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Tools and Technology

An Electronic System to Collect Distance-Sampling Data During Helicopter Surveys of Northern Bobwhite

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ABSTRACT Distance sampling during aerial surveys has been used extensively to estimate the density of many wildlife species. However, practical issues arise when using distance sampling during aerial surveys, such as obtaining accurate perpendicular distances. We assembled a computerized, electronic system to collect distance-sampling data (e.g., transect length, detection location, and perpendicular distance) during aerial surveys. We tested the accuracy of the system in a controlled trial and a mock survey. We also evaluated the electronic system during field surveys of northern bobwhite (*Colinus virginianus*) conducted in the Rio Grande Plains and Rolling Plains ecoregions of Texas, USA, during December 2007–2008. For comparison, we evaluated the accuracy of visual estimation of distance during a mock survey. A strong linear relationship existed between estimated and actual distances for the controlled trial ($r^2 = 0.99$) and mock survey ($r^2 = 0.98$) using the electronic system. Perpendicular-distance error (i.e., absolute difference between estimated distance and actual distance) for the electronic system was low during the controlled trial (1.4 ± 0.4 m; $\bar{x} \pm$ SE) and mock survey (3.0 ± 0.5 m) but not during the visual estimation of distance (10 ± 1.5 m). Estimates of bobwhite density obtained using the electronic system exhibited reasonable precision for each ecoregion during both years (CV < 20%). Perpendicular-distance error slightly increased with target distance (0.7-m increase in error for every 10-m increase in target distance). Overall, the electronic system appears to be a promising technique to estimate density of northern bobwhite and possibly other terrestrial species for which aerial-based distance sampling is appropriate. © 2012 The Wildlife Society.

KEY WORDS aerial surveys, *Colinus virginianus*, density, distance sampling, line transects, northern bobwhite.

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Estimating abundance of wildlife populations is an important aspect of wildlife management and conservation. Survey methods that incorporate detection probabilities have been recommended over indices to estimate wildlife abundance (Anderson 2001, 2003; Thompson 2002). Thus, distance sampling has become a popular and accepted technique to obtain reliable estimates of wildlife abundance provided that underlying assumptions are met (Burnham et al. 1980, Buckland et al. 2001). Estimating population abundance using distance sampling, however, can be labor-intensive and time-consuming.

General recommendations for reliable density estimates involve a minimum sample size in the range of 60–80 encounters (Buckland et al. 2001). Meeting this recommendation can be difficult when populations are sparse and/or the mode of traversing transects is walking (Kuvlesky et al. 1989). Other more efficient modes of traversing transects, such as aircraft, have been used as a possible solution. Aircraft have been used to survey for a wide variety of wildlife including white-tailed deer (*Odocoileus virginianus*; DeYoung 1985), mule deer (*Odocoileus hemionus*; White et al. 1989), elk (*Cervus elaphus*; Noyes et al. 2000), northern bobwhite (*Colinus virginianus*; Shupe et al. 1987, Rusk et al. 2007), and waterfowl (Cordts et al. 2002). However, data-collection issues can arise when using aerial modes of transportation and distance sampling. These issues include maintaining a predetermined centerline and obtaining accurate perpendicular distances and survey-line length (Shupe et al. 1987, Buckland et al. 2001, Marques et al. 2006, Rusk et al. 2007).

Studies have relied on a variety of approaches to address these issues. For example, researchers have either visually estimated distance and assumed estimates were accurate (Shupe et al. 1987), mounted devices or marked struts on aircraft to obtain crude distance-interval estimates (Johnson et al. 1991, Bengtson et al. 1995), or interrupted surveys to fly over detected animals to obtain global positioning system (GPS) coordinates of their location (Marques et al. 2006). Unfortunately, these solutions can be biased, imprecise, and/or biologically or cost-prohibitive.

Given the extensive use of aerial surveys for estimating wildlife density, the soundness of distance sampling, and recent advances in technology, we assembled an electronic system to collect distance-sampling data during aerial surveys and tested its accuracy. Our objectives were to test the accuracy of the electronic system in a controlled trial and mock survey. We also evaluated the performance of the electronic system during actual field surveys of northern bobwhite. Northern bobwhite is a species for which aerial-based distance sampling has been commonly used (Shupe et al. 1987, Rusk et al. 2007, Schnupp 2009). The species is well-suited for the technique because it occurs as coveys during autumn–winter and individual birds' initial reaction in response to an aerial predator is to "freeze" before flushing toward cover (Mueller 1976). For comparison, we also tested the accuracy of visually estimating distances during a mock survey.

STUDY AREA

We conducted the controlled trial of the electronic system on the campus of Texas A&M University-Kingsville (Kleberg County, TX) during October 2007. The James C. Jernigan Library rooftop (10 m) was used to simulate the approximate height of the surveying helicopter (7–10 m). Mock surveys for the electronic system and visual estimation of distance were conducted on the Rolling Plains Quail Research Ranch (1,902 ha; Fisher County, TX) and a private ranch (60,700 ha; Kleberg County, TX), respectively, during October 2007. We conducted the mock surveys in fallow agricultural fields (approx. 245 ha) that lacked woody cover but contained grasses that were about 1 m tall. This vegetation structure provided observers in a helicopter an unobstructed view of the landscape during surveys and represented the best-case scenario for field-testing the system.

Field surveys for bobwhites were replicated in 2 ecoregions of Texas (Rio Grande Plains and Rolling Plains) and involved 2 study sites/ecoregion. The acreage of the study sites ranged from 902 ha to 1,857 ha. Distance between study sites within an ecoregion was approximately 10 km. Surveys in the Rio Grande Plains were conducted on a private ranch (52,610 ha) in Brooks County, Texas. The major land uses on the ranch included commercial hunting and cattle production. The primary woody vegetation included mesquite (*Prosopis glandulosa*), huisache (*Acacia smallii*), live oak (*Quercus virginiana*), and prickly pear cactus (*Opuntia lindheimeri*). Surveys in the Rolling Plains were conducted on the Rolling Plains Quail Research Ranch and a private ranch (1,416 ha) in Fisher County, Texas. The major land uses on the ranches were recreational hunting, farming, and wildlife-management education. No significant cattle grazing took place on these ranches during the course of the study. Two pastures (485 ha total) were grazed with 1 animal unit (AU)/8.1 ha for 6 months at Rolling Plains Quail Research Ranch, and the private ranch was not grazed during this research. Woody vegetation was dominated by mesquite, lotebush (*Ziziphus obtusifolia*), littleleaf sumac (*Rhus microphylla*), and wolfberry (*Lycium berlandieri*). Other species included narrow-leaf yucca (*Yucca angustissima*), tasajillo (*Opuntia leptocaulis*), juniper (*Juniperus pinchotii*), shinnery oak (*Quercus havardii*), and prickly pear (*Opuntia* spp.). Schnupp (2009) provides a more detailed description of the study area and study sites.

MATERIALS AND METHODS

System Overview

Description.—Rusk et al. (2007) used an earlier prototype of the electronic system to estimate bobwhite density in their study. We made slight modifications to the original design of Rusk et al. (2007). The modified system consisted of 4 main components: 1) 2 tablet personal computers (PC), 2) 1 guidance and differential global positioning system (DGPS), 3) 2 laser rangefinders, and 4) two 17-key keypads (Fig. 1). The merging of the guidance and DPGS into 1 unit and the addition of keypads were the modifications to the original unit of Rusk et al. (2007).

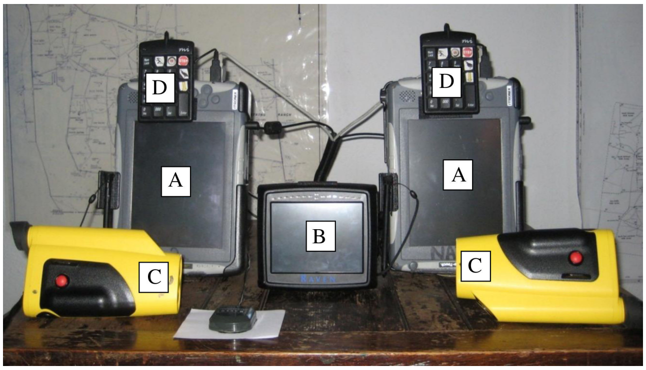

Figure 1. Components of the electronic system which include (A) 2 tablet personal computers, (B) 1 Raven Cruizer™ guidance and differential global positioning system, (C) 2 MDL LaserAce 300™ laser rangefinders, and (D) 2 custom 17-key keypads. We tested the system during aerial surveys of northern bobwhites (*Colinus virginianus*) conducted in the Rio Grande Plains and Rolling Plains ecoregions of Texas, USA, during December 2007–2008.

The PCs were General Dynamics Itronix DuoTouch™ tablets (General Dynamics, St. Petersburg, FL) with a custom ArcPad 7 (Environmental Systems Research Institute, Redlands, CA) applet installed in each. We connected tablets to a sub-meter accuracy Raven Cruizer™ (Raven Industries, Sioux Falls, SD) DGPS with Wide Area Augmentation System using universal bus serial cables. The Raven Cruizer DGPS continuously collected 5 positions/second and provided coordinates of the helicopter as well as a track log of the flight path. MDL LaserAce 300 rangefinders equipped with Bluetooth wireless communications (Measurement Devices Ltd., Aberdeen, Scotland, UK) were used to capture covey detections. Rangefinders measured distance, compass bearing, and angle of inclination and computed the horizontal offset vector from the helicopter to mark covey locations. We connected keypads to tablets via USB serial cables and used to enter covey size.

Electronic Data Solutions (Jerome, ID; contact corresponding author for access to applet) developed a custom ArcPad applet to capture information associated with detections (e.g., covey size, time, location) both on and off the transect. To capture detections not on the transect, the applet performed an offset using the GPS position of the helicopter and the information obtained from the laser rangefinders. The custom applet collected survey-line length, line ID, and covey size, and created an Environmental Systems Research Institute shapefile of these data. We analyzed shapefiles in ArcView™ 9.3 by using the Joins and Relates tool to determine perpendicular distance from the detection point to the tracklog (i.e., transect). Once perpendicular distances were computed, we exported the attribute tables to Microsoft Excel (Microsoft Corp., Redmond, WA). We then uploaded the resulting data to Program DISTANCE 6.0 (Thomas et al. 2010) for analysis. The electronic system weighed 3.6 kg and required 5–10 minutes to assemble prior to surveys.

Application.—We developed the survey design using ArcView 9.3 prior to conducting surveys. All shapefiles of the study area and transects were exported and packaged as an ArcPad 7 project and uploaded to the 2 tablet PCs. Each tablet PC was mounted to the rear-seat cross-bar with Ram Mount Brackets™ (Ram Mount, Seattle, WA). The system was powered by 3, 12-V receptacles located in the R-44 helicopter.

The Raven Cruizer was a 3D integrated guidance system that utilized a 14.5-cm color, high-resolution, touch-screen display. The guidance system enabled the pilot to navigate along the transect by displaying the distance the helicopter was from the transect, as well as displaying the transect on the display screen. As noted earlier, the Raven Cruizer DGPS collected coordinates of the helicopter and flight path.

Once in the field, we calibrated the laser rangefinders by completing an automated calibration procedure. Surveyors calibrated rangefinders to the known direction of 0° while sitting in the aircraft, to account for the magnetic field of the aircraft. The pilot then guided the helicopter to the first transect, and the survey was initiated. While traversing the first transect, we set a first calibration point when the helicopter was directly over the transect. Near the completion of the first transect, we set a second calibration point when the helicopter was directly over the transect. At this point, the guidance-system calibration process was complete because the predetermined spacing of the subsequent transects had been set in advance. The rangefinders were not calibrated for a specific side; thus, the transects could be traversed in either direction.

The survey protocol required 3 observers. A front-seat observer detected clusters (i.e., coveys) on the transect while the 2 rear-seat observers detected clusters on the left and right sides of the transect. One of the rear-seat observers was designated the senior surveyor. The senior surveyor was responsible for guidance to the transects and initiating and terminating the survey. The 2 rear-seat observers scanned for coveys on their respective side while the front-seat observer scanned directly in front of the helicopter. Although all 3 observers scanned for coveys, only the 2 rear-seat observers entered data into the system. The senior surveyor was responsible for entering all coveys detected by the front-seat observer. The pilot also noted covey detections; however, he was not considered an observer.

When a covey was detected, the respective observer informed the pilot and the pilot held the helicopter in a hovering position. The observer counted the number of individuals in the covey and used the rangefinder to mark the covey location (Fig. 2A–C). If the rangefinder took an unsuccessful measurement (e.g., the laser was not properly reflected back, button not fully compressed, etc.), then the rangefinder alerted the observer of the faulty attempt by blinking "999.999." Otherwise, the rangefinder displayed the distance, azimuth, and inclination data collected. The pilot then resumed the survey along the transect.

The data from the rangefinder were automatically communicated to the custom applet via Bluetooth connection. Once the applet received the information from the rangefinder, the observer was prompted by the applet to enter the covey size and did so using his–her keypad. Because the front-seat observer was not collecting data, he–she notified

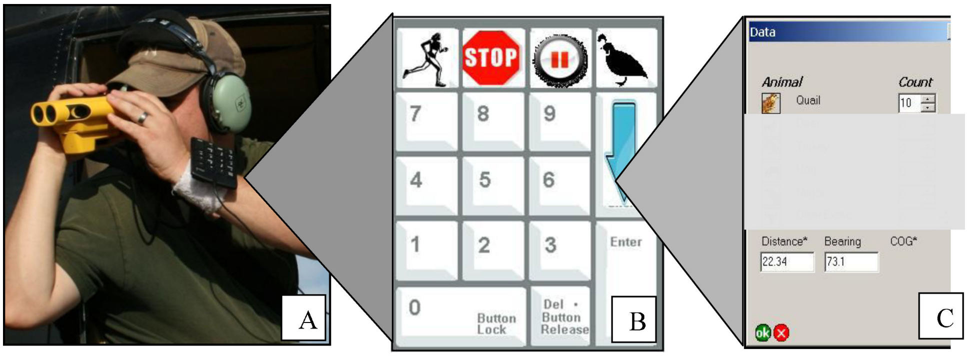

Figure 2. An observer employing the electronic system tested during aerial surveys of northern bobwhite (*Colinus virginianus*) conducted in the Rio Grande Plains and Rolling Plains ecoregions of Texas, USA, during December 2007–2008. A: An MDL LaserAce 300$^{\text{TM}}$ laser rangefinder was employed to acquire a location of a detection. B: The observer then used the custom 17-key keypad (worn on the wrist) to enter the corresponding number of individuals in the detection. C: Data are entered into the system software via keypad.

the senior surveyor when a covey was detected. The senior surveyor pressed the capture button on the keypad to enter the covey size and recorded the covey as "detected on the transect."

Upon completion of the transect, the applet saved the following transect information: region, observers, date, time, transect length, and transect ID in an ArcView 9.3 shapefile. In a separate shapefile, the applet saved the following covey encounter data: region, observer, date, time, the X,Y location data of a detection point, and the raw data from the rangefinder. These 2 separate shapefiles created in the field by the applet were uploaded to a desktop computer, and then processed in ArcView 9.3. A spatial join was performed with the Joins and Relates tool within ArcView 9.3 to determine perpendicular distance from the point shapefile (covey detections) to the tracklog shapefile (transects). Once the perpendicular distances were computed, the attribute table was exported to a format that was readable by Program Distance. The perpendicular distances, line length, and covey detections then were analyzed in Program DISTANCE 6.0 (Thomas et al. 2010).

System Evaluation

Controlled trial.—We conducted a controlled trial to determine the accuracy of the system from an elevated position in the absence of field variables (i.e., turbulence, platform motion, etc.). The James C. Jernigan Library on the campus of Texas A&M University-Kingsville was used as the testing site. This building had an approximate height of 10 m, which corresponded to the approximate height above ground level during surveys (7–10 m). Seven crosses (targets) were painted on the ground below the building at 5, 10, 20, 40, 50, 70, and 130 m. A laser rangefinder was secured to a tripod on the roof of the building, and an observer estimated distances for the 7 targets using the system. Each target was measured 5 times using the laser rangefinder. The actual position of each target was measured by a technician at the conclusion of the controlled trial by obtaining GPS coordinates from the center of each target. Thirty GPS positions were obtained for each target using ArcPad 7 software to maximize the true positional accuracy of the target.

We evaluated the accuracy of the electronic system using 2 methods 1) linear relationship between estimated and known distance, and 2) perpendicular-distance error. Perpendicular-distance error was the absolute difference between the actual distance of the target and estimated distance. We also evaluated the influence that target distance may have had on perpendicular-distance error by plotting the error as a function of target distance.

We used simple linear regression using SAS$^{®}$ to determine the relationship between estimated distance and known distance. We also used simple linear regression to evaluate the influence of target distance on perpendicular-distance error. The presence of a trend (i.e., increasing or decreasing) in measurement error was based on the slope of the regression line and its significance (H_0: $m = 0$; $P < 0.05$).

Mock survey.—We conducted a mock survey to determine the accuracy of the electronic system under field-survey conditions. The mock survey was conducted in a grassland field on the Rolling Plains Quail Research Ranch. Three experienced observers were used to evaluate the electronic system during a mock survey. The mock survey involved a 3-km line transect containing 16 targets. Eight targets were placed on each side of the transect. Targets were randomly distributed within 10-m intervals from 10 m to 70 m (Otto and Pollock 1990). Targets were spaced 300 m apart along the transect to enable an observer ample time to enter data during the trial. Targets were MOJO$^{\text{TM}}$ dove decoys that were elevated 1.2 m above the grass to mimic a flushing covey during an actual survey.

We also evaluated the accuracy of visual estimation of distance during a separate mock survey. This mock survey was conducted in a grassland field on a private ranch in the Rio Grande Plains and involved 3 observers who visually estimated distance. The mock-survey design was as previously discussed for the testing of the electronic system.

We used the same analyses that were used for the controlled trial to evaluate the accuracy of the electronic system and visual estimation during mock surveys.

Field surveys.—We created transects for surveys using ArcView 9.3. We created a systematic block of vertical lines (i.e., transects) over a map of the study sites using the Fishnet

Grid tool. Spacing between transects depended on the shape and area of the study site being surveyed and ranged 85–200 m. We wanted to establish 20–40 transects in each study site. The boundaries of each study site were used as the clipping layer and any portions of the vertical lines outside of the boundaries were discarded. All ArcView 9.3 shapefiles of the study site boundaries and transects were saved as an ArcPad 7 project and uploaded to the 2 tablet PCs.

Transects were traversed during October–November 2007 and 2008 in a R-44 helicopter at a velocity of 37 km/hour and an altitude of 7–10 m. We attempted to traverse transects during either the first or last 3 hours of daylight and on consecutive days, but this was not always possible due to weather and time constraints. Survey effort was about 92 km/site (range = 90.4–98.9 km/site). We selected a starting transect and traversed the next transect that was ≥400 m away (i.e., skipped adjacent transects) to avoid possibility of double-counting coveys. We continued with this scheme in a sequential manner (returning to sample previously skipped transects the next day) until all transects had been surveyed once. The survey took about 3–4 days to complete per ecoregion.

We estimated bobwhite density (bobwhites/ha) and associated variance estimates using Program DISTANCE 6.0 (Thomas et al. 2010). Program Distance calculates these estimates as

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

$$\mathrm{var}(\hat{D}) = \hat{D}^2 \times \{[\mathrm{CV}(n)]^2 + [\mathrm{CV}\{f(0)\}]^2\}$$

where $\hat{D}$ is the density, n is the number of coveys detected, $\hat{\mu}$ is the estimate of effective half-width, L is the length of transects, $E(s)$ is the average covey size, CV is the coefficient of variation, and $f(0)$ is the probability density function of detected distances from the line, evaluated at 0 distance. We then estimated effective half-widths in Distance by fitting detection functions to these distance histograms. We truncated 5% of the data from the right-hand tail of distance histograms to improve model fitting (Buckland et al. 2001). We evaluated the following detection functions: uniform, half-normal, and hazard-rate with cosine, simple polynomial, or Hermite polynomial series adjustments. We evaluated the various combinations of these key functions and series adjustments and selected a detection function based on Akaike's Information Criterion values for small sample size (AIC$_c$) and goodness-of-fit using chi-square analysis (Buckland et al. 2001).

We used study sites as the lowest level of resolution for density estimates, covey size, and encounter rates. We developed a global detection function using all detections from the 2 study sites within an ecoregion for a particular year. We then used this global detection function to estimate density for a study site within an ecoregion for a year. We used 95% confidence intervals (95% CI) and coefficient of variation from Program DISTANCE 6.0 (Thomas et al. 2010) to evaluate the precision of the density estimates. We considered a desirable coefficient of variation for bobwhite density to be ≤20% (Guthery 1988). We report results as mean ± standard error.

RESULTS

We documented a strong linear relationship between mean estimated distance and actual distance (Fig. 3A) during the controlled trial of the electronic system. We also observed a low perpendicular-distance error (1.4 ± 0.4 m; Table 1). There was no linear trend in perpendicular-distance error with increasing distance of targets (Fig. 4A).

We documented a strong linear relationship between mean estimated distance and actual distance during the mock survey using the electronic system (Fig. 3B). We also observed a low perpendicular-distance error (3.0 ± 0.5 m; Table 1). There was an increasing trend in perpendicular-distance error with increasing distance of targets (Fig. 4B). Error increased by about 0.7 m for every 10-m increase in target distance. Visual inspection of the graph suggested that

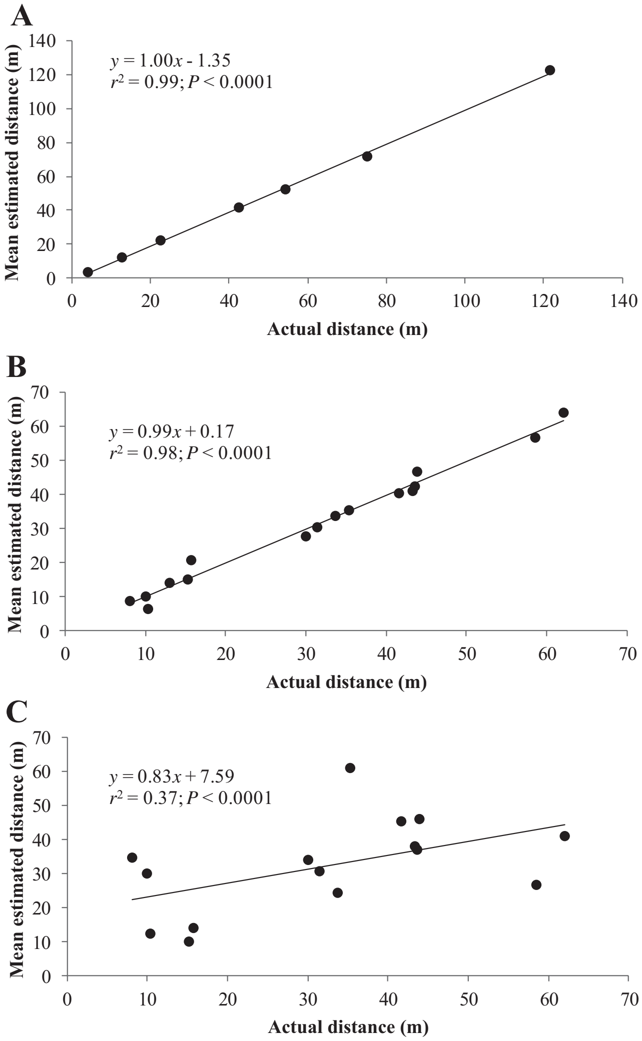

Figure 3. Linear relationship between mean estimated distance and actual distance for (A) controlled trial (electronic system), (B) mock survey (electronic system), and (C) mock survey (visual estimation) of northern bobwhite (*Colinus virginianus*), October 2007, Kleberg and Fisher Counties, Texas, USA. P-value is for the significance test of the slope (H_0: $m = 0$).

Table 1. Absolute perpendicular-distance error (*m*) during a controlled trial and mock survey of northern bobwhite (*Colinus virginianus*) to evaluate the accuracy of an electronic system and observers to estimate distance during helicopter surveys, October 2007, Kleberg and Fisher Counties, Texas, USA.

Evaluation, Method	Observer	*n*	Perpendicular error (m) $\bar{x}$	Perpendicular error (m) SE
Controlled trial				
Electronic device	1	7	1.4	0.44
Mock survey				
Electronic device	1	8	3.9	0.67
	2	8	2.3	0.65
	3	8	2.7	1.07
	Pooled	24	3.0	0.47
Visual estimation	1	15	9.7	3.23
	2	15	9.5	2.02
	3	15	10.7	2.78
	Pooled	45	10.0	1.54

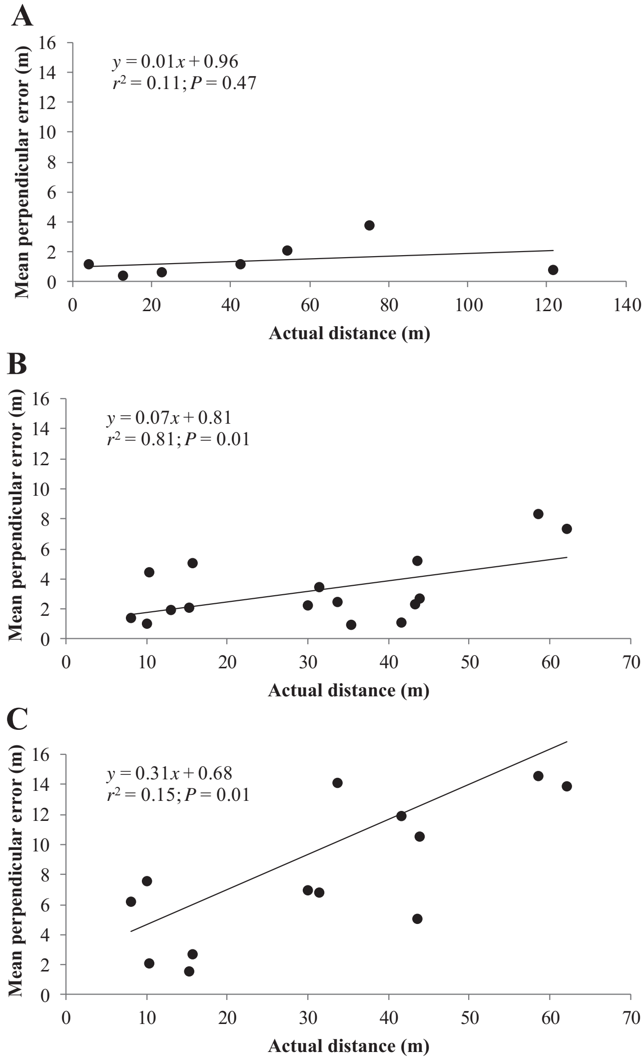

Figure 4. Linear relationship between mean perpendicular-distance error and target distance for (A) controlled trial (electronic system), (B) mock survey (electronic system), and (C) mock survey (visual estimation) of northern bobwhite (*Colinus virginianus*), October 2007, Fisher County, Texas, USA. *P*-value is for significance test of the slope (H_0: $m = 0$).

2 targets located at a distance >60 m appeared to be strongly influencing the relationship (Fig. 4B).

Regarding visual estimation of distance, we documented a weak linear relationship between mean estimated distance and actual distance (Fig. 3C). We also observed a large perpendicular-distance error (10.0 ± 1.5 m; Table 1). Perpendicular-distance error increased about 3.1 m for every 10-m increase in target distance, an increase that was 4× the rate observed for the electronic system (Fig. 4C).

We obtained 175 covey detections (2007) and 74 covey detections (2008) in the Rio Grande Plains and 79 covey detections (2007) and 150 covey detections (2008) in the Rolling Plains. We used a hazard-rate and half-normal model to fit 2007 and 2008 data, respectively, in the Rio Grande Plains (Fig. 5A,B; Table 2). We used a uniform + cosine and a half-normal model to fit 2007 and 2008 data, respectively, in the Rolling Plains (Fig. 5C,D; Table 2). The 2007 histogram for the Rio Grande Plains showed possible evasive movement away from the transect (Fig. 5A). Seven of 8 density estimates exhibited CV within the desired range (i.e., ≤20%), but 95% confidence intervals tended to be wide for sites with low detections (Table 3). Mean covey size was similar among years and ecoregions (Table 3).

DISCUSSION

The electronic system performed well during controlled, mock survey, and field surveys. We observed low error (±1.4 m) for the controlled trial. This setting represented ideal conditions (i.e., no turbulence, no flight motion, and tripod stability). Conditions during field surveys could potentially decrease accuracy of the system. However, our results from the mock survey indicated that the system could produce relatively accurate perpendicular distances even under field conditions; error only increased by ±1.6 m beyond that observed during the controlled trial.

We detected a trend of increasing error with increasing distance to target during the mock survey, a relationship possibly influenced by 2 distant (>60 m) targets. This trend of increasing error with detection distance could be of concern if detections frequently occur >50 m from the transect, as may occur with some species. Pronghorn antelope (*Antilocapra americana*), for example, have been detected at distances 100–200 m away from a transect during aerial-based distance sampling (Johnson et al. 1991). The electronic system may be useful even in these circumstances if most detections occur near the transect and the underlying assumptions of distance sampling are met (Buckland et al. 2001). In addition, truncation of the furthermost detections (e.g., 5%) is recommended to facilitate modeling of the detection function (Buckland et al. 2001). Nevertheless, researchers interested in using this technique should field-test the electronic system for their focal species and habitat prior to surveys to ensure that its use is valid or to identify possible limitations.

We could not evaluate the accuracy of the bobwhite density estimates obtained during the field evaluation of the electronic system because, as with most studies, we did not know

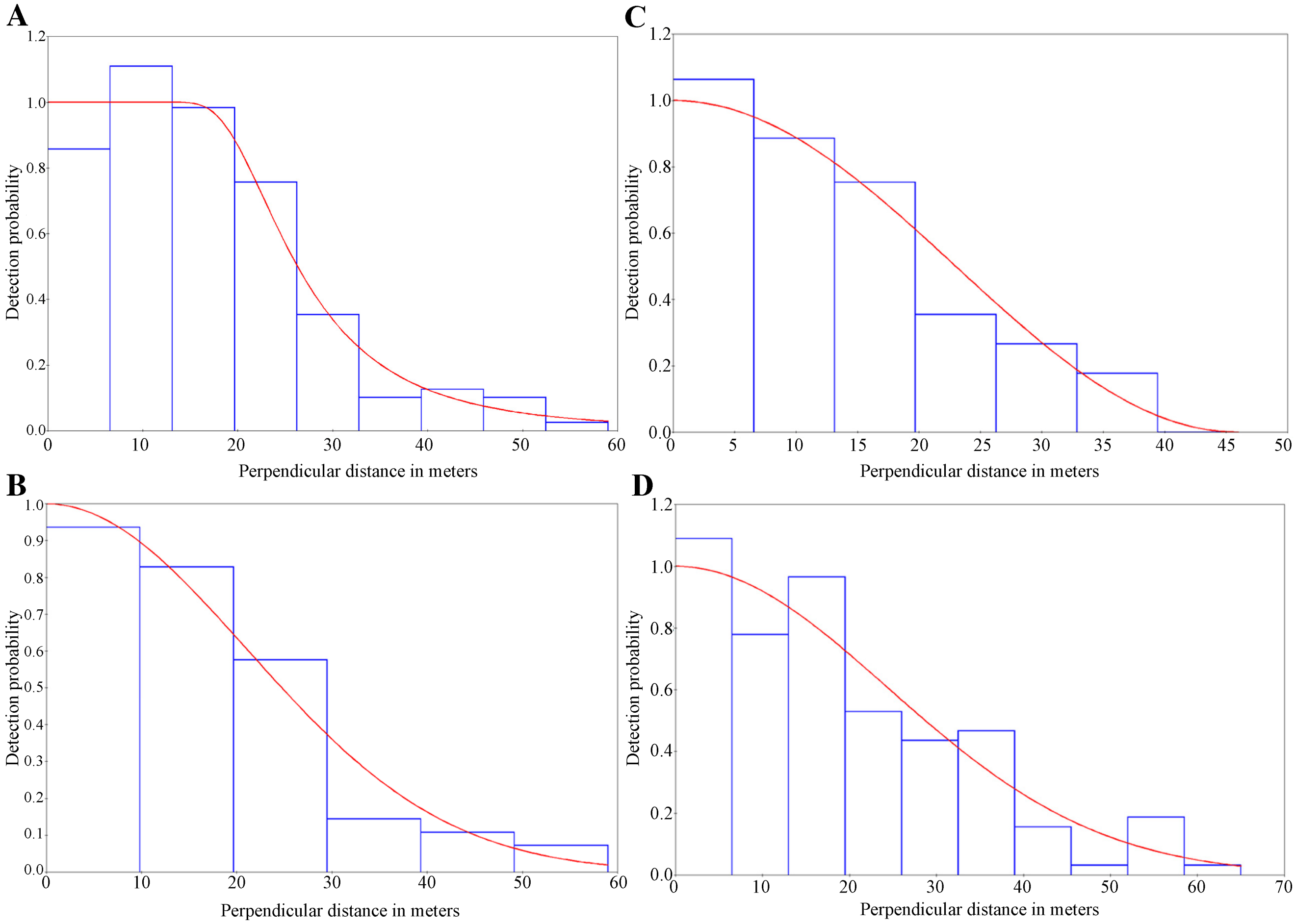

Figure 5. Histograms of perpendicular distances obtained using an electronic system to estimate northern bobwhite (*Colinus virginianus*) density using helicopter surveys in the Rio Grande Plains (Brooks County) during (A) 2007 and (B) 2008 and Rolling Plains (Fisher County) during (C) 2007 and (D) 2008, Texas, USA.

the true density (Schnupp 2009). However, distance sampling and its assumptions have been evaluated for northern bobwhite, and it is considered an appropriate technique for both terrestrial (Guthery 1988) and aerial surveys of the species (Shupe et al. 1987, Rusk et al. 2007, Schnupp 2009). Although accuracy could not be evaluated, we could assess the precision of the density estimates. Coefficients of variation of density estimates consistently were within the recommended range (7 of 8 density estimates had CV <20%). For comparison, Guthery (1988) reported that 16 of 31 density estimates obtained using walk line transects had CV <20%.

We did not obtain the recommended number of detections (60–80) for 6 of the 8 study site–year combinations despite considerable survey effort (92 km/site). Consequently, 95% confidence intervals tended to be wide for study sites with relatively low number of detections. Bobwhite populations on southwestern rangelands are strongly influenced by weather and density fluctuates drastically (Hernández et al. 2005, 2007). Thus, survey effort required to reach a sufficient number of detections or a target level of precision may be considerable during population lows. In these situations, survey effort could continue until the recommended number of encounters is met or a desired precision level is achieved. Obviously, financial and time allocation will dictate the ability to do so.

One advantage of the electronic system over traditional means of collecting distance-sampling data during aerial surveys is that it provides a georeferenced location of each detection and a tracklog. This information can be used to create density-gradient maps using the spatial models option in Program DISTANCE (Buckland et al. 2004, Thomas et al. 2010). Although this is a relatively new option, the program provides researchers with a means to spatially analyze distance-sampling data and permit the relation of density to habitat or spatial variables (Johnson et al. 2009). Another advantage is that the electronic system reduces the number of keystrokes and the need for observers to collect data in such a way that deviates their attention from the survey. Other existing technology exists (e.g., traditional mapping GPS systems) that would have potentially worked for this application but require observers to deviate their attention from the survey to navigate multiple screens within the computer. Additionally, the traditional mapping GPS systems that have this functionality were only available in 1-Hz systems (1 position/sec), which is not adequate for moving applications that are sensitive to GPS latency.

Table 2. Models used and results of fitting a detection function to line-transect data to estimate northern bobwhite (*Colinus virginianus*) density in the Rio Grande Plains (Brooks County) and Rolling Plains (Fisher County), Texas, USA, October–November, 2007 and 2008.

					Goodness-of-fit	
Ecoregion, Year	***n***	**Model**	**AIC**	χ^2	***P*-value**	**df**
Rio Grande Plains						
2007	175	Hazard-rate	641.64	4.65	0.59	6.00
		Hazard-rate + cosine	643.64	4.65	0.46	5.00
		Hazard-rate + simple polynomial	643.64	4.65	0.46	5.00
		Hazard-rate + Hermite polynomial	643.64	4.65	0.46	5.00
		Half-normal	645.57	9.96	0.19	7.00
		Half-normal + cosine	646.67	9.36	0.15	6.00
		Half-normal + Hermite polynomial	647.32	9.92	0.13	6.00
		Half-normal + simple polynomial	647.57	9.96	0.13	6.00
		Uniform + cosine	650.59	13.46	0.06	7.00
		Uniform + simple polynomial	669.87	31.73	0.00	7.00
		Uniform + Hermite polynomial	681.45	39.88	0.00	7.00
		Uniform	769.03	121.59	0.00	7.00
2008	74	Half-normal	219.05	2.76	0.60	4.00
		Hazard-rate	219.43	1.20	0.75	3.00
		Half-normal + simple polynomial	220.77	2.45	0.48	3.00
		Half-normal + cosine	220.96	2.65	0.45	3.00
		Half-normal + Hermite polynomial	221.04	2.74	0.43	3.00
		Hazard-rate + cosine	221.21	4.50	0.34	4.00
		Hazard-rate + Hermite polynomial	221.43	0.99	0.61	2.00
		Hazard-rate + simple polynomial	221.44	1.20	0.55	2.00
		Uniform + cosine	221.48	1.21	0.55	2.00
		Uniform + simple polynomial	229.44	11.58	0.02	4.00
		Uniform + Hermite polynomial	232.67	14.06	0.01	4.00
		Uniform	265.18	46.81	0.00	5.00
Rolling Plains						
2007	79	Uniform + cosine	260.56	2.40	0.79	5.00
		Half-normal	261.20	2.48	0.78	5.00
		Uniform + simple polynomial	262.22	4.12	0.53	5.00
		Half-normal + simple polynomial	262.28	2.34	0.67	4.00
		Half-normal + Hermite polynomial	263.09	2.55	0.64	4.00
		Half-normal + cosine	263.19	2.52	0.64	4.00
		Hazard-rate + simple polynomial	263.36	1.48	0.69	3.00
		Hazard-rate + Hermite polynomial	263.60	1.66	0.65	3.00
		Hazard-rate	264.39	3.14	0.53	4.00
		Hazard-rate + cosine	265.73	3.31	0.35	3.00
		Uniform + Hermite polynomial	271.17	10.84	0.05	5.00
		Uniform	307.45	43.37	0.00	6.00
2008	150	Half-normal	605.91	12.71	0.12	8.00
		Half-normal + simple polynomial	607.61	12.04	0.10	7.00
		Half-normal + cosine	607.71	12.11	0.10	7.00
		Half-normal + Hermite polynomial	607.90	12.69	0.08	7.00
		Uniform + cosine	608.40	14.29	0.07	8.00
		Hazard-rate	608.38	12.55	0.08	7.00
		Hazard-rate + Hermite polynomial	609.73	12.02	0.06	6.00
		Hazard-rate + simple polynomial	609.83	11.97	0.06	6.00
		Hazard-rate + cosine	610.38	12.55	0.05	6.00
		Uniform + simple polynomial	621.05	23.36	0.00	8.00
		Uniform + Hermite polynomial	625.54	26.88	0.00	8.00
		Uniform	690.78	88.93	0.00	9.00

Overall, the electronic system appeared to be an improvement over current methods to estimate distance during line-transect, aerial surveys. Marques et al. (2006) acquired distances to detections by flying away from the transect to a polar bear (*Ursus maritimus*), so that detections could be recorded as GPS coordinates. These coordinates subsequently were used to calculate perpendicular distances to transects. This solution may not always be feasible or logistically possible because the pilot may not observe the initial location of the detection or the detection itself. Also, such additional time could involve more money and may increase the risks of assumption violations. The electronic system also offered other advantages over traditional distance-estimation approaches, such as reduced subjectivity in distance estimation. We observed that measurement error was high and varied considerably when distances were visually estimated, a finding also documented by Rusk (2006). Moreover, the electronic system eliminated observer tendency to round off distances into convenient intervals (Buckland et al. 2001).

In summary, the electronic system provided relatively accurate and precise measurements in both controlled and field settings. Density estimates may still exhibit wide confidence

Table 3. Number of transects (*k*), total transect length (km, *L*), number of northern bobwhite (*Colinus virginianus*) covey detections (*n*), density (bobwhites/ha, $\hat{D}$), 95% confidence intervals ($\hat{D}$ 95% CI), coefficient of variation (CV [$\hat{D}$]), and estimated covey size (*E*[*s*]) obtained using an electronic system during helicopter line-transects in the Rio Grande Plains (Brooks County) and Rolling Plains (Fisher County), Texas, USA, October–November, 2007 and 2008.

Ecoregion, Year, Site	*k*	*L*	*n*	$\hat{D}$	95% CI	CV ($\hat{D}$)	*E*(*s*)
Rio Grande Plains							
2007							
Site 1	23	98.4	61	1.1	0.8–1.4	15.4	8.4
Site 2	23	97.9	114	2.0	1.5–2.5	12.4	8.2
Pooled	46	196.3	175	1.5	1.2–1.9	10.6	
2008							
Site 1	23	98.9	33	0.3	0.1–0.5	63.0	6.2
Site 2	25	95.6	41	0.7	0.5–1.0	18.7	8.5
Pooled	48	194.5	74	0.5	0.3–0.7	16.7	
Rolling Plains							
2007							
Site 1	33	91.2	50	1.2	0.9–1.7	14.1	10.2
Site 2	19	96.1	29	0.6	0.4–0.8	17.6	9.0
Pooled	52	187.3	79	0.8	0.6–1.0	11.6	
2008							
Site 1	34	93.0	98	1.9	1.4–2.6	15.4	10.6
Site 2	19	90.4	52	0.9	0.6–1.3	19.1	9.3
Pooled	53	183.4	150	1.2	0.9–1.6	13.1	

intervals, particularly if the number of detections is low. We recommend that researchers using the electronic system field-test the unit to evaluate its appropriateness and limitations in their particular study. The electronic system appears to be a promising method for estimating density of terrestrial species for which aerial-based distance sampling is an appropriate technique.

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