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Distance sampling survey effort to improve density estimates of northern bobwhite

Andrea Montalvo[1] | Leonard A. Brennan[2] | Michael L. Morrison[3] | Eric D. Grahmann[2] | Andrew N. Tri[4]

[1]East Foundation, Hebbronville, TX 78361, USA

[2]Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, Kingsville, TX 78363, USA

[3]Department of Rangeland, Wildlife and Fisheries Management, Texas A&M University, College Station, TX 77843, USA

[4]Forest Wildlife Population and Research Group, Minnesota Department of Natural Resources, Grand Rapids, MN 55744, USA

Correspondence

Andrea Montalvo, East Foundation, Hebbronville, TX 78361.
Email: amontalvo@eastfoundation.net

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Abstract

Distance sampling from aerial platforms can provide researchers with precise and efficient density estimates for wildlife populations, particularly over large areas. The intensity of the distance sampling survey depends on the survey effort. Effort can be referred to as coverage, where transect spacing is determined by the observer's sightability distance of the object or animal. Managers and researchers in Texas often use helicopters to survey and collect data for northern bobwhite (*Colinus virginianus*) density estimates. For bobwhites, 100% coverage represents transect spacing of 200 m, assuming observers can cover out to 100 m on either side of the transects. Often surveys are conducted at 50% coverage or 400 m spacing to reduce cost. Still, the implications of lowering survey effort on the precision of density estimates are unknown, particularly in coverage prescriptions. We flew 2,641 km of line transects each December from 2014 to 2017 and detected 2,333 bobwhite coveys across 7,648 ha of rangeland on the San Antonio Viejo Ranch in Jim Hogg County, TX, USA. We conducted line-transect distance sampling from a helicopter platform at 50 and 100% coverage and simulated results at coverage <50% using empirical data. Based on the results of simulated surveys at <100% coverage, surveying for bobwhites using helicopters with less than 50% coverage results in variable density estimates (wide 95% confidence intervals) and low precision (coefficient of variation >20%). Empirical surveys conducted at 50 and 100% coverage show little variation in density estimates between the 2 levels of coverage. However, when broken into substrata (areas less than ~1,000 ha), conducting surveys at 50% coverage resulted in <60 detections, which led to low precision in density estimates (coefficient of variation >20%). Our results 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 evaluated in other arid and semi-arid rangeland systems.

KEYWORDS

bobwhites, *Colinus virginianus*, distance sampling, effort, helicopter survey, line transects, survey coverage

An underlying assumption nested in the design of a distance sampling survey is that there is sufficient survey effort to detect the minimum required number of objects. For example, the minimum for distance sampling with line transects translates to achieving 60–80 detections (Buckland et al. 2001) on 10–20 lines (Buckland et al. 2001). To determine the appropriate amount of survey effort, Buckland et al. (2001, 2015) recommended conducting a pilot survey and using the data to calculate total line length based on a target coefficient of variation (CV) on the density estimate (e.g., CV < 20% for bobwhites; Guthery 1988). However, a higher amount of survey effort translates to higher survey costs causing managers to choose fewer transects at wider spacings to survey their property or management area.

During the past 15 years, helicopters have become widely used as a platform to survey wildlife populations and collect distance sampling data for estimating population densities. For example, helicopters combined with line-transect distance sampling have been extensively used in Texas to estimate northern bobwhite (*Colinus virginianus*) abundance (Shupe et al. 1987, Rusk et al. 2007, Schnupp et al. 2013, Bruno 2018, Edwards 2019). The amount of effort expended on a survey is typically referred to as survey coverage. The concept of survey coverage is based on the assumed visibility of observers on either side of the helicopter to detect objects of interest out to a specified distance, for example, 100 m for bobwhite surveys. 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, 400 m transect spacing translates to 50% coverage when assuming the observers can effectively make detections out to 100 m on either side of the helicopter. Surveys designed at higher coverage (100%) cover more area (200 m spacing) and thus cost more money and time to conduct; however, increasing strip width (decreasing survey coverage) may result in a loss of reliability and precision.

Increasing strip width 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. Increasing the number of transects rather than doubling effort results in increased spatial coverage, improved estimates of encounter rate variance, and better confirmation of the assumption of uniform animal distribution concerning the line placement. Additionally, for animals 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 also be necessary to reach the minimum number of detections (60–80) during years when populations are low, in areas with poor visibility, and on small properties.

We used data collected during the initial phase of a long-term study on cattle grazing and monitoring of bobwhite populations to assess the following objectives: (1) evaluating the precision (CV and 95% confidence intervals (CI)) of bobwhite density estimates using 2 methods (a) by randomly simulating survey coverage between 90% and 10% and (b) manipulating estimates from surveys at 100% to 50 and 25% coverage; (2) 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; and (3) how survey coverage affected the precision on stratum-specific density estimates on smaller areas within the large survey (i.e., individual treatments from the long-term grazing study).

For the first objective, we hypothesized that density estimates below the simulated 50% coverage would be less precise due to a lack of sufficient detections, but density and precision estimates would be similar between 100% and 50% of simulated surveys pooled over substrata (2014 and 2015). Furthermore, we hypothesized that density and precision would be similar between 100% and 50% of flown surveys pooled over substrata (2016 and 2017). For the second objective, we hypothesized there would be no significant difference in detection and density between replicated surveys within a year. For the third objective, we hypothesized the CV would be >20% for surveys at 50% coverage on individual stratum where <60 detections were made. Our research provided the basis for density estimates used in monitoring changes by treatment and year for developing a long-term grazing demonstration project (Bruno 2018).

STUDY AREA

We conducted our study on the East Foundation, San Antonio Viejo Ranch (SAVR; 60,298 ha) in Jim Hogg County, Texas, on a 7,689 ha pasture called the Coloraditas Grazing Research and Demonstration Area (hereafter grazing complex; Figure 1). The grazing complex was divided into 4 grazing treatments for a large-scale grazing study; for this paper, we will refer to the treatments as substrata 1–4 (Figure 1). The SAVR was located within the South Texas Plains Ecoregion (Gould et al. 1960). The 30-year average annual precipitation on the property was 53.6 cm (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu). Based on the 30-year average, temperatures are between 12 and 13°C in January and 27–30°C in July. Elevation ranges from 52 m on the eastern edge to 64 m on the property's western edge. The grazing complex was located within the Coastal Sand Plain and Texas-Tamaulipan Thorn Scrub ecoregions (Omernik 1987). There were 6 different ecological sites on the grazing complex, of which 3 (Sandy PE 25–44, Loamy Sand PE 19–31, Red Sand Loam PE 19–31; Natural Resources Conservation Service and United States Department of Agriculture 2021) comprised 95% of the area. Woody plant communities on the study areas were dominated by honey mesquite (*Prosopis glandulosa*), huisache (*Acacia farnesiana*), brasil (*Condalia hookeri*), granjeno (*Celtis ehrenbergiana*), 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*) dominated the herbaceous plant community.

METHODS

Transect design

Distance sampling assumes that animals are distributed uniformly with respect to the transect placement. Using the fishnet tool in ArcMap 10.4.1 (Environmental Systems Research Institute [ESRI], Redlands, CA, USA), we placed a systematic set of parallel lines randomly (i.e., randomly across vegetation gradients and roads) spaced 200 m apart and oriented East-West (Figure 1) across the study site (n = 33 transects). Prior to flight, we uploaded transects onto a Garmin Nuvi 52 LM (Garmin Corp, Lenexa, KS, USA) using Mapwel 11.0 (BALARAD, s.r.o.; Presov, Slovak Republic) to ensure accuracy of coverage by the helicopter pilot.

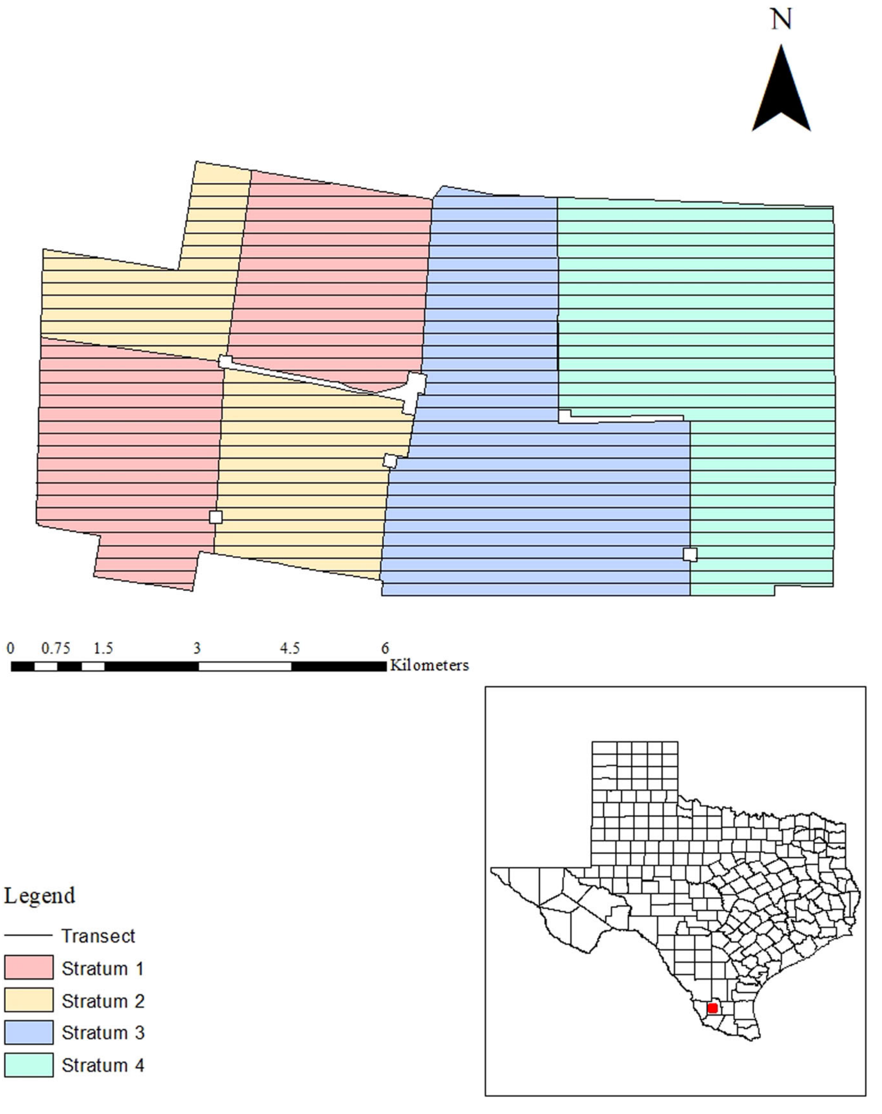

FIGURE 1 Map of the grazing complex by substratum (1–4) with area (ha) and line transects spaced 200 m apart on the San Antonio Viejo Ranch in Jim Hogg County, Texas, USA, 2014–2017.

Aerial surveys

We conducted flights each December from 2014 to 2017. Conditions during flights ranged from 1–32°C with wind speed from 0–6 km/hr and cloud coverage from 0–100%. We flew in December to ensure bobwhites were already in coveys and that first-year birds were old enough to flush or be seen in the open. We flew a single survey of all transects in December 2014 (100% coverage). We replicated flights in the subsequent years. In 2015, we conducted 2 flights replicated at 100% coverage on 6–19 December 2015. Replicating flights allowed us to analyze 2 surveys at 100% coverage. In December 2016 and 2017 we conducted 2 flights where we flew even-numbered transects for survey 1 (50%) and odd-numbered transects for survey 2 (50%) so that we flew one complete survey over 2 time periods. Splitting the flight into 2 surveys at 50% coverage allowed us to analyze 3 surveys for 2016 and 2017, 2 at 50% coverage, and one combined survey at 100% coverage. No more than 10 days elapsed between any 2 survey events. Three observers and the pilot traversed transects at the height of 7–10 m and a velocity of 37 kilometers/hour (km/hr; Rusk et al. 2007, Schnupp 2009, Schnupp et al. 2013) using a Robinson R-44 helicopter (Rio Grande Helicopters, Laredo, TX, USA) in sequential order with a random starting point. We followed the search and survey protocol developed by Schnupp et al. (2013), where one front seat observer and the pilot (when able) scanned the area directly in front of the helicopter to the doorframe of the back seat, and the 2 back seat observers scanned the area from the door frame to the tail rotor.

When a covey was detected, the helicopter pilot moved into a hover position that was perpendicular to the transect line, and 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, USA) at the initial point of detection. We linked the laser rangefinder to a Juno handheld unit (Trimble Juno T41 handheld, Trimble Navigation Ltd, Sunnyvale, CA, USA) via Bluetooth. The Juno recorded and stored the following information: date, time of detection, survey region, flight path, transect number, transect length, covey location (x, y), covey size, and the range, azimuth, and inclination of each detection via the Caesar Kleberg Wildlife Research Institute Wildlife Survey Database application (Schnupp Consulting, LLC, Kingsville, TX, USA). A Trimble Enhanced Patch Antenna was mounted (Ram Mounts, Seattle, WA, USA) to the helicopter door frame to ensure a continuous global positioning system (GPS) signal for the Juno handheld unit. Upon survey completion, we uploaded data stored in the Juno into CyberTracker (CyberTracker Conservation NPC, Cape Town, South Africa). At data import, the program stored each covey location at the helicopter's position at the time of detection. CyberTracker uses the information collected by the laser rangefinder (range, azimuth, and inclination) to calculate the location of the covey so a perpendicular distance to the transect line can be determined.

Due to a lack of observer availability in 2014, 3 pairs of different observers collected data in the back seats of the helicopter. From 2015 to 2017, we used the same back-seat observers for each survey period within a year. Prior to each survey season starting in 2015, we trained observers by conducting a short orientation on distance sampling theory and survey procedure. We then had observers practice using the survey equipment. Observers were prompted to locate the initial point where coveys flush from and focus search effort to detect 100% of coveys at zero distance. Due to our use of laser rangefinders, we did not need to train observers on accurate distance estimation.

Analyses

Density estimation

To obtain a baseline estimate of bobwhite density at 100% coverage, we performed conventional distance sampling analyses on each area by survey and year following as outlined in Buckland et al. (2001) using Program Distance version 7.0, Release 1 (Thomas et al. 2010). We estimated detection probability (P_a), or the proportion of animals detected in the covered region (a), by fitting a detection function $\hat{g}(x)$ to the observed data and modeled using the recorded distances (x) of detected animals in clusters from the line (Buckland et al. 2015).

We estimated bobwhite density on the grazing complex for all surveys using a 2-stage process. First, we examined histograms of the entire dataset partitioned into 10–20 groups to determine an appropriate truncation distance in Program R version 3.3.2 (R Core Team 2018). Then, in Program Distance, we examined the resulting goodness-of-fit tests from different truncation distances and removed large gaps in distances where no detections were made. When estimating detection probability, we also evaluated histograms for indications of potential evasive movement, or bobwhites running away from the line and then flushing, indicated by spikes in detections in the distance bins further from the line (i.e., when the curve is not strictly monotonically decreasing).

Next, using the chosen truncation distance, we assessed data fit to several detection function models. We 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. We selected the best-fit models based on Akaike's Information Criterion (AIC), where ΔAIC values were <2.00. Among each best fit detection function model, we chose a final model based on 3 goodness-of-fit tests (Kolmogorov–Smirnov [K-S], Cramér-von Mises [CvM unif], and Cramér-von Mises [CvM cos]) where $P > 0.05$. The K-S and CvM tests determine model fit based on H_0: $F = 0$ models, where the difference between the estimated cumulative distribution and empirical distribution function is zero (Buckland et al. 2015), is indicated by $P = 1.00$. We report all density estimates as density ($\hat{D}$; bobwhites/ha) ± standard error (SE).

Coverage evaluation

For the 2014 and 2015 surveys conducted at 100%, we used 2 methods to simulate lower levels of survey coverage. For method 1, we removed transects from the completed survey (100% coverage, 33 transects) at random in 10% accumulating intervals. We used a random number generator (www.random.org) to arrange transect numbers randomly and removed transects from the data in the sequential order generated from the random number output. For example, at 90% coverage, we removed 10% ($n \sim 3$) of transects ($n = 33$) and we analyzed density from 30 transects; at 80% coverage we removed 20% ($n \sim 7$) of the transects. We continued to remove transects in 10% intervals until only 10% of the original transects remained. We analyzed each level of survey coverage as an individual survey in that they had a truncation distance appropriate for that individual survey and the appropriate model (detection function + key adjustment) for that individual survey. Simulating lower coverage resulted in 9 individual surveys at each of the 9 levels of coverage from 90 to 10% for a single trial. We repeated randomly removing transects in 10% increments for 3 trials resulting in 27 individual surveys for each year. We assessed density ($\hat{D}$) ± SE, CV of density (CV($\hat{D}$)), and 95% CI 90% to 10% coverage in decreasing increments of 10%.

For method 2, we removed transects spaced at 50 and 25% coverage in ArcMap and re-analyzed the data using all the detections from the completed 100% survey. At each 50 and 25% transect spacing, we used the spatial-join tool in ArcMap to match the detected coveys from the completed survey to new transects. The spatial-join matched the new transect ID and length to the detection and recalculated a perpendicular distance (specifying the nearest distance from the point to the line). We analyzed each survey individually, just like the first method resulting in 6 new individual surveys, 2 new surveys for each year where we flew transects at 100% (2014, 2015 survey 1; 2015 survey 2). For 2016 and 2017, we compared actual surveys flown at 50% coverage (2 surveys per year) to the resulting estimates from the combined effort at 100% coverage. We assessed changes in density ($\hat{D}$) and CV of density (CV($\hat{D}$)) for each analysis.

Comparisons between surveys within years

We conducted 2 survey periods each in December 2015, 2016, and 2017 and analyzed each survey within a year as a separate survey to obtain an independent $\hat{f}(0)$ for each survey year. We conducted 2 surveys at 100% in 2015 and 2 surveys at 50% in 2016 and 2017, respectively. We used a Z-test for independent samples (Buckland et al. 2001) 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. We 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.

Comparisons between surveys within year and strata

To determine how a drop in coverage would affect substrata (smaller survey areas within the larger), we analyzed 4 (Figure 1) strata as individual analyses within a year where density was high (2016) and low (2017). Within a single analysis of a substratum, we plotted the CV($\hat{D}$) and the total number of detections from both 50% surveys to the combined effort at 100%. The amount of effort for a survey was also estimated by specifying a target CV using the data we collected in 2014 and 2015 using equation 7.5 provided in Buckland et al. (2001).

RESULTS

Coverage evaluation

Method 1

In 2014 and 2015, 95% CI of bobwhite density increased when we removed more than 50% of the transects in all 3 trials (Figures 2 and 3). Similarly, CV($\hat{D}$) began to increase past 20% when 50% of the transects were removed (Figures 2D and 3D). At 50% coverage, CV($\hat{D}$) varied between trials, with at least one trial >20%.

Method 2

In 2014 and 2015, the variance and goodness of fit were similar for estimates from actual surveys at 100% and simulated surveys at 50% coverage. However, a reduction in effort to 25% coverage resulted in

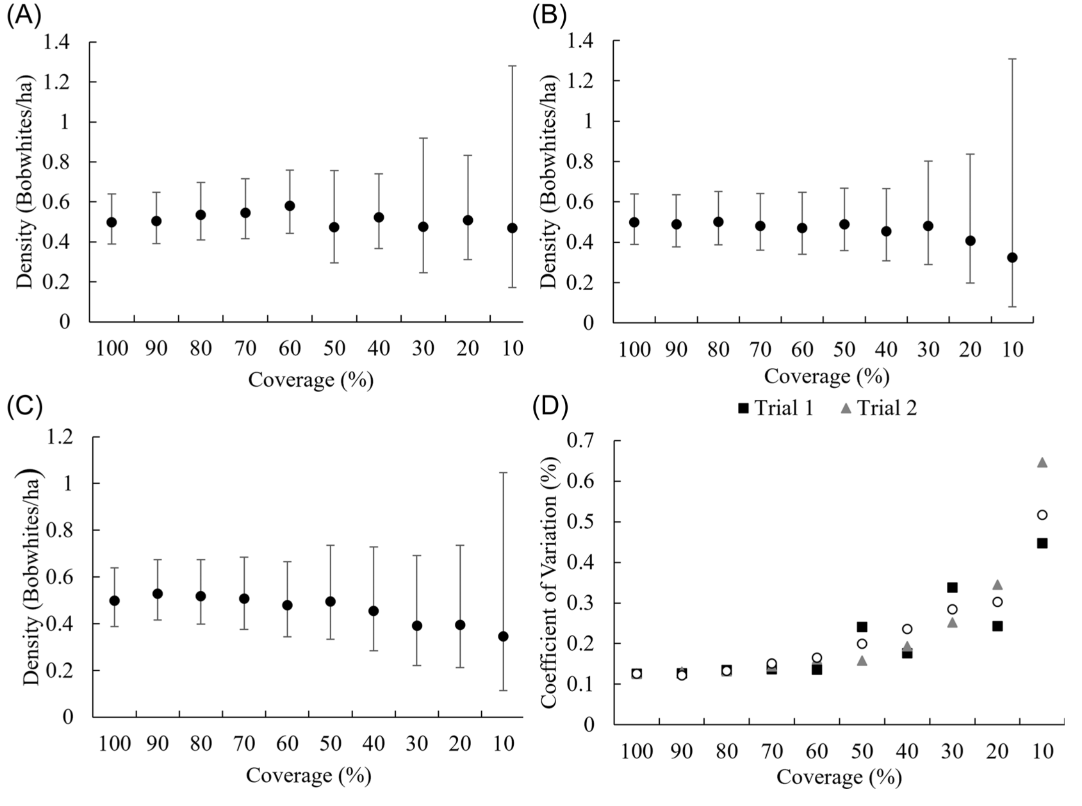

FIGURE 2 Relationship between northern bobwhite density estimates (bobwhites/ha; gray circles) and 95% confidence intervals for decreasing survey coverage: (A) trial 1, (B) trial 2, (C) trial 3, and (D) their respective coefficient of variation (%CV[$\hat{D}$]) on the San Antonio Viejo Ranch in Jim Hogg County, Texas, USA, 2014.

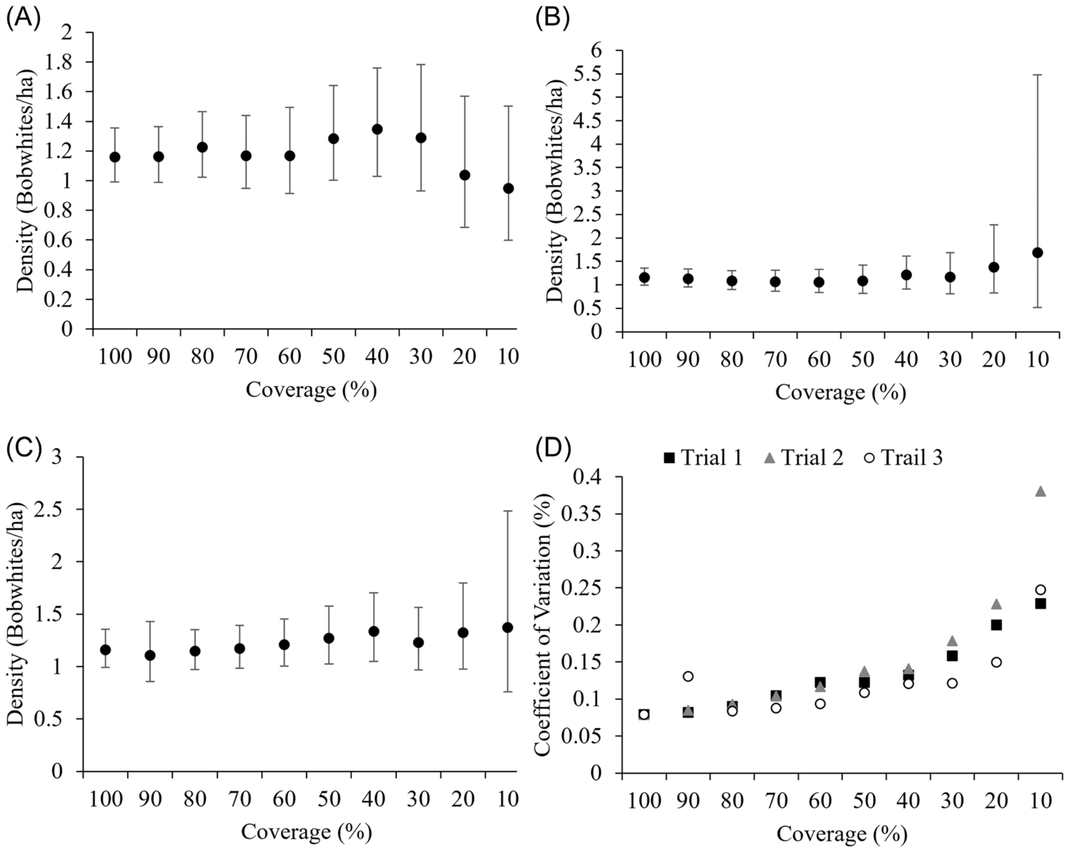

FIGURE 3 Relationship between northern bobwhite density estimates (bobwhites/ha) and 95% confidence intervals for decreasing survey coverage: (A) trial 1, (B) trial 2, (C) trial 3, and (D) their respective coefficient of variation (%CV[$\hat{D}$]) from pooled detections on the San Antonio Viejo Ranch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

a doubling of the CV($\hat{D}$) (Table 1). Density estimates were similar between 100% and 50% coverage for 2014 ($z = -1.00$, $P = 0.317$), 2015 survey 1 ($z = 1.14$, $P = 0.258$), and 2015 survey 2 ($z = -1.28$, $P = 0.200$). Density estimates were similar between 100% and 25% coverage for 2014 ($z = -0.84$, $P = 0.401$), and 2015 survey 2 ($z = -0.71$, $P = 0.473$), but differed between 100% and 25% for 2015 survey 1 ($z = 2.970$, $P = 0.003$).

In surveys flown at alternating 50% intervals (2016 and 2017) and combined for 100% coverage, the CV ($\hat{D}$) for each year decreased below 10% when 50% surveys were combined into 100% coverage (Table 2). Estimates from each of the 2 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 ($z = -0.200$, $P = 0.841$, $z = 0.198$, $P = 0.843$). In 2016 and 2017, goodness of fit tests from surveys flown at 50% coverage were similar to combined estimates at 100% coverage (Table 2).

Comparisons between surveys within years

In 2015, we flew 760 km of transects over 7,689 ha. Density estimates from survey 1 ($\hat{D} = 1.26 \pm 0.09$ bobwhites/ha) and survey 2 ($\hat{D} = 1.28 \pm 0.09$ bobwhites/ha) were similar (Table 3). However, $\hat{g}(0)$ was <1 for

TABLE 1 Number of transects (*k*), total transect length (*L*), number of northern bobwhite covey detections (*n*), detection probability (*p*), coefficient of variation (%CV($\hat{p}$)), density (bobwhites/ha [$\hat{D}$ ± SE]), coefficient of variation (%CV[$\hat{D}$]), 95% confidence intervals (95%CI [$\hat{D}$]), from a survey at 100, 50, and 25% coverage. Surveys are from 2014 and 2015 on the San Antonio Viejo Ranch in Jim Hogg County, Texas, USA. Also shown for each model are the results (*P*-value) from a Kolmogorov–Smirnov goodness of fit test.

							$\hat{D}$			(GOF)
Survey	**Coverage (%)**	***k***	***L* (m)**	***n***	**$\hat{p}$**	**%CV($\hat{p}$)**	**$\hat{D}$ ± SE**	**% CV($\hat{D}$)**	**95% CI**	**K-S**
2014	100	33	380,317	131	0.58	7.52	0.48 ± 0.06	12.93	(0.37–0.63)	0.97
	50	16	187,445	69	0.58	7.24	0.50 ± 0.08	15.42	(0.37–0.68)	0.77
	25	8	90,854	31	0.53	13.64	0.64 ± 0.18	27.79	(0.36–1.13)	0.73
2015 survey 1	100	33	380,317	484	0.71	3.87	1.26 ± 0.09	6.93	(1.1–1.44)	0.00
	50	16	187,445	196	0.88	6.69	1.08 ± 0.13	11.76	(0.86–1.38)	0.02
	25	8	90,854	96	0.91	5.96	0.79 ± 0.13	17.05	(0.55–1.13)	0.09
2015 survey 2	100	33	380,317	405	0.68	4.52	1.28 ± 0.09	7.35	(1.11–1.48)	0.95
	50	16	187,445	188	0.63	5.61	1.55 ± 0.19	12.26	(1.21–1.99)	0.89
	25	8	90,854	96	0.76	9.8	1.56 ± 0.38	24.71	(0.91–2.65)	0.99

TABLE 2 Number of transects (*k*), total transect length (*L*), number of northern bobwhite covey detections (*n*), detection probability (*p*), coefficient of variation (%CV($\hat{p}$)), density (bobwhites/ha [$\hat{D}$ ± SE]), coefficient of variation (%CV[$\hat{D}$]), 95% confidence intervals (95%CI [$\hat{D}$]), from 2 alternating surveys at 50% coverage (odd and even-numbered transects) and the combined survey at 100% coverage. Surveys are from 2016 and 2017 on the San Antonio Viejo Ranch in Jim Hogg County, Texas, USA. Also shown for each model are the results (*P*-value) from a Kolmogorov–Smirnov goodness of fit test.

							$\hat{D}$			GOF
Survey	**Coverage (%)**	***k***	***L* (m)**	***n***	**$\hat{p}$**	**%CV($\hat{p}$)**	**$\hat{D}$ ± SE**	**% CV($\hat{D}$)**	**95% CI**	**K-S**
2016	100	33	380,317	346	0.57	4.43	2.00 ± 0.16	8.21	(1.71–2.36)	0.73
	50_odd	17	192,872	178	0.42	8.89	1.72 ± 0.21	12.41	(1.34–2.20)	1.00
	50_even	16	187,445	199	0.35	6.94	2.43 ± 0.27	11.1	(1.95–3.03)	0.74
2017	100	33	380,317	271	0.61	5.27	0.76 ± 0.06	9.15	(0.64–0.94)	0.71
	50_odd	17	192,872	143	0.67	7.69	0.73 ± 0.11	14.67	(0.54–0.98)	0.83
	50_even	16	187,445	130	0.55	4.4	0.77 ± 0.08	11.3	(0.62–0.97)	0.48

survey 1 compared to survey 2 (Figure 4A, B), but the overall detection probability was similar (Table 1). In 2016, we flew 380 km (192.8 for survey 1 and 187.4 for survey 2) of transects over 7,689 ha. Density estimates from survey 1 at 50% ($\hat{D}$ = 1.72 ± 0.21 bobwhites/ha) and survey 2 at 50% ($\hat{D}$ = 2.43 ± 0.27 bobwhites/ha) were different (Table 3). The probability of detection decreased by 17% from survey 1 to survey 2 (Table 2; Figure 4C, D). We flew the same distance and area in 2017 as in 2016. Density between survey 1 at 50% ($\hat{D}$ = 0.73 ± 0.11 bobwhites/ha) and survey 2 at 50% (D: 0.77 ± 0.08 bobwhites/ha) were similar (Table 3). Similar to 2016, the probability of detection decreased by 18% from survey 1 to survey 2 (Table 2; Figure 4E, F).

TABLE 3 Summary statistics for annual differences in northern bobwhite densities between 2 surveys within 2015 (100% vs. 100%), 2016 (50% vs. 50%), and 2017 (50% vs. 50%) on the San Antonio Viejo Ranch in Jim Hogg County, Texas, USA.

	2015 Survey 1 vs. 2	2016 Survey 1 vs. 2	2017 Survey 1 vs. 2
Difference	0.019	0.711	0.040
SE for the diff.	0.129	0.342	0.136
z-score	0.147	2.077	0.294
P-value 2 tailed	0.888	0.038	0.772

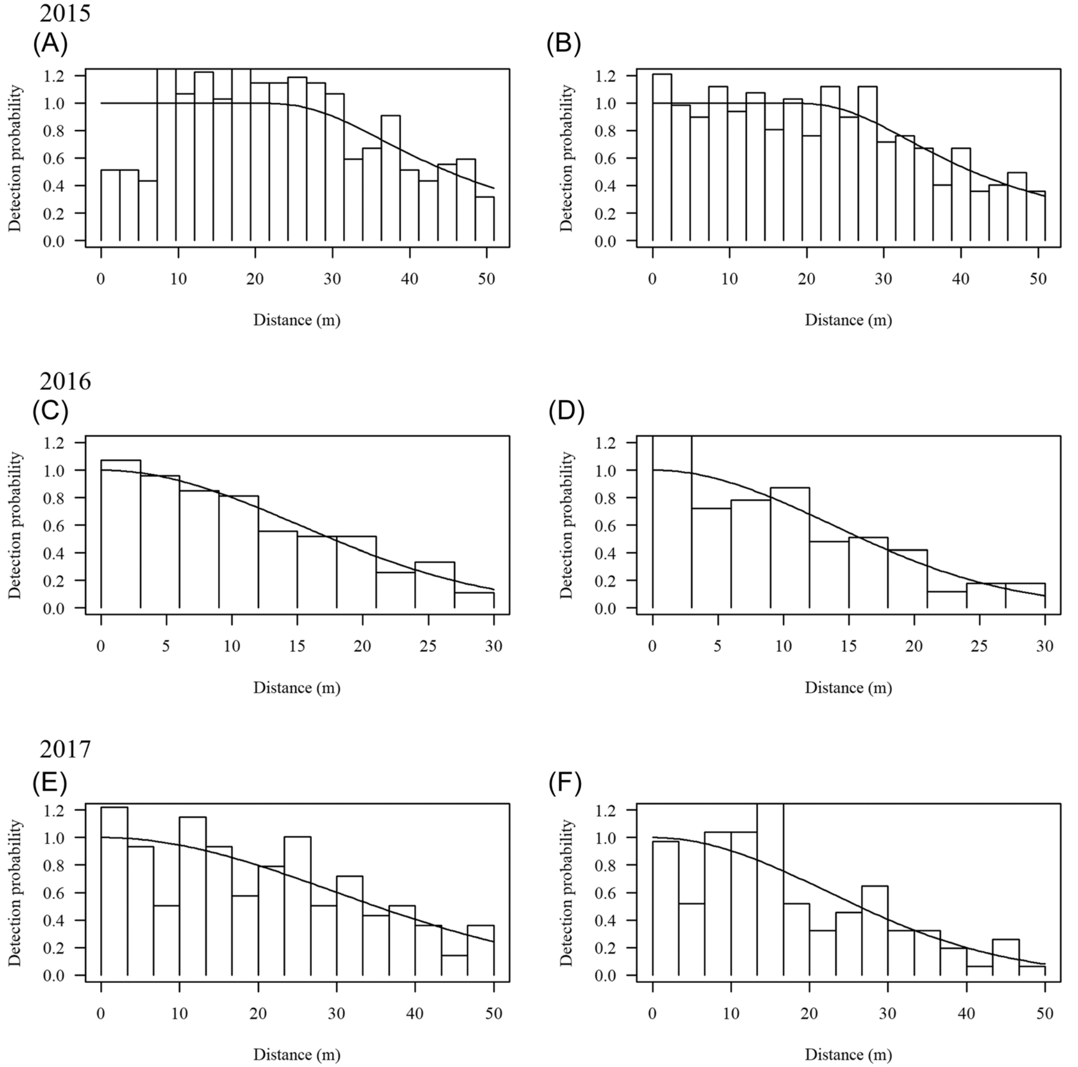

FIGURE 4 The estimated conventional distance sampling detection function by year and survey number from coveys on the San Antonio Viejo Ranch in Jim Hogg County, Texas, USA, from 2015, 2016, and 2017. Survey coverage by year was as follows: (A) survey 1 and (B) survey 2 at 100% coverage, 2015; (C) survey 1 and (D) survey 2 at 50% coverage, 2016; (E) survey 1 and (F) survey 2 at 50% coverage, 2017.

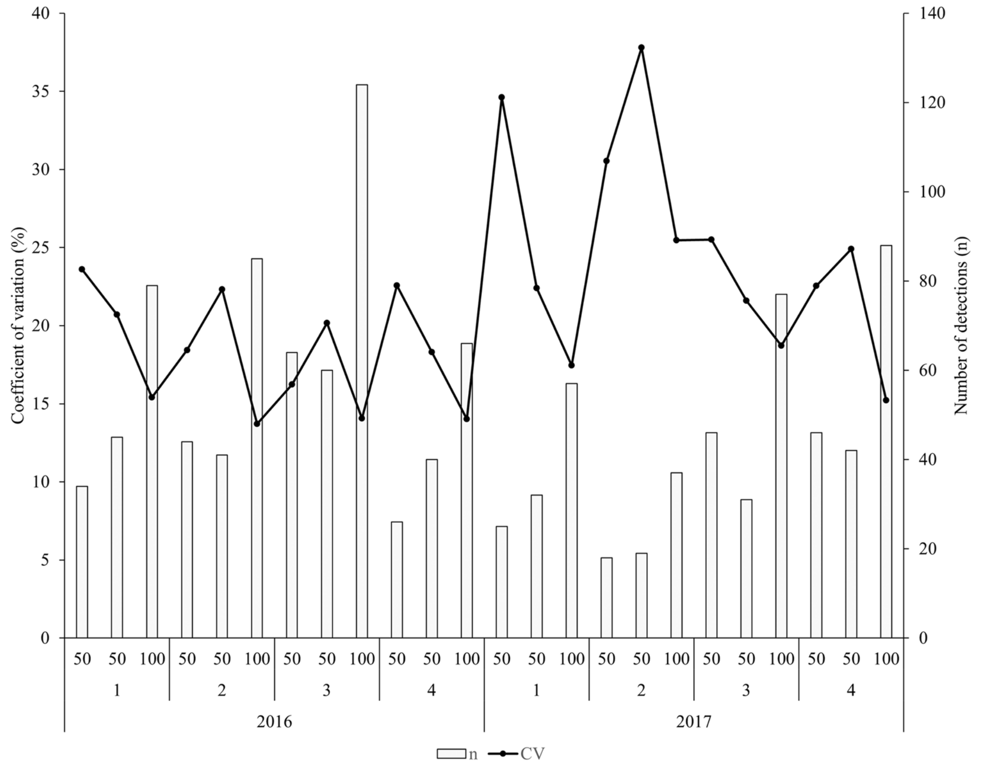

FIGURE 5 The relationship between the coefficient of variation ([CV%]; lines) and the number of detections (*n*; white bars) for each survey at 50 and 100 within each substratum (1–4) for a year with high bobwhite density (2016) and a year with low bobwhite density (2016) on the San Antonio Viejo Ranch in Jim Hogg County, Texas, USA.

Comparisons between surveys within year and strata

The CV($\hat{D}$) for each 50% survey within substrata was higher than the combined survey at 100% coverage (Figure 5). However, there is a change in the height of the peaks in CV($\hat{D}$) from 2016 to 2017. The lower total number of detections in 2017 affected the precision of the estimates derived from 50% coverage greater than in 2016. The CV($\hat{D}$) for 3 of the 4, 50% surveys in strata's 1 and 2 were >30% in 2017.

Target coefficient of variation

In 2014, we flew a total of 380 km (one complete survey at 100%) and detected 143 coveys with a CV($\hat{D}$) of 11.5%. Based on 2014 surveys, the total line length necessary to achieve a targeted CV($\hat{D}$) of 20% was 120 km with 47 detections expected, 15% was 215 km with 83 detections expected, and 10% was 484 km with 188 detections expected. Surveys of the grazing complex conducted at 50% cover approximately 190 km/survey. If surveys were restricted to 50% coverage in 2014, this would yield a CV($\hat{D}$) of 18% (Buckland et al. 2001), which is below the recommended target (20%), but ~10% higher than what was achieved with actual surveys flown at 100% coverage.

DISCUSSION

Coverage evaluation

The data supported our hypothesis that density and precision estimates simulated below 50% coverage were more variable and less precise in all scenarios. Additionally, there were few differences between surveys simulated at 50% and actual surveys at 100% (2014 and 2015), and actual surveys flown at 50% and combined estimates at 100% (2016 and 2017). Therefore, based on simulations, transects for distance sampling surveys at our study site should not be spaced farther than 400 m (<50%).

Surveying at 100% coverage on the grazing complex required 2 or 3 consecutive days to complete. Conducting 2 separate surveys at 50% coverage in 2016 and 2017 was beneficial in that we could conduct surveys of a whole pasture in a single day rather than over 2–3 days without sacrificing a decrease in survey coverage below 100%. Splitting the survey into 2 surveys at 50% coverage allowed us 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%.

Comparisons between surveys within years

Contrary to our hypothesis, there was a significant increase in density from survey 1 to survey 2 in 2016, but density from all other surveys were statistically similar within years and study sites for 2015 and 2017. However, $g(0)$ was <1 for the 2015 survey 1, which was likely due to new observers with no prior experience counting quail from a helicopter. Although low detection on the line did not affect density between the 2 surveys, the variance from the first estimate was high (i.e., poor detection probability model fit). The estimate from survey 1 would have little reliability had it been the only survey we conducted that year. We attempted to prevent missed 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 is expected (Buckland et al. 2001).

Comparisons between surveys within year and strata

The data supported our hypothesis that precision would decrease on substrata where <60 detections were made. Surveys with a low number of detections in substrata exhibited high variance, particularly in 2017 when bobwhite density was lower. Had we only conducted surveys at 50% in 2016 and 2017, grazing treatment density estimates would have been unreliable in substrata with <60 detections. For example, between 2 surveys within a substratum, density estimates differed by 57–73% in 2016 and 21–43% in 2017. Therefore, it is important to consider the survey effort in substrata and allocate the necessary effort to achieve the recommended number of detections. Depending on the project's goals, individual treatment densities can be modeled using a multiple covariate distance sampling analysis with stratum (or treatment) as a covariate. Still, the increased number of transects at 100% helps 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. We do not recommend any survey designed with <25% survey coverage.

Target coefficient of variation

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). Researchers can use a small-scale pilot survey or information from previous literature to estimate survey effort at the target CV (Buckland et al. 2001). Alternatively, researchers can conduct a more extensive pilot survey and define a targeted CV($\hat{D}$) based on empirical estimates from the survey rather than from the literature (Buckland et al. 2001). Using a target CV to determine survey effort is useful when refining the second year of a study.

An alternative approach for researchers to estimate the optimal amount of survey effort may be to conduct simulations of surveys with different design options using the R package DSsim (Marshall 2014) in Program Distance. In DSsim, 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 and the total effort associated with each design can help design line-transect distance sampling surveys (Buckland et al. 2015).

MANAGEMENT IMPLICATIONS

Based on our results, we do not recommend conducting aerial northern bobwhite surveys below 50% coverage. However, surveying at 50% coverage is likely acceptable for large areas in the rangeland vegetation typical of South Texas and perhaps other areas or regions with similar vegetation. When smaller stratum specific density estimates are needed, we recommend conducting a pilot survey at 100% coverage and adjusting the coverage of subsequent surveys using the formula 7.5 provided by Buckland et al. (2001). The survey date should not affect the density estimate in December, but we recommend conducting replicate surveys at either 50% or 100% to improve precision.

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CONFLICTS OF INTEREST
The authors declare no conflicts of interest.

ETHICS STATEMENT
Permitting and institutional approval was not required for aerial quail surveys from a helicopter platform. No animals were captured, handled, or harmed in this observational study.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Andrea Montalvo http://orcid.org/0000-0002-6463-9466
Andrew N. Tri https://orcid.org/0000-0002-2345-940X

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