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Comparative Analysis of Population Estimators in a Known Population of White-Tailed Deer

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ABSTRACT The number of small geographically closed populations of white-tailed deer (*Odocoileus virginianus*) is increasing, and there is little information on the reliability of population estimators at small spatial scales. We compared informal (spotlight, mobile, Hahn, blind, and helicopter) and formal (infrared-triggered camera, distance sampling) population estimators on a known population of white-tailed deer within a 214 ha game fenced enclosure. Estimated sex ratios and abundance were compared to known values. Precision (% coefficient of variation) and accuracy (% relative bias) of all methods were highly variable within and across years. Precision ranged from 4% (blind survey in the afternoon) to 70% (Hahn) and 11% to 26% for informal and distance sampling estimates respectively. Relative bias ranged from -67% (helicopter) to 42% (spotlight) and -49% (camera) to -11% (camera) for informal and formal estimators respectively. All sex ratio estimates demonstrated bias towards does in August and estimates varied greatly across years in September. It is important that biologists and managers consider the variability inherent with deer abundance and sex ratio estimators in small geographically closed populations. Meeting assumptions in survey design and implementation is critical. Comparing estimates to known values in environmental settings that estimators will be applied is essential.

Key words. abundance, herd composition, known population, *Odocoileus virginianus*, population estimators, sex ratio, Texas.

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Game fencing is often used to obtain geographic closure and maximize productivity of white-tailed deer (*Odocoileus virginianus*) herds. An important attribute of deer herd management is estimating herd composition (i.e., buck:doe and fawn:doe ratios) and abundance parameters reliably (Whipple et al. 1994). The accuracy and precision of an estimator becomes especially important as size of the enclosure decreases, where small changes in abundance or herd composition may significantly alter herd and habitat sustainability.

The average tract size held by landowners in Texas is decreasing (Wilkins et al. 2000) and is now 213 ha (USDA 2009). Furthermore, game fences are common in the Edwards Plateau (Wagner 2006). Small geographically closed populations of deer are a consequence of land use trends in Texas, wherein evaluation of population estimators is unexplored.

Numerous methods are available to estimate population abundance and herd composition: spotlight (Young et al. 1995), Hahn and mobile (Hahn 1949), helicopter (Synatske 1984), infrared-triggered camera (Jacobson et al. 1997), and distance sampling (Buckland et al. 2001and Pierce 2000). The reliability of estimates obtained from these techniques, however, is unclear because estimates have not been compared to known numbers of deer (Jacobson et al. 1997 and McCullough 1982). Furthermore, contemporary techniques such as blind surveys are used to estimate abundance and sex ratios but have not been evaluated. Because logistics are a major factor in selecting a survey, the time or effort required to conduct each technique should be considered and compared to the accuracy and precision of estimates. Comparisons of these estimators under known conditions within a small, closed population of deer will be valuable to managers.

An evaluation of abundance and sex ratio estimators should consider whether all animals in the population are assumed to be detected (Lancia et al. 1996:218). Many estimators assume all animals are detected within the estimated sampled area, which we call informal estimates. For inclusive evaluation of methods available to managers, we evaluated informal and formal methods in a 214 ha enclosure with known abundances and sex ratios. We treat spotlight, mobile, Hahn, blind, and helicopter surveys as informal methods and infrared-triggered cameras and distance sampling as formal methods. To allow biologists and managers, in Texas and elsewhere, to make informed decisions about methods to estimate population parameters on small geographically closed populations of deer, we evaluated the 7 informal and formal methods, our objective in this study.

STUDY AREA

We evaluated abundance and herd composition estimators in a game fenced (2.44 m, netted wire) enclosure on Mason Mountain Wildlife Management Area (MMWMA), located in Mason County, Texas, situated in the Central Mineral Ecological Region of the Edwards Plateau. The enclosure was 214 ha and 0.95 km wide (E-W) by 2.4 km long (N-S). Average annual rainfall (6 yr average) was 67.5 cm but varied considerably among years within the study (Fig. 1). Two permanent water sources, 1 livestock water trough, and 1 man made impoundment (Comanche lake) were available in addition to several seasonal pools of water in low lying areas and natural springs. Topography is undulating, ranging from 518 m to 566 m in elevation and included moderately steep outcroppings of granite rock. Vegetation types present in the enclosure included: blackjack (*Quercus marilandica*) - post oak (*Q. stellata*) woodlands, live oak (*Q. fusiformis*) woodlands, mixed oak woodlands, and mesquite (*Prosopis glandulosa*) whitebrush (*Aloysia gratissima*) associations. No disturbance from cattle grazing or prescribed fire occurred during the study.

METHODS

Design

We compared a known number of deer (research herd) to each method's estimate in 2006, 2007 and 2008. Each year the herd was established, surveyed and then removed. We followed Texas Parks and Wildlife (TPWD) and Texas State University protocols concerning the ethical treatment of animals in the capture, transport, and removal of all deer in the study.

Herd Establishment.— Department (TPWD) personnel obtained deer from private properties and TPWD State Parks, using privately contracted trappers and TPWD personnel and equipment. We obtained all deer in Central Texas each year within the months of January through April by drop netting (Peterson et al. 2003) and chemical immobilization projectile (Amass and Drew 2005). Captured deer were transported and released in the study area at a target density of 0.36 deer per ha and a male:female ratio of 0.5 (Table 1).

Upon capture, all deer were aged by examining tooth wear and replacement (Cain and Wallace 2003) and categorized: juvenile (< 1 yr), immature (1.5 to 3.5 yr), and mature (> 3.5 yr). Our objective for collection included 42% juvenile, 34% immature, and 24% mature to represent all age classes of deer in the research herd. We marked all captured deer with cattle ear tags (5 x 5 cm) in both ears. Ear tags were numbered and color coordinated by year, yielding a unique combination for all individuals in the entire study. Following release (May – July), deer acclimatized to the study area and we monitored mortality.

Survey.— We conducted all surveys (formal and informal) in August and September, the time in which many biologists and managers estimate abundance and herd composition in Texas. All methods (excluding helicopter) were conducted with and without bait (pre-bait and baited). We replicated each method 4 times in each setting; one camera survey was conducted each setting and helicopter surveys were conducted exclusively in baited settings (Table 2). Because of bait station placement, spotlight, mobile and Hahn included bait stations in their respective sample area (Fig. 2A, 2B). Surveys were not conducted during rainfall.

Bait Stations.— Baiting deer is legal in Texas and shelled corn (bait) is often available or used while estimating abundance and sex ratios. Although baiting deer could bias estimates of some methods, others use bait (blind, camera). We established 5 bait stations based on visibility and proximity to existing roads in an attempt to maintain consistency with private landowner practices for this area (Fig. 2A). Stations were placed a minimum of 0.7 km apart. Commercially available spin-cast feeders distributed bait and were calibrated to feed 1.13 kg of corn per feeding by adjusting spin duration. Spin duration ranged from 14 to 20 seconds. We adjusted feeding time to dispense daily at sunrise and 30 minutes before sunset during baited periods.

Harvest.— Immediately following the surveys (October – December), we harvested or accounted for all deer, establishing the known population each year. We considered the removal complete when infrared-triggered cameras were unable to detect observations of deer for a 2 week period at bait stations ($n = 5$). Following harvest we monitored the enclosure searching for tracks and fecal pellet groups by foot and vehicle ($\geq$ 50 man hrs) to ensure all deer were removed. All harvest efforts were completed by 31 December each year.

Informal

Spotlight.— We established a 7.34 km spotlight route along existing roads and included all vegetation types within the enclosure (Fig. 2A). Surveys were initiated approximately 45 minutes after sundown. Observers were positioned in seats mounted in the rear of the vehicle and equipped with 100,000 candle power spotlights and 10x42 binoculars. The survey route was driven at approximately 8.0 kph.

We collected a sampled area estimate each year by estimating the perpendicular distance a deer could be observed from both sides of the vehicle. The initial distance was obtained at the beginning of the line and repeated at 169 m intervals. We obtained distances to the enclosure boundary at the intervals when the boundary was visible from the route. We used Bushnell Yardage Pro 500 (Bushnell Inc., Overland Park, KS) rangefinders during daylight hours to reduce observer bias (Fafarman and DeYoung 1986). The mean distance on each side of the vehicle and length of line resulted in the sample area (Hahn 1949, Fafarman and DeYoung 1986, Shult and Armstrong 1999). All deer observed were recorded as buck, doe, fawn, or unidentified.

Population estimates were derived by

$$N = 214 / ((S_b+S_d+S_f+S_u / A)) \qquad (1)$$

where, A is the estimated sampled area of the route and S_b,S_d,S_f, and S_u were the respective counts of bucks, does, fawns, and deer unidentified to sex and age class. The mean of 4 surveys (N) served as the population estimate.

Mobile.— To include all vegetation types within the enclosure the mobile route and sampled area estimate did not differ from the spotlight route (Fig. 2A). We initiated surveys approximately 30 minutes before official sunset. The survey route was driven at approximately 8.0 kph by a driver. One observer recorded deer encountered as buck, doe, fawn, or unidentified, aided with 10x42 binoculars. Population estimates were derived in the same manner as the spotlight method (equation 1).

Hahn.— The 3.98 km route traversed a north to south bearing (Fig. 2B). The relatively narrow width of the enclosure precluded the establishment of a straight west to east route as suggested by Hahn (1949) and as a result, traversed a north to south bearing. We collected the sampled area estimate each year in the same manner as the spotlight and mobile methods at 91.4 m intervals. The survey began approximately 30 minutes before official sunset, with one observer at normal walking pace. Deer or groups of deer encountered were recorded as buck, doe, fawn, or unidentified with the aid of handheld binoculars. Population estimates were derived in the same manner as the spotlight and mobile methods (equation 1).

Blind.— One deer blind was placed an average distance of 62 m from feeders at each bait station. Construction consisted of 1.2 m wide and 1.8 m tall plywood boxes providing a 180º field of view through 20 cm openings. Three of the 5 blinds were positioned at ground level, 1 on granite rock 2 m above ground level, and another on a 1.8 m tower platform.

A blind survey consisted of a single observer occupying the blind for 120 minutes. All 5 blinds were occupied concurrently during each survey. Evening (PM) surveys began 90 minutes before sunset; morning (AM) surveys began 30 minutes before sunrise. Observers continuously recorded the presence of deer in the field of view at the blind. We utilized morphological characteristics based on observer’s judgment to record unique sightings of deer at blinds. We defined unique as an individual deer not previously observed at the blind during that survey. Observations were confirmed using tag numbers of individual deer and recorded as buck, doe, fawn, or unidentified with the aid of binoculars. We used confirmation of tag observations to evaluate the observer's accuracy to identify unique deer and corrected all observer mistakes before conducting population estimates.

We derived population estimates by summing unique deer sightings at each blind for AM and PM surveys during pre-bait and baited periods: Each respective (AM and PM) survey was replicated 4 times. The abundance estimate was derived by

$$N = S_b+S_d+S_f \tag{2}$$

where S_b, S_d, S_f is the respective sum of unique bucks, does, and fawns at all 5 blinds in each survey and N is the sum for each survey in the AM or PM survey. We excluded unidentified deer from the estimate because unique observations were required. The mean of respective surveys (N) was the population estimate.

Summing unique sightings of deer at each blind introduces the possibility of recording individuals more than once (multiple visits to different blinds). We investigated multiple sighting occurrences in 2007 and 2008 as all deer in the population were marked.

Helicopter.— We conducted 1-AM and 1-PM aerial survey during baited periods in 2007 and 2008. Surveys employed a contracted pilot and observer in a Robison R22 helicopter. The entire study area was flown in east to west transects in approximately 183 m strips at an average speed of 41 kph and a height of 75 m. Observers counted deer within the estimated strip (91 m) on each side of the helicopter. Deer observed were recorded as buck, doe, and fawn. The population estimate was the sum of all deer observed.

Formal

Infrared-triggered camera.— We placed one camera at each of the 5 bait stations (1 camera per 43 ha). Leaf River models DC-1BU and DC-2BU (Leaf River Outdoor Products, Taylorsville, MS) were positioned facing north towards the bait station on a stationary post at a height of 1 m and distance of 5 m from each automatic spin cast feeder. We conducted camera surveys for 14 days in both pre-bait and baited periods. Cameras operated 24 hrs a day, detected movement at maximum distance (17 m), and captured 1 photograph when movement was detected. We programmed cameras to pause for 3 minutes after taking a photograph. The time and date stamp feature in addition to auto flash feature were activated in all units. Photographs were stored in digital format (.jpeg) on Compact Flash (CF) cards. CF cards were replaced every third day, images downloaded, numbered, and stored for analysis.

The population estimate was determined using Jacobson et al.'s (1997) methodology. We identified the number of branch antlered bucks and the number of spikes, does, and fawns were estimated. We used antlers from harvested bucks, tag numbers, and morphological characteristics to identify individual branch-antlered deer in photographs. The ratio of branch-antlered bucks to spikes was as follows:

$$P_s = N_s/N_b \qquad (3)$$

where

P_s = ratio of spikes : branch-antlered bucks

N_s = total number of spikes occurring in photographs

N_b = total number of branch-antlered bucks occurring in photographs

The estimated buck population (B) was calculated as:

$$B = (B_i \text{ X } P_s) + B_i$$

where

B_i = identified branch-antlered deer

The total number of does and fawns in the population was calculated by using occurrences of each respective age or sex in photographs (adult doe:adult buck, and fawn:adult doe) and the estimated buck population, i.e.,

$$P_d = N_d/N_b$$

where

P_d = estimated ratio of does:bucks

N_d = total adult antlerless deer occurrence in photographs

N_b = total adult buck occurrence in photographs

The doe population (D) was estimated as:

$$D = B \text{ X } P_d$$

We calculated the fawn population (F) with the same method using the occurrences in photographs to establish the ratio of fawns:adult doe. The population estimate was the sum of each segment (buck (B), doe (D), and fawn (F)) for each year.

Distance Sampling.— Distance sampling can be an effective tool to estimate deer abundance in the Edwards Plateau of Texas (Pierce 2000) where the estimate is a function of distance from the line to each object detected (Buckland et al. 2001). Data were collected concurrently with the spotlight method (Pierce 2000). We conducted 4 surveys in the pre-bait and 4 surveys in the baited period. Distance and azimuth to deer or groups of deer observed were collected using Leupold RXB - IV (Leopold Inc., Beaverton, OR) rangefinder with compass. An observer collected the distance and azimuth data while the second observer held the light and reported the number and sex of deer seen (buck, doe, fawn, unidentified). The collected information was relayed to the driver who recorded georeferenced information into CyberTracker field data-collection system (CyberTracker Conservation, Bellville, Cape Town, South Africa) on a Garmin iQue M5 (Garmin International, Olathe, KS) (Lockwood 2009). Perpendicular distances obtained from distance and azimuth data (4 surveys per period) were used for analysis in the software program DISTANCE 5.0 (Thomas et al. 2010). The following detection models were considered as possible estimators: half-normal cosine, uniform cosine, and hazard polynomial. We used the model with the smallest Akaike's Information Criterion (AIC; Buckland et al. 2001) value as the abundance estimate in any year and period (pre-bait and bait). No data were truncated, grouped, or otherwise manipulated prior to DISTANCE analysis (Lockwood 2009).

Comparative Analysis

We measured precision by coefficient of variation (%CV), the standard deviation of the replicate estimates divided by the estimate and expressed as a percent. We assessed accuracy for each survey by percent relative bias (%RB), the deviation of the estimate from the known number, divided by the known and expressed as a percent. Sex ratio estimates were summarized for each method as the total bucks and does observed (buck:doe) ratio and compared to the known ratio for each method. Time required to complete surveys were ranked numerically (1-7), from highest to lowest commitment of time to survey and produce an estimate. Time to produce estimate included all required data analysis following data collection in the field. Survey hours were a product of numbers of observers and number of hours to complete each method and compile data.

RESULTS

Spotlight

We observed 491 deer (238 pre-bait, 253 baited) in 24 surveys. Sampled area did not change in 2006 or 2007; however it decreased drastically (23%) in 2008.

Percent CV of the spotlight estimate in pre-bait periods ranged from 10% to 51% across all years (Table 3). Pre-bait estimates were positively biased (%RB: 9% and 42%) in years with high precision (%CV: 2006: 18%, 2008: 10%). The 2007 estimate was negatively biased (%RB: -27%) and coupled with the lowest precision (%CV: 51%) within the period. Pre-bait estimates were not consistently precise and unbiased. In the baited period, estimates had lower precision (%CV: 32% and 51%) in 2006 and 2008, respectively. Similar to the pre-bait period estimates, we observed positive bias in 2006 and 2008 (%RB: 28% and 20%), and negative bias in 2007 (%RB: -16%).

Mobile

We observed 448 deer (174 pre-bait, 274 baited) in 24 surveys. Changes in 2008 sampled area were identical (23% decrease) to spotlight as both methods used the same route and sampled area.

Precision ranged from 35% to 51% in pre-bait periods (Table 3). Pre-bait estimates demonstrated negative bias in all years and ranged from -4 to -41 (%RB). Baited period estimates resulted in higher precision (30%, 16%, and 24%) although all estimates were positively biased (%RB: 17, 13, and 27) across all years.

Hahn

We observed 281 deer (116 pre-bait, 102 baited) in 24 surveys. Sampled area did not change in 2 of 3 years; however similar to the spotlight and mobile sampled area estimate, the 2008 estimate decreased dramatically (16%).

Precision ranged from 28% to 70% in pre-bait periods (Table 3). The 2006 estimate demonstrated high accuracy (3 %RB), although all other estimates were heavily biased (%RB: 41, 2007 and -45, 2008). Baited period estimates demonstrated similar precision (52%, 26%, and 42%) across all years. Accuracy ranged from -10 to -4 (%RB) across all years within the baited period.

Blind

Blind surveys (AM and PM) recorded 376 unique deer sightings in pre-bait periods and 1108 in baited periods. The few sightings of deer in pre-bait resulted in biased and imprecise estimates of population abundance (Table 3). Conversely, deer sightings at baited stations were less biased. Coefficient of variation was lowest among all informal methods for blind surveys in 2006 and 2008 (2006: 13% AM, 6% PM; 2008: 12% AM, 4% PM). Furthermore, precision was coupled with higher accuracy and ranged from -20 to 5 (%RB) in 2006 and 2008. Although estimates were precise in 2 of 3 years, the 2007 mean was much less accurate (%RB:-47 AM and -31 PM) and precision was lower (CV: 27% AM and 26% PM).

We evaluated potential bias associated with summing unique deer sightings (multiple counts) in 2007 and 2008, by recording tag numbers on marked deer observed at blinds. Among unique deer sightings, we observed 21 multiple counts in 2007 (7%, *n* = 309) and 84 multiple counts in 2008 (22%, *n* = 387). Deer visited multiple blinds at a higher frequency during PM surveys in 2007 (13) and there were no differences in multiple counts between AM and PM surveys in 2008. Among both years (2007 and 2008), we experienced 1 multiple count in every 6.6 unique deer sightings. Finally, observers were accurate in determining unique deer observations as 20 mistakes occurred (0.4%) in all deer observations (*n* = 5,433).

Helicopter

We conducted an AM and PM estimate in 2007 and 2008. In each year, counts in AM and PM only differed by 4-5 deer (Table 4). Although helicopter surveys were completed quickly, all estimates were negatively biased with %RB ranging from -67% to -35%. We were unable to evaluate precision as only 1 survey was conducted in each period.

Infrared-Triggered Camera

Camera's captured 59 images with deer in pre-bait and 9,995 images in the baited periods. Similar to the blind count results, pre-bait had too few observations to warrant an unbiased estimate; hence, only baited results are presented (Table 5). We identified 54 of 55 (98%) of branch-antlered deer in the entire study. Furthermore, all branch-antlered deer were detected in photographs by day 6 (Fig. 3). Additionally, we evaluated antlerless (adult doe) photographic capture rates by identifying antlerless deer by tag number. In 2007 and 2008 we identified 65 of 66 (98%) adult antlerless deer. Although capture and detection rates for individual deer were very favorable, the photographic occurrence or ratio (number of bucks in photographs:number of does in photographs) were not proportionate to the known ratio (Table 5). Using the Jacobson et al. (1997) methodology to estimate abundance, all estimates were negatively biased (%RB: -49%, -11%, and -40%) by year respectively.

Distance Sampling

Deer observations did not differ with spotlight observations as both methods were collected concurrently. The following models were chosen based on minimum AIC values: hazard polynomial (2006; AIC: 1060.9), uniform cosine (2007; AIC: 635.6), and half-normal cosine (2008; AIC: 702.2). Bias ranged from -43 to -27 and -12 to -42 (%RB) in pre-bait and baited periods, respectively (Table 6). Precision ranged from 11% to 22% in pre-bait periods and 18% to 26% in baited periods. Distance sampling demonstrated better precision in pre-bait periods although bias was lower within baited periods.

Herd Composition

We excluded fawn:doe ratio estimates and pre-bait results of blind and camera methods due to small sample size. Spotlight and distance sampling results are presented as spotlight (Table 7). We observed bias towards does in pre-bait ratio estimates for the spotlight, Hahn, and mobile methods across all years. The spotlight estimate was the most accurate in 2007 (0.44 estimate; 0.58 known), and the mobile surveys were the most accurate in 2006 (0.44 estimate; 0.79 known) and 2008 (0.58 estimate; 0.71 known). The Hahn method was the least accurate among pre-bait ratio estimates. Analogous to pre-bait, mobile surveys in the baited period had the most accurate ratio estimates in 2006 (0.78

estimate; 0.79 known) and 2008 (0.69 estimate; 0.71 known). Spotlight had the greatest accuracy in 2007 (0.57 estimate; 0.58 known). Camera estimates demonstrated bias towards bucks across all years. Although blind surveys resulted in biased estimates in any given year, AM ratio estimates were more consistent across years than all other methods. Helicopter ratio estimates demonstrated bias towards does in 2007 and bias towards bucks in 2008.

Survey Effort

The 2 most time consuming techniques were the camera and blind surveys, ranking first and second in survey effort. As camera surveys were efficient in collecting photographs, intensive survey hours were required to examine pictures (160 survey hrs), consuming the bulk of total survey hours (166 survey hrs). Conversely, many blind survey hours were required to collect data in the field as 5 observers are needed for each survey (40 survey hrs) and survey hours for data analysis were few (1 survey hr). Spotlight and distance sampling survey effort were similar (26 and 26.5 survey hrs) and ranked third and fourth. Mobile (11 survey hrs) and Hahn (7 survey hrs) ranked fifth and sixth. Helicopter required the least survey effort (2 survey hrs) and ranked seventh.

DISCUSSION

In most cases, biologists and managers conduct surveys to estimate population size and sex ratios to make harvest recommendations. The goal of the recommendations are to increase productivity of the habitat and health of the associated deer herd. By strictly using any one of the survey methods we evaluated, it is obvious that harvest decisions would be erroneous if managers do not consider the uncertainty and bias involved (McCullough

1994). The amount of literature on this subject suggests that the bias and imprecision we observed is not new, although known populations are rarely used for comparison. Additionally, evaluating methods within the environmental settings in which they will be used is essential. This is important because many different settings exist in Texas where deer management is conducted (enclosure size, not enclosed, bait presence, bait type etc.). These variables can influence any methods assumptions, and deer associations with habitat types. For our evaluation, no single method was superior in both accuracy and precision. It is important that managers consider these flaws when applying methods within a small geographically closed population. Overlooking the variation we observed in relative bias is dangerous and can lead to mismanagement of a species (Pierce 2000).

Informal Methods

Spotlight, mobile, and Hahn methods rely on meeting several assumptions to obtain reliable estimates: deer are evenly distributed, only deer within the sampled area are counted, every deer has the same probability of detection; and deer are only counted once (Young et al. 1995). These assumptions are often difficult to meet (Pierce 2000). This could explain the high variability in precision and accuracy in spotlight, mobile, and Hahn methods, as all share the same assumptions. Additionally, sampled area changed dramatically during the study in 2008. We attribute this change to unseasonably high rainfall during 2007 (Fig. 1), when warm season grasses were especially productive. Little bluestem (*Schizachyrium scoparium*), a dominant grass in the study area, matured in late September after the 2007 survey period resulting in reduced sampled area in 2008.

There are variables that may influence deer behavior which in turn, may impact detectability. Temperature, humidity, cloud cover, dew, and precipitation may influence deer behavior (Progulske and Duerre 1964). Hahn (1949) found significant effects of humidity and cloud cover on deer activity in the Edward’s Plateau of Texas, although, managers in Texas regularly conduct surveys without regard to these variables. Yet, issues with detectability, sampled area, and environmental factors suggest high variability in precision and accuracy of estimates can be expected.

Baiting deer can also violate assumptions of methods when bait is not equally distributed among habitat types. This is similar to sampling issues recognized by Hahn (1949) where deer were attracted to roads due to favorable stages of plant succession that increase forage availability. In both cases deer can be attracted to the area sampled thereby positively biasing estimates. Indeed, positive bias during baited periods in this study is likely because 2 or more bait stations were included in all (spotlight, mobile, and Hahn) method’s sampled area. We did observe a consistent positive bias during the mobile survey although the range in bias of spotlight, mobile, and Hahn was similar among pre-bait and baited periods. While baiting did attract deer, a positive bias was only linked to surveying when bait had been dispensed within the hour (mobile survey).

Shelled corn is effective at attracting deer (Koerth and Kroll 2000) and some methods rely on bait to be effective. Blind surveys were ineffective without bait and shelled corn was effective at attracting deer. Among informal methods, blind surveys were precise in 2 of 3 years as coefficient of variation ranged from 4% to 13% in 2006 and 2008. Multiple counts of deer, however, were frequent and influenced bias within the estimate. Precision was notably lower and estimates were more severely biased in 2007. The low precision and increased negative bias in 2007 coincided with above average rainfall and subsequent forage availability in habitats which affected the frequency that deer visited bait.

Although the visitation frequency (sighting frequency) at bait stations varied considerably in 2007, 2008 and in both AM and PM, Weckerly and Foster (2010) were able to obtain reliable estimates in blind surveys using Bowden's estimator. Bowden's estimator was able to accommodate differences in individual sighting frequencies or sighting heterogeneity. Accommodating sighting heterogeneity while counting deer from blinds or within sampled area (informal methods), is not possible. Until a reasonable approach or method is designed to account for sighting heterogeneity using these methods, one should assume a similar lack of accuracy and precision will persist.

Formal Methods

Both formal methods were negatively biased in all years. In the camera estimate, sex bias is known to occur (Jacobson et al. 1997, Koerth et al. 1997, Moore 2008). Although, increased camera density (>1/65 ha) was suggested to possibly alleviate bias (Jacobson et al. 1997), the high camera density we had (1/43 ha) did not alleviate the sex ratio bias. In place of photographic (doe:buck and fawn:doe) ratios, it may be practical to use sex ratio data obtained from a method that is less biased to improve accuracy in the camera method. Although our results exhibit accurate detection of branch antlered deer, accurately recording the number of branch antlered bucks depends on the observers correctly identifying deer in photographs. As Jacobson et al. (1997) has demonstrated, observers with a minimum of 2 years experience observing deer were able to correctly identify deer in a sample of photographs.

Distance sampling estimates were negatively biased, as all estimates were below the known population. Precision among years and periods were superior to any informal method excluding blind surveys. Although precise, the method was negatively biased indicating assumptions may have been violated. Three assumptions are critical to obtaining reliable estimates: objects on the line are always detected, objects are detected at their original location, and measurements are exact (Buckland et al. 2001). Observers were trained, devices calibrated (Koenen et al. 2001), and no evidence of deer moving in response to observers presence was observed, yet, the bias could originate by sampling design. Buckland et al. (2001) stresses the importance of placing lines randomly. By simply using existing roads to sample small geographically closed populations, it is likely that a representative sample of relevant distances was not obtained.

Determining sex ratio estimates assumes all animals are observed with the same probability (Downing et al. 1977). All informal methods were biased towards does in pre-bait periods indicating bucks were less observable than does. We observed improved accuracy in baited periods in many methods although results were variable. Although biased, blind surveys in the morning (AM) appeared more reliable among all sex ratio estimates across years. Additionally, accuracy of sex ratio estimates in mobile surveys were superior to all other methods in 2 of 3 years. However, the biased estimate we observed in 2007 (0.43 estimate; 0.58 known) questions the reliability of the method to estimate sex ratios.

Management Implications

Many methods are applied in Texas over a variety of environmental settings. The methods we reviewed are used because they are considered practical to implement. Our objective was to determine if any traditionally employed methods provide accurate and precise estimates of population size and sex ratios in a small, closed population of deer. Our findings provide little evidence that practical results will derive from a method that are considered practical to implement. All methods were determined to be biased and imprecise among years; however some methods demonstrated useful attributes. Methods with useful attributes were related to a high cost of many survey hours. Improved precision and accuracy may be attainable using camera data to identify branched-antlered deer and AM blind count data to determine herd composition. The 2 methods combined appear to provide the most reliable population size and herd composition information; however, resource managers should not expect perfection. Stresses in time and resources should also be considered when determining what method(s) to apply. Additionally, harvest data and habitat evaluations should always be integrated into any deer management practice. Lastly, Meeting assumptions in survey design and implementation is critical. Methods that deal explicitly with sighting heterogeneity should provide more reliable estimates. Our strongest recommendation is to compare methods to known values in the environmental conditions that the methods will be used.

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Associate Editor:

Figure Legend

Fig. 1. Accumulation of precipitation at Mason Mountain Wildlife Management Area, Mason County, Texas, USA, 2006-2008. Average rainfall represents data collected in the years, 2002-2008.

Fig. 2A. Map of the 214 ha enclosure, location of bait stations and survey routes of spotlight, distance sampling and mobile methods, Mason Mountain Wildlife Management Area, Mason County, Texas, USA.

Fig. 2B. Map of the 214 ha enclosure and survey route of the Hahn method, Mason Mountain Wildlife Management Area, Mason County, Texas, USA.

Fig. 3. Number of days to photograph all branch-antlered deer in the 214 ha enclosure with infrared-triggered cameras, 2006-2008, Mason Mountain Wildlife Management Area, Mason County, Texas, USA.

Table 1. Number of deer (buck, doe, and fawn), alive during surveys the 214 ha enclosure, Mason Mountain Wildlife Management Area, Mason County, Texas, 2006-2008.

	2006	2007	2008
Bucks	25	22	20
Does	32	38	28
Fawns [a]	2	3	0
(N) Known Population	59	63	48
Known Sex Ratio (Buck:Doe)	0.78	0.58	0.71

[a] Fawns born during acclimation and survivied to surveys

Table 2. Temporal sequence and number of surveys to data collections by method, Mason Mountain Wildlife Management Area, 2006 - 2008. Bait acclimation occurred 15 August - 7 September.

	Pre-bait	**Baited**
	1 Aug - 15 Aug	7 Sept - 30 Sept
Spotlight	4	4
Mobile	4	4
Hahn	4	4
Blind Counts[a]	8	8
Helicopter[c]	0	2
Camera[b]	1	1
Distance Sampling	4	4

[a] Blind counts represent 4 AM and 4 PM in each setting.

[b] Camera operated for total of 14 days in each setting (pre-bait and baited).

[c] Helicopter method conducted in AM and PM in 2007 and 2008.

Table 3. Informal abundance estimates (by method) in the 214 ha enclosure, Mason Mountian Wildlife Management Area, Mason County, 2006-2008. Percent relative bias (%RB) calculated in excel using % RB = ((Mean-N) / N)*100. Percent CV calculated in excel using %CV=(Sdmean/Mean)*100.

2006 (*N* = 59)						
		Spotlight	Hahn	Mobile	Blind	
					AM	PM
A - Pre-bait						
	Mean	64.29	60.81	46.51	19.25	25
	% RB	8.97	3.07	-21.17	-67.37	-57.63
	% CV	17.55	28.02	51.04	23.38	17.28
B - Baited						
	Mean	75.9	53.4	69.1	53.3	47
	% RB	28.64	-9.49	17.12	-9.66	-20.34
	% CV	32.4	52.1	30.4	12.95	6.26
2007 (*N* = 63)						
A - Pre-bait						
	Mean	45.82	88.99	36.93	10.5	15
	% RB	-27.27	41.25	-41.38	-83.33	-76.19
	% CV	50.75	31.27	34.47	29.61	33.99
B - Baited						
	Mean	52.66	60.81	71.13	33.25	43.25
	% RB	-16.41	-3.48	12.90	-47.22	-31.35
	% CV	20.51	25.66	16.32	27.05	25.56
2008 (*N* = 48)						
A - Pre-bait						
	Mean	68.21	26.33	46.07	6	11.25
	% RB	42.10	-45.15	-4.02	-87.50	-76.56
	% CV	9.83	70.13	36.08	36	40.65
B - Baited						
	Mean	57.58	43.88	61.13	45.75	50.5
	% RB	19.96	-8.58	27.35	-4.69	5.21
	% CV	51.09	42.08	23.83	11.62	4.12

Table 4. Results of the helicopter method in the 214 ha enclosure, Mason Mountain Wildlife Management Area, Percent relative bias (%RB) values calculated in excel using % RB = ((Total-*N*) / *N*)*100.

	2007 (*N*=63)		**2008 (*N*=48)**	
	AM	**PM**	**AM**	**PM**
Bucks	7	3	10	8
Does	13	14	8	6
Fawns	6	4	13	13
Total (Estimate)	26	21	31	27
% RB	-58.73	-66.67	-35.42	-43.75

Table 5. Photographic occurrence and the camera estimate in a 214 ha enclosure, Mason Mountain Wildlife Management Area, Mason County, 2006-2008. Percent relative bias (%RB) calculated as ((Estimate-*N*) / *N*)*100.

Baited	Year		
	2006 (*N* =59)	**2007 (*N* =63)**	**2008 (*N* =48)**
No. Photographs[a]	2683	3195	4117
No. Branch Antlered[b]	18/18	20/20	16/17
No. Antlerless[b,d]	0[c]/33	38/38	27/28
Branch Occurrence	2501	1349	3723
Spike Occurrence	71	64	202
Adult Buck Occurrence	2642	1748	4167
Adult Doe Occurrence	1613	2718	3015
Fawn Occurrence	0	207	0
Estimate	30	56	29
% RB	-49.15	-11.11	-39.58

[a] Sum of pictures with deer present.

[b] Number photographed/known number of deer.

[c] Antlerless tag numbers not recorded in 2006.

[d] Adult doe identified by tag numbers.

Table 6. Summary of detection models, Akaike's Information Criterion (AIC) values and distance sampling estimates, in a 214 ha enclosure, Mason Mountain Wildlife Management Area, Mason County, 2006-2008. Percent relative bias (%RB) calculated as ((Estimate-*N*) / *N*)*100.

	Year	Model	AIC	Setting	Estimate	% RB	% CV
N =59	2006	Hazard Polynomial	1060.99	Pre-bait	43.03	-27.07	11.26
				Baited	52.06	-11.76	18
N =63	2007	Uniform	635.63	Pre-bait	36.07	-42.75	22.1
				Baited	36.85	-41.51	25.69
N =48	2008	Half-Normal	702.21	Pre-bait	31.37	-34.65	17
				Baited	34.52	-28.08	25.94

Table 7. Buck:doe ratio estimates of 6 different methods and results by method in a 214 ha enclosure, Mason Mountian Wildlife Management Area, Mason County, 2006-2008.

	2006	2007	2008
	Known Ratio = .78	Known Ratio = .58	Known Ratio = .71
A - Pre-Bait Ratio Estimates			
Spotlight	0.42	0.44	0.41
Hahn	0.38	0.38	0.25
Mobile	0.44	0.32	0.58
B - Baited Ratio Estimates			
Spotlight	0.37	0.57	0.62
Hahn	0.83	0.24	0.2
Mobile	0.78	0.43	0.69
Blind AM	0.68	0.62	0.76
Blind PM	0.73	0.74	0.79
Camera	1.64	0.64	1.38
Helicopter AM[a]		0.54	1.25
Helicopter PM[a]		0.21	1.33

[a] No helicopter surveys were conducted in 2006.