	Experience F	HZ	4	85.16	7692.47	0.50	0.50	0.62
MCDS	Treatment	HZ	5	86.08	7693.39	0.50	0.50	0.60

[a]Analysis: CDS = Conventional Distance Sampling; MCDS =Multiple Covariate Distance Sampling

[b]Covariate: PLAND = Percentage of Landscape (brush)

[c]Key functions: HN = Half-normal; HZ = Hazard-rate; Unif = uniform. Adjustment terms: cos = cosine, sp = simple polynomial

Appendix C2. Results from model selection to survey data using conventional distance sampling with a pooled detection function, conventional distance sampling with a fully stratified detection function, and multiple-covariates distance sampling to estimate annual northern bobwhite density by pasture on the reference sites for December 2014–2017. Results for each model include covariate, key function + adjustment terms, number of parameters, Akaike's Information Criterion (AIC), and differences in AIC (ΔAIC), and goodness of fit tests (GOF): CvM = Cramer VonMises (cosine and uniform); K-S =Kolmorogov-Smirnov.

Analysis[a]	Covariate[b]	Key function[c]	# parameters	ΔAIC	AIC	CvM (cos)	CvM (unif)	K-S
MCDS	Year + Wind	HN	5	0.00	3195.16	0.90	0.90	0.87
MCDS	Year + Wind + Hour	HN	6	1.38	3196.53	0.90	0.90	0.85
MCDS	Temperature	HN	6	1.73	3196.88	0.90	0.90	0.79
MCDS	Year + Wind + PLAND	HN	6	1.84	3197.00	1.00	1.00	0.93
MCDS	Year + Wind + Experience	HN	6	1.98	3197.14	0.90	0.90	0.85
MCDS	Year + Wind + Condition	HN	6	2.00	3197.15	0.90	0.90	0.89
MCDS	Year	HN	4	2.14	3197.30	1.00	1.00	0.87
MCDS	Year + Temp	HN	5	3.42	3198.58	1.00	1.00	0.84
MCDS	Year + Survey	HN	5	3.84	3199.00	1.00	1.00	0.95
MCDS	Year + Hour	HN	5	4.03	3199.19	1.00	1.00	0.86
MCDS	Experience	HN	2	4.07	3199.22	0.90	0.90	0.93
MCDS	Year + Experience	HN	5	4.12	3199.27	1.00	1.00	0.85
MCDS	Experience	HZ	3	4.38	3199.53	1.00	1.00	1.00
MCDS	Year	HZ	5	5.45	3200.60	0.90	0.90	0.96
MCDS	Stratum	HZ	13	14.10	3209.26	0.90	0.90	0.94
MCDS	Stratum	HN	12	15.00	3210.15	0.90	0.90	0.93

Appendix C2 continued

Analysis[a]	Covariate[b]	Key function[c]	# parameters	ΔAIC	AIC	CvM (cos)	CvM (unif)	K-S
CDS	Stratified $f(0)$	HN	12	15.10	3210.26			
MCDS	Survey	HN	2	19.53	3214.69	0.90	0.90	0.76
MCDS	Survey	HZ	3	22.99	3218.15	1.00	1.00	0.96
MCDS	Hour	HN	2	26.94	3222.09	1.00	1.00	0.89
MCDS	Hour	HZ	3	28.35	3223.51	0.90	0.80	0.75
MCDS	PLAND	HN	2	31.88	3227.03	1.00	1.00	1.00
CDS	-	Unif+cos	1	35.91	3231.06	1.00	1.00	0.99
MCDS	Temperature	HN	2	36.49	3231.64	1.00	1.00	0.85
MCDS	Temperature	HZ	3	36.85	3232.00	1.00	1.00	0.99
MCDS	Wind	HN	2	37.19	3232.35	1.00	1.00	0.88
CDS	-	HN	1	37.45	3232.60	0.90	1.00	0.87
CDS	-	HZ	2	38.02	3233.17	1.00	1.00	1.00
MCDS	Wind	HZ	3	38.40	3233.56	1.00	1.00	1.00
MCDS	Condition	HN	2	39.21	3234.37	0.90	0.90	0.72
MCDS	PLAND	HZ	3	39.48	3234.64	1.00	1.00	0.99
MCDS	Condition	HZ	3	39.99	3235.14	1.00	1.00	1.00
CDS	-	HN+cos	3	40.56	3235.71	1.00	1.00	1.00
MCDS	Pasture	HN	3	40.73	3235.89	1.00	1.00	0.96
MCDS	Pasture	HZ	4	41.75	3236.91	1.00	1.00	1.00

[a]Analysis: CDS = Conventional Distance Sampling; MCDS =Multiple Covariate Distance Sampling

[b]Covariate: PLAND = Percentage of Landscape (brush)

[c]Key functions: HN = Half-normal; HZ = Hazard-rate; Unif = uniform. Adjustment terms: cos = cosine, sp = simple polynomial

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