# Accuracy of the Camera Technique for Estimating White-tailed Deer Population Characteristics

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*Abstract:* Infrared-triggered cameras are increasingly used in wildlife management and require refinement for optimal use. We compared photographic recapture rates of tagged animals on two enclosed Mississippi study areas and a third enclosed study area in Oklahoma. We evaluated effects of camera density (one camera per 41 ha and one camera per 81 ha) and sampling duration (1 to 14 days) on accuracy of deer population estimates, cumulative new occurrences of adult males, cumulative sex ratio, and cumulative fawn crop on the Mississippi study areas. Photographic recapture rate varied from 92% for adult males and 89% for adult females in Mississippi to 22% for adult males and 34% for adult females in Oklahoma. A three-day survey provided stable sex ratio and fawn crop estimates at 41 and 81 ha per camera. A seven-day survey provided stable estimates of adult males with 76% accuracy at 41 ha per camera and with 59% accuracy at 81 ha per camera. Infrared-triggered camera surveys can accurately estimate population characteristics for management of white-tailed deer. However, a high level of accuracy for estimating density should not be assumed for all locations.

*Key words:* sex ratio, fawn crop, infrared-triggered cameras, mark-recapture, Mississippi, Oklahoma, *Odocoileus virginianus*, white-tailed deer

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Managers and researchers need accurate estimates of white-tailed deer (*Odocoileus virginianus*; hereafter, deer) population characteristics, especially in urban environments and intensively managed lands (Beringer et al. 1998). Infrared-triggered cameras (hereafter, camera technique) could be effective to estimate deer population characteristics, but need further evaluation (Jacobson et al. 1997). This camera technology may provide robust estimators of animal abundance (Swann et al. 2004), but the assumption of equal detectability among individuals and locations may not be valid (Cutler and Swann 1999)

The camera technique uses minimum number of known-antlered adult males to estimate numbers of adult females and fawns. Jacobson et al. (1997) called for evaluation of the technique's accuracy, especially for adult females and fawns. Additional research is also needed to assess how camera density and survey duration affect accuracy of parameter estimation for deer populations. Our objectives were to (1) compare photographic recapture rate and accuracy at two camera densities; and (2) determine how sampling duration of up to 14 days affected occurrence of new animals and thus accuracy of the survey.

## Study Areas

The 809-ha Juniper Creek Farm, located in Pearl River County, Mississippi, was private property enclosed by a 2.4-m net-wire fence. Vegetation consisted of an overstory dominated by longleaf pine (*Pinus palustris*) and loblolly pine (*Pinus taeda*) and an understory dominated by yaupon (*Ilex vomitoria*) and large gallberry (*Ilex coriacea*). The owners planted warm-season food plots (16 ha) and cool-season food plots (41 ha) with agronomic forages. Mean deer conception date was during 23 January–6 February (S. Demarais, Mississippi State University, unpub. data).

The 255-ha Walker Brothers' Farm, located in Noxubee County, Mississippi, was private property enclosed by a 2.4-m net-wire fence. Loblolly pine and shortleaf pine (*Pinus echinata*) dominated overstory vegetation, with interspersed hardwood stands composed of sweetgum (*Liquidambar styraciflua*), oaks (*Quercas* spp.), and various hickories (*Carya* spp.). Understory vegetation included Japanese honeysuckle (*Lonicera japonica*), blackberry and dewberry (*Rubus* spp.), greenbrier (*Smilax* spp.) and wild grapes (*Vitis* spp.). The owners planted warm and cool-season food plots (21 ha) with agronomic forages. Mean deer conception date was during 25 December–7 January (S. Demarais, Mississippi State University, unpub. data).

The 1,193-ha Noble Foundation Wildlife Unit, located in Pontotoc, Hughes, and Coal counties in south-central Oklahoma, was enclosed by a 2.5-m, 8-strand electric fence. Breaks in the fence at the entrance and exit of a creek bisecting the property potentially allowed animal egress. The area was 60% wooded and 40% open

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and had a diverse plant community with over 500 species documented (Gee et al. 1994). The wooded overstory was dominated by oaks, ashes (*Fraxinus* spp.), hackberry (*Celtis occidentalis*), osage orange (*Maclura pomifera*), elms (*Ulmus* spp.), and hickories. Agronomic plantings were limited to a 6.8 ha winter wheat (*Triticum aestivum*) field planted for cattle grazing. Mean deer conception date was late November (K. L. Gee, Samuel Roberts Noble Foundation, unpub. data).

## Methods

We established a known population of tagged deer within each enclosure by capturing and ear-tagging adult females, adult males, and fawns using a dart gun or drop-net. We immobilized darted deer with 4.4 mg/kg Telazol plus 2.2 mg/kg xylazine. We immobilized netted deer using 3.3 mg/kg xylazine only. We reversed all deer with 0.125 mg/kg yohimbine (Kreeger 1997). While deer were immobilized, we fitted them with two uniquely numbered, colored, large double eartags (Allflex, Dallas, Texas). We assumed all marked animals to be alive and marked unless found dead.

We evaluated effects of camera densities of one per 41 ha and one per 81 ha, which are representative of densities used by managers. We overlaid study areas with 41-ha and 81-ha grids and chose camera stations near the center of each block, in a location of easy access and maximum deer activity. We conducted surveys consecutively at each of the camera densities, separated only by a six-day pre-baiting period. Order of the two surveys was decided by coin flip. We kept approximately 10 kg of shelled corn 3 m from the camera unit throughout the sampling period. We surveyed Walker Brothers' Farm during September–October 1998, January–February 1999, September–October 1999, and January–February 2000 and Juniper Creek Farm during September–October 1999 and January–February 2000. We used passive infrared-triggered camera units (Trailmaster, Goodson and Associates, Lenexa, Kansas) with Olympus Infinity Twin 35mm cameras (Olympus America, Denver, Colorado) and narrowed the 160-degree infrared beam with electrical tape to about 30 degrees.

We conducted camera surveys for 13 days on the Noble Foundation Wildlife Unit in January 1999 and January 2000 with a single, mid-range density of one camera per 61 ha. Camera orientation, film, and bait were identical to surveys conducted in Mississippi. We used results from the Oklahoma study area only to compare photographic recapture rate of tagged adults.

A single observer analyzed each photograph for number of tagged and untagged adult males, adult females, fawns, and unknowns. We identified untagged males using antler and body characteristics (Jacobson et al. 1997). We used number of unique, identifiable adult males as the adult male density estimate. We estimated numbers of adult females and fawns according to Jacobson et al. (1997).

Date and time were printed automatically on each photograph. We added the first appearance of each adult male to a cumulative list of new occurrences. We used daily cumulative totals of pictures of adult males, adult females, and fawns to estimate cumulative sex ratio (number of adult females per one adult male) and cumulative fawn crop (number of fawns per one adult female). We averaged values for adults across seasons because season did not affect estimates (McKinley 2002). We used only February fawn crop results because fawn crop estimates from September were inaccurate (McKinley 2002).

We created a "best estimate" of population density, sex ratio, and fawn crop for each study area and year for comparison with each camera density. We assumed males occurring in the September survey were alive during the following February survey unless harvested. We assumed males occurring in the February survey to have been present during the previous September survey. We created the adult male best estimate using minimum known number of males from the photographs from fall and winter of one antler cycle, harvest data from that year, and our incidental observations during field work. We created the adult female best estimate using percentage recaptured of known, tagged adult females in the population. We then applied this percentage recaptured to the untagged population and extrapolated to 100 percent. We summed number of known tagged adult females and the extrapolated untagged female estimate, adjusted for harvest, to generate the best estimate of adult females. The fawn best estimate was the fawn density estimate from the February camera survey and was assumed to be conservative. We divided population estimates by the best estimate to calculate a percentage of the best estimate obtained in each season. We used this percentage of the best estimate as the dependent variable for statistical comparisons of accuracy.

We compared accuracy between camera densities in Mississippi for adult males, adult females, and fawns using a paired *t*-test. Within each camera density, we compared cumulative population characteristics among days of the survey and season with a mixed-effects, repeated-measures analysis of variance (Littell et al. 1996) with day, season, and day x season as fixed effects. Area and area x season were random effects and area x season was the subject for repeated measures. We used a Bonferronni-adjusted *t*-statistic for multiple comparisons. We assumed observations more closely related in time were more correlated than observations farther apart in time and therefore chose an order 1 autoregressive covariance structure for the models. We considered statistical comparisons of potential biological significance at $\alpha \leq 0.1$ due to the low number of spatial replicates (Tacha et al. 1982).

## Results

We had a total known population of 133 tagged animals. We captured 35 deer (15 males, 20 females) on Juniper Creek Farm and 10 deer (3 males, 7 females) on Walker Brothers' Farm from 22 September 1997 to 15 January 2000. We captured 97 deer (36 males, 61 females) on the Noble Foundation Wildlife Unit from 21 January 1998 to 23 March 1999.

We recorded 28,337 photographs during four seasons on the two Mississippi study areas and during two seasons on the Oklahoma study area. Number of pictures per camera day of operation varied slightly within Mississippi, from 15.5 pictures at the lowest camera density (1/81 ha) to 14.5 pictures at the highest camera density (1/41 ha). However, in Oklahoma at a moderate camera density of 1/61 ha, only 3.4 pictures were taken per camera day. We continued to identify new adult males out to day 14 at all camera densities.

Camera density and location affected photographic recapture rate of tagged animals (Table 1). At 41 ha per camera, we photographed an average of 92% of tagged adult males and 89% of tagged adult females during a 14-day survey. At 81 ha per camera, we photographed an average of 82% of tagged adult males and 82% of tagged adult females during a 14-day survey. Photographic recapture rate of tagged animals in Oklahoma averaged 22% for adult males and 34% for adult females during a 13-day survey.

The 41-ha per camera survey was more accurate than the 81-ha per camera survey (Table 2). The 90% overall accuracy of the 41-ha per camera survey was higher ($t_{17}$ = 4.21, $P$ = 0.001) than the 61% accuracy of the 81-ha per camera survey. The 41-ha per camera survey yielded more accurate estimates of adult males ($t_5$ = 2.06, $P$ = 0.094) and adult females ($t_5$ = 2.67, $P$ = 0.04) regardless of season and of fawns ($t_5$ = 2.34, $P$ = 0.07) during February (Table 2). Our best estimate of overall deer density on the Mississippi study areas was 1 deer per 4.5 ha.

Cumulative new occurrences of adult males at 41 ha per camera did not differ by season ($F_{3,3}$ = 0.17, $P$ = 0.91) and we found no season x day interactions ($F_{39,52}$ = 0.83, $P$ = 0.73). Cumulative new occurrences of adult males at 41 ha per camera differed among days ($F_{13,52}$ = 14.48, $P \leq 0.001$), but did not differ ($P > 0.1$) after day 7 (Table 3). Cumulative new occurrences of adult males at 81 ha per camera did not differ by season ($F_{3,1}$ = 2.39, $P$ = 0.44), and we found no season x day interactions ($F_{39,26}$ = 1.23, $P$ = 0.30). Cumulative new occurrences of adult males differed among days ($F_{13,26}$ = 6.80, $P < 0.0001$), but did not differ ($P > 0.1$) after day 6 (Table 3).

Cumulative sex ratio at 41 ha per camera did not differ by season ($F_{3,3}$ = 0.61, $P$ = 0.65) or day ($F_{13,52}$ = 0.88, $P$ = 0.58) and we found no season x day interactions ($F_{39,52}$ = 0.80, $P$ = 0.77, Table 4). Cumulative sex ratio at 81 ha per camera did not differ by sea-

**Table 1.** Number of tagged deer (*N*) and photographic recapture rates (%) during surveys at two camera densities on two enclosed Mississippi study areas and one camera density on one enclosed Oklahoma study area sampled seasonally during September 1998–February 2000.

| | Mississippi | | | | Oklahoma | |
|---|---|---|---|---|---|---|
| | 1/41 ha | | 1/81 ha | | 1/61 ha | |
| | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE |
| Adult male | | | | | | |
| *N* | 8 | 2 | 8 | 2 | 29 | 7 |
| % | 92 | 3 | 82 | 8 | 22 | 5 |
| Adult female | | | | | | |
| *N* | 11 | 2 | 11 | 2 | 52 | 9 |
| % | 89 | 3 | 82 | 5 | 35 | 10 |

**Table 2.** Accuracy of abundance estimates for white-tailed deer (percentage of the best estimate) at two camera densities on two Mississippi study areas during September 1998, February 1999, September 1999, and February 2000.

| | 1 camera/41 ha | | 1 camera/81 ha | | *P*-level |
|---|---|---|---|---|---|
| | $\bar{x}$ | SE | $\bar{x}$ | SE | |
| Adult male | 84 | 5 | 66 | 5 | 0.094 |
| Adult female | 92 | 3 | 63 | 11 | 0.044 |
| Fawn | 100 | 0 | 49 | 13 | 0.067 |
| Overall | 90 | 3 | 61 | 5 | 0.001 |

a. Fawn estimates were computed using only February results.

**Table 3.** Cumulative new occurrences as a percentage of the best estimate of male white-tailed deer populations on two Mississippi study areas at two camera densities during September 1998, February 1999, September 1999, and February 2000.

| | 1 camera/41 ha | | 1 camera/81 ha | |
|---|---|---|---|---|
| Day | $\bar{x}$ [a] | SE | $\bar{x}$ | SE |
| 1 | 48 a | 5.3 | 30 a | 5.7 |
| 2 | 58 b | 5.7 | 33 a | 6.5 |
| 3 | 63 c | 5.6 | 42 b | 7.0 |
| 4 | 67 cd | 5.5 | 47 bc | 6.5 |
| 5 | 71 de | 4.3 | 50 c | 5.8 |
| 6 | 73 def | 4.9 | 56 d | 5.4 |
| 7 | 76 efg | 4.6 | 59 d | 5.2 |
| 8 | 77 efg | 4.8 | 62 d | 5.2 |
| 9 | 79 efg | 4.3 | 63 d | 5.3 |
| 10 | 80 fg | 4.5 | 64 d | 5.7 |
| 11 | 82 g | 4.2 | 64 d | 5.7 |
| 12 | 83 g | 4.3 | 65 d | 5.6 |
| 13 | 84 g | 4.5 | 66 d | 5.3 |
| 14 | 84 g | 4.5 | 66 d | 5.3 |

a. Means within a column with the same letter are not different ($P > 0.1$)

son ($F_{3,1}$ = 0.97, $P$ = 0.62) or day ($F_{13,26}$ = 0.55, $P$ = 0.87), but there was evidence of a season × day interaction ($F_{39,26}$ = 1.65, $P$ = 0.09, Table 4).

Cumulative fawn crop at 41 ha per camera did not differ by season ($F_{1,1}$ = 8.35, $P$ = 0.21) or day ($F_{13,26}$ = 1.22, $P$ = 0.32). We found season x day interactions ($F_{13,26}$ = 2.36, $P$ = 0.03) in cumulative fawn crop (Table 4). Cumulative fawn crop at 81 ha per camera did not differ by day ($F_{13,13}$ = 2.04, $P$ = 0.11) and we found no season x day interactions ($F_{13,13}$ = 0.63, $P$ = 0.80, Table 4).

We compared costs for 41 ha and 81 ha camera density surveys on 243 ha. During the 41 ha per camera survey, we took an average of 14 pictures per camera per night. Pictures cost US$0.33 each, including film and development. Assuming $300 per infrared-triggered camera unit and a five-year life expectancy, annual cost for a 14-day, 41-ha per camera survey of 243 ha using six cameras would be $3.08/ha. During the 81-ha per camera survey, we took an average of 16 pictures per camera per night. Assuming the same picture cost, camera cost, and life expectancy, annual cost for a 14-day, 81-ha per camera survey of 243 ha using three cameras would be $1.65/ha. Effort involved for both surveys would include a 20-minute set-up per camera and 10 minutes per camera per day after day 1 to check the cameras. Picture analysis would require 10 hours for the 41-ha per camera survey and six hours for the 81-ha per camera survey. One person can conduct all survey procedures.

**Table 4.** Cumulative sex ratio (adult females per one adult male) and cumulative fawn crop (fawns per one adult female) of white-tailed deer using two camera densities on two Mississippi study areas during September 1998, February 1999, September 1999, and February 2000.

| | Cumulative sex ratio | | | | Cumulative fawn crop[a] | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 camera/41 ha | | 1 camera/81 ha | | 1 camera/41 ha | | 1 camera/81 ha | |
| Day | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$[b] | SE | $\bar{x}$ | SE |
| 1 | 0.7 | 0.2 | 0.6 | 0.2 | 0.70 ab | 0.10 | 0.73 | 0.37 |
| 2 | 0.8 | 0.3 | 0.5 | 0.1 | 0.68 a | 0.07 | 0.54 | 0.25 |
| 3 | 0.7 | 0.2 | 0.5 | 0.1 | 0.79 b | 0.12 | 0.52 | 0.25 |
| 4 | 0.7 | 0.2 | 0.5 | 0.1 | 0.76 ab | 0.11 | 0.58 | 0.21 |
| 5 | 0.7 | 0.2 | 0.5 | 0.1 | 0.78 ab | 0.13 | 0.57 | 0.20 |
| 6 | 0.7 | 0.2 | 0.5 | 0.1 | 0.76 ab | 0.11 | 0.54 | 0.19 |
| 7 | 0.7 | 0.2 | 0.5 | 0.1 | 0.76 ab | 0.09 | 0.55 | 0.19 |
| 8 | 0.7 | 0.1 | 0.5 | 0.1 | 0.77 ab | 0.08 | 0.53 | 0.19 |
| 9 | 0.7 | 0.1 | 0.5 | 0.1 | 0.76 ab | 0.09 | 0.54 | 0.19 |
| 10 | 0.7 | 0.1 | 0.5 | 0.1 | 0.76 ab | 0.09 | 0.55 | 0.19 |
| 11 | 0.7 | 0.1 | 0.5 | 0.1 | 0.77 ab | 0.09 | 0.55 | 0.20 |
| 12 | 0.7 | 0.1 | 0.5 | 0.1 | 0.77 ab | 0.10 | 0.58 | 0.20 |
| 13 | 0.7 | 0.1 | 0.5 | 0.1 | 0.75 ab | 0.10 | 0.56 | 0.20 |
| 14 | 0.7 | 0.1 | 0.5 | 0.1 | 0.76 ab | 0.10 | 0.56 | 0.19 |

a. Fawn estimates were computed using only February results.
b. Means within a column with the same letter do not differ ($P$ > 0.1).

## Discussion

We had 23%–43% of the estimated antlerless population marked during survey periods. High photographic recapture rates of tagged deer in Mississippi (mean adult male = 92%, mean adult female = 89%) suggest that we captured on film a large proportion of the population. We never observed four marked deer, but assumed they were alive and marked for accuracy calculations. If these deer were dead or unmarked, and thus unavailable to be photographed, then the mean recapture rates would have increased to 99% for adult males and 95% for adult females. In either case, our recapture rates were similar to previous photographic recapture rates in Mississippi (Jacobson et al. 1997). Jacobson et al. (1997) listed the potential for a sex bias in attracting deer to bait. Our results revealed little difference in recapture rates of males and females.

The much lower photographic recapture rate of deer in Oklahoma compared to Mississippi is noteworthy. We believe the relative attractiveness of corn was lower on the Oklahoma study area compared to the two Mississippi study areas. Bait type affected rate at which photographs were taken during a Texas study (Koerth and Kroll 2000), and deer response to alternative natural food sources should vary in a similar fashion. A significant presence of oak on the Oklahoma study area provided acorns as a preferred food in the winter deer diet (Gee et al. 1994). In contrast, both Mississippi study areas are composed primarily of pine, so acorns were not available as an alternative to corn during the survey.

We offer several other secondary explanations for the variation in photographic recapture rate between Mississippi and Oklahoma. The Oklahoma study area fence may have allowed egress of tagged deer without our knowledge, resulting in a reduced number of tagged animals available for photographic recapture. Additionally, deer trapping with drop-nets occurred yearly on the Oklahoma study area. The nets were baited primarily with corn, so some tagged deer may have become trap shy to corn, which was used as bait for the camera surveys. The much lower number of pictures per camera day of operation supports the fact that fewer deer were present at bait piles on the Oklahoma study area. Regardless of the cause, the high level of accuracy reported for the camera technique should not be assumed for all locations.

Camera density, and thus number of cameras needed to survey a given area, is an important practical consideration. Our results differed from Jacobson et al. (1997), in that they found a higher recapture rate of adult males compared to adult females at low camera densities. Our methods differed from Jacobson et al. (1997), in that we conducted our surveys separately for each density while they removed results from a high density survey in order to artificially create a lower density survey. Therefore, our results more likely represent surveys of differing camera density.

Accuracy and cost effectiveness are important considerations when determining ideal survey length and camera density. Monetary and time costs increase as survey intensity increases. While cost is reduced at lower camera densities, accuracy declined from 90% at the 41-ha per camera density to 61% at the 81-ha per camera density. Loss of accuracy should be considered when evaluating cost effectiveness of differing camera densities.

Infra-red triggered still cameras are now available at a third or less than the cost of the units we used, which would reduce cost considerably over those of our study. Digital cameras in systems equivalent to what we used are available for about the same price we paid for film-based camera systems. Digital cameras would reduce cost of a camera survey by eliminating film and development cost.

To optimize cost effectiveness of the camera survey, we tried to determine minimum number of consecutive camera-days needed to generate stable estimates of population parameters. A seven-day survey provided relatively stable data for an estimate of the male population at both camera densities, but more days would provide a higher minimum population. The 41-ha per camera survey generally resulted in more individual adult males than the 81-ha surveys and, thus, would provide a closer estimate to the true population. Our results indicate stable sex ratio and fawn crop estimates were generated within 3 days. Fawn crop estimates also stabilized at day 3 in Texas (Koerth et al. 1997).

More refinement is needed to reach full effectiveness of the camera survey. Photographing new adult males at day 14 on many of the surveys suggests that we did not photograph all individual males. Thus, we do not know the camera density or survey duration required for a complete census, or if it is even possible to photograph every adult male. How habitat quality and alternative food sources affect survey accuracy needs further quantification. How accuracy could be affected by presence of a confining fence and varying acreage within the fence should also be addressed.

## Management Recommendations

Camera density and survey length should vary with intensity of deer management. Higher density camera surveys are most applicable and cost-effective on properties managed intensively, where there is a need for detailed knowledge of population characteristics and antler development within age classes. To estimate density, sex ratio, and fawn crop, the most accurate survey would require a 41-ha per camera density for 14 days, but cost will be reduced if the manager will accept the lower accuracy of the 81-ha per camera density for 14 days or a 41-ha density for fewer days. If density estimates are too costly or are not crucial to the manager, stable sex ratio and fawn crop estimates can be achieved with either camera density during February in three to four camera nights. Stable sex ratio estimates can be achieved at either camera density in September or February in three to four camera nights. Any camera density will also provide general qualitative information on body condition, antler development, and overall appearance of the herd. An added benefit of a camera survey is they can provide information about other species, such as wild turkey (*Meleagris gallopavo*) (Cobb et al. 1995) and wild pigs (*Sus scrofa*) (Sweitzer et al. 2000), that may be important to the manager.

Timing of fawning, antler drop, and acorn availability affect selection of an optimum sampling period. Fawns must be old enough to travel with their dams and young enough to be differentiated from yearlings. Antlers must be present on bucks for identification of unique males so sampling must be completed prior to antler shedding. Sampling should not be conducted during periods of high acorn availability due to reduction in bait attractiveness at camera sites.

The camera technique provides a minimum number of antlered males derived from identification of unique males in the pictures. Estimating age class based on body characteristics can allow evaluation of antler characteristics within age classes prior to harvest. Intensively-managed properties can benefit by using pictures of individual bucks to improve hunter education and have a positive impact on success of selective harvest strategies. This is important because selective harvest of bucks based solely on antler characteristics may negatively impact antler development in successive years (Strickland et al. 2001, Demarais et al. 2005).

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## Literature cited

Beringer, J., L. P. Hansen, and O. Sexton. 1998. Detection rates of white-tailed deer with a helicopter over snow. Wildlife Society Bulletin 26:24–28.

Cobb, D. T., D. L. Francis, and R. W. Etters. 1995. Validating a wild turkey population using cameras and infrared sensors. Proceedings of the National Wild Turkey Symposium 7:213–218.

Cutler, T. L. and D. E. Swann. 1999. Using remote photography in wildlife ecology: a review. Wildlife Society Bulletin 27:571–581.

Demarais, S., B. K. Strickland, and L. E. Castle. 2005. Antler regulation effects on white-tailed deer on Mississippi public hunting areas. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 59: 1–9

Gee, K. L., M. D. Porter, S. Demarais, F. C. Bryant, and G. V. Vreede. 1994. White-tailed deer: their foods and management in the cross timbers. Samuel Roberts Noble Foundation, Ardmore, Oklahoma.

Jacobson, H. A., J. C. Kroll, R. W. Browning, B. H. Koerth, and M. H. Conway. 1997. Infrared-triggered cameras for censusing white-tailed deer. Wildlife Society Bulletin 25:547–556.

Koerth B. H. and J. C. Kroll. 2000. Bait type and timing for deer counts using cameras triggered by infrared monitors. Wildlife Society Bulletin 28:630–635.

———, C. D. McKown, and J. C. Kroll. 1997. Infrared-triggered camera versus helicopter counts of white-tailed deer. Wildlife Society Bulletin 25:557–562.

Kreeger, T. J. 1997. Handbook of wildlife chemical immobilization. International Wildlife Veterinary Services, Inc., Laramie, Wyoming.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS system for mixed models. SAS Institute, Cary, North Carolina.

McKinley, W. T. 2002. Evaluating infra-red camera and other census techniques for white-tailed deer in Mississippi. Master's Thesis. Mississippi State University, Mississippi State.

Strickland, B. K., S. Demarais, L. E. Castle, J. W. Lipe, W. H. Lunceford, H. A. Jacobson, D. Frels, and K. V. Miller. 2001. Effects of selective-harvest strategies on white-tailed deer antler size. Wildlife Society Bulletin 29:509–520

Swann, D. E., C. C. Hass, D. C. Dalton, and S. A. Wolf. 2004. Infrared-triggered cameras for detecting wildlife: an evaluation and review. Wildlife Society Bulletin 32:357–365.

Sweitzer, R. A., D. Van Vuren, I. A. Gardner, W. M. Boyce, and J. D. Waithman. 2000. Estimating sizes of wild pig populations in the north and central coast regions of California. Journal of Wildlife Management 64:531–543.

Tacha, T. C., W. D. Wade, and K. P. Burnham. 1982. Use and interpretation of statistics in wildlife journals. Wildlife Society Bulletin 10:355–362.