Are camera surveys useful for assessing recruitment in white-tailed deer?

Author(s): M. Colter Chitwood, Marcus A. Lashley, John C. Kilgo, Michael J. Cherry, L. Mike Conner, Mark Vukovich, H. Scott Ray, Charles Ruth, Robert J. Warren, Christopher S. DePerno and Christopher E. Moorman

Source: Wildlife Biology, ()
Published By: Nordic Board for Wildlife Research
DOI: http://dx.doi.org/10.2981/wlb.00178
URL: http://www.bioone.org/doi/full/10.2981/wlb.00178

Wildlife Biology 2017: wlb.00178
doi: 10.2981/wlb.00178

Subject Editor: Christophe Bonenfant. Editor-in-Chief: Dries Bonte. Accepted 9 May 2016

Are camera surveys useful for assessing recruitment in white-tailed deer?

M. Colter Chitwood, Marcus A. Lashley, John C. Kilgo, Michael J. Cherry, L. Mike Conner, Mark Vukovich, H. Scott Ray, Charles Ruth, Robert J. Warren, Christopher S. DePerno and Christopher E. Moorman

M. C. Chitwood (chitwoodmc@missouri.edu) and M. A. Lashley, Fisheries, Wildlife and Conservation Biology Program, Dept of Forestry and Environmental Resources, North Carolina State Univ., Raleigh, NC 27695, USA. Present address for MCC: Fisheries and Wildlife Sciences Dept, Univ. of Missouri, Columbia, MO, USA. Present address for MAL: Dept of Wildlife, Fisheries and Aquaculture, Mississippi State Univ., Mississippi State, MS, USA. – J. C. Kilgo and M. Vukovich, USDA Forest Service, Southern Research Station, New Ellenton, SC, USA. – M. J. Cherry and L. M. Conner, Joseph W. Jones Ecological Research Center, Newton, GA, USA. – H. S. Ray, USDA Forest Service, Francis Marion and Sumter National Forest, Columbia, SC, USA. – C. Ruth, South Carolina Dept of Natural Resources, Columbia, SC, USA. – R. J. Warren, Warnell School of Forestry and Natural Resources, Univ. of Georgia, Athens, GA, USA. – C. S. DePerno and C. E. Moorman, Fisheries, Wildlife and Conservation Biology Program, Dept of Forestry and Environmental Resources, North Carolina State Univ., Raleigh, NC, USA

Camera surveys commonly are used by managers and hunters to estimate white-tailed deer *Odocoileus virginianus* density and demographic rates. Though studies have documented biases and inaccuracies in the camera survey methodology, camera traps remain popular due to ease of use, cost-effectiveness, and ability to survey large areas. Because recruitment is a key parameter in ungulate population dynamics, there is a growing need to test the effectiveness of camera surveys for assessing fawn recruitment. At Savannah River Site, South Carolina, we used six years of camera-based recruitment estimates (i.e. fawn:doe ratio) to predict concurrently collected annual radiotag-based survival estimates. The coefficient of determination (R^2) was 0.445, indicating some support for the viability of cameras to reflect recruitment. We added two years of data from Fort Bragg Military Installation, North Carolina, which improved R^2 to 0.621 without accounting for site-specific variability. Also, we evaluated the correlation between year-to-year changes in recruitment and survival using the Savannah River Site data; R^2 was 0.758, suggesting that camera-based recruitment could be useful as an indicator of the trend in survival. Because so few researchers concurrently estimate survival and camera-based recruitment, examining this relationship at larger spatial scales while controlling for numerous confounding variables remains difficult. Future research should test the validity of our results from other areas with varying deer and camera densities, as site (e.g. presence of feral pigs *Sus scrofa*) and demographic (e.g. fawn age at time of camera survey) parameters may have a large influence on detectability. Until such biases are fully quantified, we urge researchers and managers to use caution when advocating the use of camera-based recruitment estimates.

Long-lived herbivores follow a particular pattern of demographic rate variation that is characterized by high and weakly variable adult survival and highly variable juvenile survival (Gaillard et al. 1998). Temporal variation in juvenile survival arguably makes this vital rate the most critical component of large herbivore population dynamics, despite the fact that it tends to have a relatively weak effect on the population growth rate (Gaillard et al. 2000). Indeed, numerous studies across multiple taxa have suggested that juvenile survival may be the predominant driver of ungulate population dynamics. For example, studies of elk *Cervus elaphus* (Raithel et al. 2007), mule deer *Odocoileus hemionus* (Unsworth et al. 1999), white-tailed deer *O. virginianus* (Chitwood et al. 2015b) and roe deer *Capreolus capreolus* (Gaillard et al. 1993) have all concluded that annual survival of juveniles varies dramatically compared to survival of prime-age adults. Hence, estimating juvenile survival (or recruitment) and understanding its effects on population growth are important to managers of ungulate populations.

Researchers and managers strive for an accurate, precise, and inexpensive technique for estimating ungulate population size and demographics. Unfortunately, such a technique has remained fairly elusive, with most approaches failing in accuracy or precision or being too expensive (DeYoung 2011). As a result, methods for estimating the number of ungulates on the landscape have changed as additional scrutiny has demonstrated each technique as weak as the last. For example, track counts and fecal pellet counts have been abandoned largely because they are not reliable methods for estimating population size (reviewed by DeYoung 2011). Similarly, spotlight surveys are rife with detectability issues (Collier et al. 2007, 2013), and more technologically advanced approaches like infrared thermal imagery do not fare much better (Beaver et al. 2014), as background temperature and forest cover characteristics can result in poor accuracy and precision (DeYoung 2011). Aerial survey techniques are most useful in open areas lacking canopy (precluding use in much of the eastern United States) and still require consideration of detectability biases (DeYoung 2011). Finally, in more vocal species such as red deer *Cervus elaphus*, roaring counts do not appear to be reliable indicators of abundance (Douhard et al. 2013).

Jacobson et al. (1997) established a camera survey methodology for surveying white-tailed deer that has been used widely by managers and researchers. Though it is not a panacea, it provides reasonable demographic information in forested areas (DeYoung 2011). A major limitation to this technique is that it does not provide any measure of uncertainty associated with parameter estimates, though recent advancements have overcome this deficiency (Weckel et al. 2011, Gulsby et al. 2015). Biases and detectability issues are still relevant (McCoy et al. 2011), but cameras are easy to deploy, cover large areas, and require relatively little effort in the field compared to techniques mentioned previously. Given the level of use and acceptance of camera surveys, particularly among managers and the public (Thomas, Jr. 2010, Gulsby and Miller 2013, 2014), little work has addressed the degree to which cameras can be trusted to provide reliable demographic estimates. For example, McCoy et al. (2011) demonstrated that unbaited cameras along trails were a feasible alternative to using baited cameras and that baited cameras failed to provide sex ratio and recruitment estimates that matched estimates from randomly placed unbaited cameras.

In the eastern US, white-tailed deer managers are interested in understanding the potential impacts of coyotes *Canis latrans* on deer populations, particularly fawn recruitment. Recently, numerous studies have quantified fawn survival in the presence of coyotes (Saalfeld and Ditchkoff 2007, Kilgo et al. 2012, 2014, Jackson and Ditchkoff 2013, McCoy et al. 2013, Chitwood et al. 2015a, Nelson et al. 2015), and most have shown that coyotes affect the number of fawns recruited into the huntable, fall population. Unfortunately, fawn survival studies are expensive and time-consuming, making them limited in spatial and temporal scope. Thus, a less costly method would be beneficial to research and management. Gulsby et al. (2015) recently employed camera-based fawn recruitment estimates to corroborate effects of coyote removals. Camera-based approaches should provide an index for year-to-year comparisons on the same site, but no research has compared camera-based data to radiotag-based survival. Further, no research has evaluated if camera-based recruitment estimates change over time consistent with changes in radiotag-based survival. Thus, our objective was to test the relationship between concurrently collected radiotag-based survival estimates and camera-based recruitment estimates. We hypothesized that camera-based recruitment estimates would mirror radiotag-based survival and that even if point estimates of recruitment were not exactly the same as survival estimates, the trend over time might be useful for indexing survival using cameras.

Material and methods

Study area

We conducted the study using data from two sites, spanning a large geographic area of the southeastern United States: Savannah River Site, South Carolina and Fort Bragg Military Installation, North Carolina. The Savannah River Site (SRS) is a 78 000-ha National Environmental Research Park in the Upper Coastal Plain physiographic region of South Carolina. Uplands are comprised of loblolly pine *Pinus taeda* and longleaf pine *P. palustris* forests, and floodplains are comprised of bottomland hardwood and cypress *Taxodium distichum*-tupelo (*Nyssa aquatic* and *N. sylvatica* var. *biflora*) forests. Deer density was 4–8 deer km^{-2} and the sex ratio was even (Johns and Kilgo 2005). Coyotes were first documented at SRS in 1986 (Kilgo et al. 2010), and population size appeared to stabilize during the late 1990s–early 2000s (Kilgo unpubl.). Fawn survival was low (23%; Kilgo et al. 2012), and coyotes were the leading cause of mortality for neonatal deer at SRS (Kilgo et al. 2012, 2014). Annually, SRS conducted a camera survey in September, prior to hunting at the site. Fawns were typically 3.5 months old at the time of the survey.

Fort Bragg Military Installation (Fort Bragg; 50 000 ha) is located in the Sandhills physiographic region of central North Carolina. Fort Bragg is dominated by longleaf pine uplands with interspersed, densely vegetated drainages. Fort Bragg is managed with an intense growing-season prescribed fire regime, using a three-year return-interval (see Lashley et al. 2014 for details). Fort Bragg's deer density was 2–6 deer km^{-2} and fawn survival was the lowest reported from the region (14%; Chitwood et al. 2015a). Coyotes were the leading cause of neonatal mortality (Chitwood et al. 2015a) and a documented source of adult female mortality (Chitwood et al. 2014). Fort Bragg conducted its annual camera survey in August, which is prior to the Fort Bragg hunting season; fawns were typically three months old at the time of the survey.

Methods

Our objective was to determine if recruitment calculated from camera surveys was consistent with radiotag-based fawn survival estimates collected concurrently at the same site. The Jacobson et al. (1997) survey method is widely advocated and used by managers and hunters in the United States (e.g. see Thomas, Jr. 2010, a book devoted to the use of cameras by managers and hunters and published by the Quality Deer Management Association), so our objective was not to control for the many intricacies related to camera densities, deer densities, or detection probabilities. Rather, we wanted to use camera data commonly collected by managers and hunters to see if they provided reliable information about fawn recruitment (as measured via radiotags). Specifically, we tested the assumption that camera-based recruitment estimates were correlated to fawn survival estimates, given that recruitment is a rate (i.e. fawns per doe) that could be influenced by changes in productivity (i.e. recruitment = survival × productivity).

To compare fawn survival rates to estimates of recruitment, we used 6 annual fawn survival estimates (through 16 weeks of age; using known-fate modeling in program MARK (White and Burnham 1999)) already reported from SRS (i.e. Kilgo et al. 2012, 2014) and concurrent camera data (Kilgo unpubl.) from the same site. The survival estimates and 95% confidence intervals (2007–2012, in chronological order) were: 0.318 (0.160–0.534, n = 20), 0.232 (0.119–0.403, n = 26), 0.167 (0.071–0.343, n = 24), 0.513 (0.338–0.685, n = 30), 0.202 (0.118–0.322, n = 51) and 0.431 (0.294–0.581, n = 37).

We estimated recruitment using camera survey data across the same six years, generally following the procedures of Jacobson et al. (1997). We deployed 20 cameras in 2007 (1 per > 1000 ha), 36 in 2008 (1 per 40.5 ha), and 45 in 2009–2012 (1 per 215 ha). We used Cuddeback (models Expert and Capture; Non Typical, Inc., Green Bay, WI), Reconyx (model HC600; Holmen, WI), and HCO Scoutguard (model SG565F-8M; Norcross, GA), set for a 5-min delay between photographs, except in 2007 when the delay was 1 min. Surveys consisted of a five-day pre-baiting period (11 kg shelled corn) followed by a 10-day survey period during September, except in 2007 when the survey period was seven days. After initial baiting, we refreshed bait as needed at camera deployment and again five days later. We calculated the recruitment ratio as the total number of fawn photographs divided by the total number of adult female photographs. Camera densities varied due to changes in study objectives over time and logistical limitations. However, because we only were interested in the ratio of fawns per doe and did not use spatial statistics to estimate abundance or recruitment ratios, camera density was less important than the number of cameras used. We assessed the relationship between survival and recruitment estimates using Pearson's correlation (coefficient of determination, R^2); to determine the R^2, we added 1 to each point estimate and logit-transformed the data.

To further test the validity of the relationship determined by six years of data from SRS, we added two years of fawn survival and camera recruitment data from Fort Bragg. The Fort Bragg fawn survival estimates were derived from field and analytical methods that were consistent with those at SRS (i.e. vaginal implant transmitter (VIT)-based sample of fawns and 16 weeks of survival monitoring using known-fate modeling in program MARK). The previously reported estimates and 95% confidence intervals were 0.185 (0.039–0.332, n = 27) and 0.105 (0.008–0.203, n = 38) in 2011 and 2012, respectively (Chitwood et al. 2015a). We obtained fawn recruitment estimates from camera data collected concurrently by Fort Bragg Wildlife Branch (C. Brown, Fort Bragg Wildlife Branch, unpubl.). Fort Bragg deployed 100 cameras (Reconyx [model PC800]) at a density of 1 per 500 ha, generally following the procedures described above except that they used 14-day pre-baiting and survey periods and 3-min delay between photographs. We assessed the relationship between survival and recruitment estimates by combining Fort Bragg and SRS data and calculating Pearson's correlation (R^2), while acknowledging the approach does not control for site-specific differences in the estimates. To determine the R^2, we added 1 to each point estimate and logit-transformed the data.

Because recruitment estimates derived from camera surveys often are used to monitor deer populations through time, the variation across years can be as informative to managers as the point estimates. Therefore, we conducted a second analysis using the SRS data to explore the efficacy of using camera surveys to observe changes in fawn survival rates over time. We used the year-to-year changes in camera-based recruitment estimates to predict year-to-year changes in fawn survival. We calculated the difference in recruitment by subtracting each estimate from its counterpart in the previous year. We followed the same procedure with the survival estimates and then used Pearson's correlation to assess the relationship between year-to-year changes in recruitment and survival estimates.

Results

Each site obtained a large sample of deer photos for calculating recruitment estimates. Savannah River Site camera data contained 18 000 photographs of deer, with a range of 794–4087 photographs per year, and Fort Bragg collected 19 915 photographs of deer (9703 in 2011 and 10 212 in 2012). The six camera-based SRS recruitment estimates (with 95% confidence intervals) were: 0.288 (0.2835–0.2925), 0.470 (0.4676–0.4724), 0.290 (0.2897–0.2903), 0.652 (0.6510–0.6531), 0.165 (0.1647–0.1653) and 0.350 (0.3494–0.3506; from 2007–2012, respectively; Table 1). When correlated to the radiotag-based fawn survival

Table 1. Concurrently collected estimates of white-tailed deer fawn recruitment (fawn:doe ratio from camera surveys) and survival (from radiotags) from Savannah River Site (SRS), South Carolina, USA and Fort Bragg Military Installation, North Carolina, USA.

Site	Year	Recruitment estimate	Recruitment 95% CI	Survival estimate[a]	Survival 95% CI
SRS	2007	0.288	0.2835–0.2925	0.318	0.160–0.534
	2008	0.470	0.4676–0.4724	0.232	0.119–0.403
	2009	0.290	0.2897–0.2903	0.167	0.071–0.343
	2010	0.652	0.6510–0.6531	0.513	0.338–0.685
	2011	0.165	0.1647–0.1653	0.202	0.118–0.322
	2012	0.350	0.3494–0.3506	0.431	0.294–0.581
Fort Bragg	2011	0.174	0.1739–0.1741	0.185	0.039–0.332
	2012	0.106	0.1059–0.1061	0.105	0.008–0.203

[a]Savannah River Site (SRS) survival estimates from Kilgo et al. (2012, 2014); Fort Bragg survival estimates from Chitwood et al. (2015a).

estimates from the respective years, R^2 was 0.445 and slope was 0.57 ($y = 0.5663x + 0.0915$). Fort Bragg recruitment estimates were 0.174 (95% CI: 0.1739–0.1741) and 0.106 (95% CI: 0.1059–0.1061) in 2011 and 2012, respectively (Table 1). When combined with SRS data, R^2 was 0.621 and slope was 0.64 (Fig. 1; $y = 0.6417x + 0.0640$). The correlation between year-to-year changes in recruitment and survival included five time intervals from SRS and resulted in an R^2 value of 0.758 and slope of 0.67 ($y = 0.6715x + 0.0143$).

Discussion

Our results provide the first empirical test of how recruitment estimates from camera surveys relate to ratiotagged fawn survival. Given the correlations we reported, camera surveys may be useful to hunters and managers for indexing recruitment of fawns in some situations, though the intricacies of such a relationship warrant further testing. Indeed, using data from SRS, we demonstrated the relative strength of the relationship at a local scale. When SRS initiated coyote removals in 2010, fawn survival essentially doubled in that year, reaching the largest rate in the six-year period, and the camera survey conducted that September reflected the greatest recruitment rate for the entire six-year period (Kilgo et al. 2014). Likewise, during years of lower survival, the recruitment estimates from cameras tended to be lower. At Fort Bragg, the survival rates were low in both years, and the camera estimates of recruitment matched well numerically. Importantly, SRS data demonstrated strong correlation (i.e. R^2-value of 0.758) between camera-based recruitment and radiotag-based survival when assessing year-to-year trends, suggesting that managers could use camera-based recruitment as a coarse indicator of the trend in survival (i.e. increasing or decreasing). Also, the correlation could suggest that baited camera surveys are capable of detecting changes in fawn survival, even if the actual point estimates are inaccurate (McCoy et al. 2011).

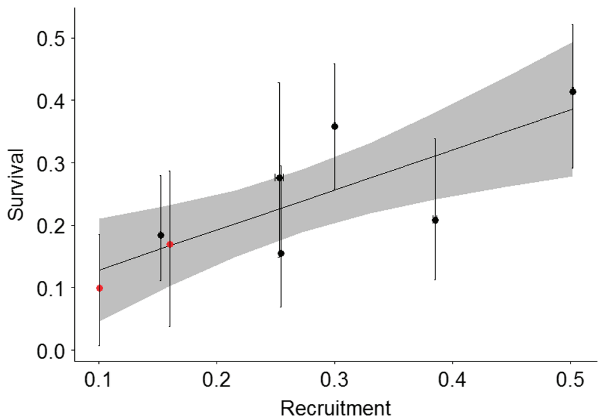

Figure 1. Linear trendline ($y = 0.6417x + 0.0640$; 95% confidence interval represented by shaded area) showing relationship ($R^2 = 0.621$) between logit-transformed white-tailed deer fawn recruitment estimates (derived from camera surveys) and logit-transformed survival estimates (derived from radiotags). Data are from Savannah River Site, South Carolina, USA, 2007–2012 (black), and Fort Bragg Military Installation, North Carolina, USA, 2011–2012 (red).

The lack of a stronger relationship between the camera-based recruitment index and survival rate may have been attributable to many factors. First, our estimates of survival were based on a sample of radiotagged fawns and were subject to sampling variability. Survival estimates from SRS and Fort Bragg should be robust, as they were derived from similar VIT-based protocols with adequate sample sizes. Therefore, we believe our survival estimates better represent actual survival than camera-based recruitment indices from those sites. Second, our two metrics do not measure exactly the same thing. Recruitment is a combination of fawn survival and the productivity (i.e. fertility) of female deer. Thus, changes in fertility could affect recruitment estimates even if fawn survival stays constant. For many white-tailed deer populations (including the two under consideration here), it is unlikely that productivity changed markedly from year-to-year because deer density and resources were fairly stable. However, in areas with more extreme winters, where forage limitations could feedback negatively on physiological condition, the potential for reduced productivity in females must be considered (Ditchkoff 2011).

Other factors that may have affected the camera-based recruitment index included the number and density of cameras, relative to the density of deer. The number and density of cameras and deer must be adequate to sample a representative portion of the population. Indeed, survival estimates and camera-based recruitment matched up best in our study when we used at least 45 cameras (i.e. 2009–2012 at SRS and both years at Fort Bragg; Table 1). Too few cameras or deer, or cameras spaced so closely that individual deer visit multiple cameras, can result in a few individuals disproportionately influencing the recruitment index. Our camera densities should have been sufficiently low to avoid such bias, particularly because deer densities at both sites were low enough that individuals were unlikely to visit multiple camera sites. However, future research could be designed to incorporate marked individuals to estimate biases caused by camera-happy mother–fawn groups (or camera-happy mothers that lost their fawn[s]).

Another factor that could have affected the camera-based recruitment index was the presence of competitors, particularly feral pigs *Sus scrofa*. The presence of feral pigs may introduce bias because pigs often take over a bait station, competitively excluding deer or greatly reducing their visitation rate (Newbolt et al. 2013, Keever 2014, Kilgo unpubl.), which renders that camera nonfunctional and reduces overall sampling efficiency of the survey. Pigs were not present at Fort Bragg but may have had significant effects at SRS, biasing recruitment indices from some cameras.

Additionally, the timing of camera surveys can influence the detectability of fawns. We collected camera data at SRS and Fort Bragg when fawns were at least in their 3rd month (9–12 weeks). By week 9, neonate home range size should approach that of the dam, and in weeks 10–12, neonates should be functionally weaned and as active as their dams (DeYoung and Miller 2011). Importantly, fawns must be old enough to move with their dams at the time of the camera survey (McKinley et al. 2006) to minimize bias related to detectability.

In spite of inconsistencies in camera survey methodology across our two sites, we detected a relationship between camera-based recruitment and radiotag-based survival. Importantly, our camera data are illustrative of the kind of data most commonly acquired by managers and hunters (i.e. baited surveys; variable densities and numbers of cameras; variable densities of deer). Baiting has a documented bias on camera-based recruitment estimates (McCoy et al. 2011), yet the Jacobson et al. (1997) methodology (which is baited) still predominates on the landscape. Thus, we acknowledge the weaknesses in our analysis, which was not designed to account for such intricacies given its retrospective nature. Additionally, we contacted numerous deer researchers in the United States and no other sites had concurrently collected camera data and radiotag-based fawn survival estimates. Thus, our retrospective analysis of camera-based recruitment and radiotag-based survival represents a baseline comparison until researchers design studies to test the relationship. Indeed, future work needs to evaluate the strength of the relationship we have presented, particularly in other portions of the white-tailed deer range where fawn survival is greater and deer exist at greater densities. Because so few studies of fawn survival concurrently collected camera data, we were not able to test for trends across larger geographical ranges, more variable deer densities, and at greater rates of fawn survival. The deer density conditions and predominant vegetation type were consistent across our two study sites (i.e. low deer density and mostly upland pine), but variation in deer density and land cover could have dramatic effects on detectability, and therefore, the applicability of camera surveys to estimate recruitment.

Conclusions

Our data indicated that camera-based recruitment indices potentially are related to radiotagged fawn survival rates, at least when camera surveys are designed to maximize the number of adult females and fawns detected. However, research should assess the effects of biases before fully relying on the camera-based recruitment index as an accurate representation on small properties, particularly if the average landowner can only deploy a few cameras. Subsequent research could be designed to quantify biases such as camera-trap happiness or shyness, while providing useful guidelines to managers and hunters regarding the minimum number of cameras per ha required to obtain reasonable recruitment estimates. Until biases are understood fully, we suggest researchers and managers will have continued need for more direct measurements of survival and recruitment (e.g. radiotags) and should use caution when advocating the use of camera-based recruitment estimates.

Acknowledgements – We thank the numerous technicians who assisted in the field. We thank D. Morin, D. Corcoran and A. Main for comments on our analysis. We thank C. Bonenfont for helpful comments.

Funding – Funding was provided by: United States Dept of Energy-Savannah River Operations Office through the USDA Forest Service-Savannah River under Interagency Agreement DE-AI09-00SR22188; South Carolina Dept of Natural Resources; USDA Forest Service Southern Research Station; Joseph W. Jones Ecological Research Center at Ichauway; United States Dept of Defense; Fort Bragg Wildlife Branch; and the North Carolina State University Fisheries, Wildlife, and Conservation Biology Program.

References

Beaver, J. T. et al. 2014. Aerial vertical-looking infrared imagery to evaluate bias of distance sampling techniques for white-tailed deer. – Wildl. Soc. Bull. 38: 419–427.

Chitwood, M. C. et al. 2014. Confirmation of coyote predation on adult female white-tailed deer in the southeastern United States. – Southeast. Nat. 13: N30–N32.

Chitwood, M. C. et al. 2015a. Do biological and bedsite characteristics influence survival of neonatal white-tailed deer? – PLoS ONE 10: e0119070.

Chitwood, M. C. et al. 2015b. White-tailed deer population dynamics and adult female survival in the presence of a novel predator. – J. Wildl. Manage. 79: 211–219.

Collier, B. A. et al. 2007. Detection probability and sources of variation in white-tailed deer spotlight surveys. – J. Wildl. Manage. 71: 277–281.

Collier, B. A. et al. 2013. Spotlight surveys for white-tailed deer: monitoring panacea or exercise in futility? – J. Wildl. Manage. 77: 165–171.

DeYoung, C. A. 2011. Population dynamics. – In: Hewitt, D. G. (ed.), Biology and management of white-tailed deer. CRC Press, pp. 147–180.

DeYoung, R. W. and Miller, K. V. 2011. White-tailed deer behavior. – In: Hewitt, D. G. (ed.), Biology and management of white-tailed deer. CRC Press, pp. 311–351.

Ditchkoff, S. S. 2011. Anatomy and physiology. – In: Hewitt, D. G. (ed.), Biology and management of white-tailed deer. CRC Press, pp. 43–73.

Douhard, M. et al. 2013. Roaring counts are not suitable for the monitoring of red deer *Cervus elaphus* population abundance. – Wildl. Biol. 19: 94–101.

Gaillard, J. M. et al. 1993. Roe deer survival patterns: a comparative analysis of contrasting populations. – J. Anim. Ecol. 62: 778–791.

Gaillard, J. M. et al. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. – Trends Ecol. Evol. 13: 58–63.

Gaillard, J. M. et al. 2000.Temporal variation in fitness components and population dynamics of large herbivores. – Annu. Rev. Ecol. Syst. 31: 367–393.

Gulsby, W. D. and Miller, K. V. 2013. Three ways to track fawn recruitment. – Quality Deer Management Association. <www.qdma.com/articles/three-ways-to-track-fawn-recruitment>. Accessed 9 September 2014.

Gulsby, W. D. and Miller, K. V. 2014. Coyote control: when is it the right option? – Quality Deer Management Association. <www.qdma.com/articles/coyote-control-when-is-it-the-right-option>. Accessed 9 September 2014.

Gulsby, W. D. et al. 2015. White-tailed deer fawn recruitment before and after experimental coyote removals in central Georgia. – Wildl. Soc. Bull. 39: 248–255.

Jackson, A. M. and Ditchkoff, S. S. 2013. Survival estimates of white-tailed deer fawns at Fort Rucker, Alabama. – Am. Midl. Nat. 170: 184–190.

Jacobson, H. A. et al. 1997. Infrared-triggered cameras for censusing white-tailed deer. – Wildl. Soc. Bull. 25: 547–556.

Johns, P. E. and Kilgo, J. C. 2005. White-tailed deer. – In: Kilgo, J. C. and Blake, J. I. (eds), Ecology and management of a forest landscape: fifty years on the Savannah River Site. Island Press, pp. 380–389.

Keever, A. C. 2014. Use of N-mixture models for estimating white-tailed deer populations and impacts of predator removal and

interspecific competition. – MS thesis, Auburn Univ., Auburn, USA.
Kilgo, J. C. et al. 2010. Can coyotes affect deer populations in southeastern North America? – J. Wildl. Manage. 74: 929–933.
Kilgo, J. C. et al. 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. – J. Wildl. Manage. 76: 1420–1430.
Kilgo, J. C. et al. 2014. Coyote removal, understory cover, and survival of white-tailed deer neonates. – J. Wildl. Manage. 78: 1261–1271.
Lashley, M. A. et al. 2014. Subtle effects of a managed fire regime: a case study in the longleaf pine ecosystem. – Ecol. Indicators 38: 212–217.
McCoy, J. C. et al. 2011. Bias associated with baited camera sites for assessing population characteristics of deer. – J. Wildl. Manage. 75: 472–477.
McCoy, J. C. et al. 2013. Factors influencing survival of white-tailed deer fawns in coastal South Carolina. – J. Fish Wildl. Manage. 4: 280–289.
McKinley, W. T. et al. 2006. Accuracy of the camera technique for estimating white-tailed deer population characteristics. – Proc. Annu. Conf. of the Southeast. Ass. of Fish and Wildl. Agencies 60: 83–88.
Nelson, M. A. et al. 2015. Coyote and bobcat predation on white-tailed deer fawns in a longleaf pine ecosystem in south-western Georgia. – J. Southeast. Ass. Fish Wildl. Agencies 2: 208–213.
Newbolt, C. H. et al. 2013. Presence of wild pigs affects occupancy and detection rates of white-tailed deer. – In: Proc. 36th Annu. Meeting Southeast Deer Study Group, February 2013, Greenville, South Carolina, pp. 33.
Raithel, J. D. et al. 2007. Impact of spatial and temporal variation in calf survival on the growth of elk populations. – J. Wildl. Manage. 71: 795–803.
Saalfeld, S. T. and Ditchkoff, S. S. 2007. Survival of neonatal white-tailed deer in an exurban population. – J. Wildl. Manage. 71: 940–944.
Thomas, Jr., L. (ed.) 2010. Deer cameras: the science of scouting. – Quality Deer Management Ass.
Unsworth, J. W. et al. 1999. Mule deer survival in Colorado, Idaho and Montana. – J. Wildl. Manage. 63: 315–326.
Weckel, M. et al. 2011. A modification of Jacobson et al.'s (1997) individual branch-antlered male method for censusing white-tailed deer. – Wildl. Soc. Bull. 35: 445–451.
White, G. C. and K. P. Burnham. 1999. Program MARK – survival estimation from populations of marked animals. – Bird Study 46: S120–S139.