

Articles

Factors Influencing Survival of White-tailed Deer Fawns in Coastal South Carolina

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Abstract

The social and environmental pressures exerted on white-tailed deer *Odocoileus virginianus* in the southeastern United States are dynamic. Understanding factors that contribute to neonatal white-tailed deer mortality is vital to population management. To determine survival rates and causes of mortality, we captured and radio-monitored neonate white-tailed deer in the coastal plain of South Carolina. Using date of birth, mass, sex, age, and year as predictor variables, we created a candidate set of survival models to evaluate which factors influenced daily survival rates. We captured and monitored 210 fawns and recorded 68 total mortalities (32.3%). We recorded few mortalities in 2006 ($n = 5$; 12.8%) and 2007 ($n = 5$; 12.5%), but we observed a significant increase in mortality in 2008 ($n = 18$; 37.5%), 2009 ($n = 28$; 53.8%), and 2010 ($n = 12$; 38.7%). Predation accounted for the majority of mortalities ($n = 29$; 42.6%). We found that male fawns were more than twice as likely to survive as females, and older fawns were more likely to succumb to predation than younger fawns. Overall survival in our study was higher than estimates recently reported in the southeastern United States. Recent increases in coyote predation have been cause for concern in some parts of the Southeast, but our results indicate that although it appeared coyote predation increased over the course of our study, predation did not reach levels that have been reported elsewhere, possibly due to predator-control activities on our study site. Close monitoring of the deer population at Brosnan Forest allowed managers to adequately adjust harvest prescriptions to maintain deer populations at the desired level despite an apparent decline in fawn survival.

Keywords: *Canis latrans*; coyote; fawn; *Odocoileus virginianus*; predation; survival; white-tailed deer

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Introduction

White-tailed deer *Odocoileus virginianus* management in the United States has undergone significant changes over the course of the past century (Côté et al. 2004). Populations were increased through habitat protection, hunting regulations, predator control, and restocking

during the early–mid-1900s. Deer populations in the southeastern United States have grown rapidly in response to habitat alterations and the absence of natural predators such as wolves *Canis rufus* and mountain lions *Puma concolor*, which has led to problems of overpopulation in many areas (McShea et al. 1997). The primary focus of management efforts



has shifted to population reduction, mainly via increased antlerless harvest (Miller and Marchinton 1995). Though hunters were originally reluctant to embrace antlerless harvests (Riley et al. 2003), antlerless deer now contribute to >50% of the total harvest in many southeastern states (Adams et al. 2012). Despite overpopulation problems, some areas in the southeastern United States have recently noted declines in deer numbers, harvest, and/or recruitment (Kilgo et al. 2010). Though regarded as an encouraging trend by many wildlife managers, maintaining these populations at desired levels requires an understanding of the factors involved in the decline.

Recent research has indicated that the addition of the coyote *Canis latrans* to the predator community of the southeastern United States has the potential to impact neonatal survival and recruitment (Saalfeld and Ditchkoff 2007; VanGilder et al. 2009; Kilgo et al. 2010, 2012). Within the past half century, coyotes have expanded their range eastward, either by natural range expansion (Gompper 2002) or by direct translocation (Hill et al. 1987), and now occur throughout eastern North America. Coyotes have been established in some parts of the southeastern United States for several decades, but areas along the Atlantic coast have been more recently colonized (Main et al. 2000; Houben 2004). In South Carolina, the first record of a coyote was in 1978, but by the mid-1990s coyotes were thought to occur throughout the state (Ruth 2011).

Research has documented that coyote predation on white-tailed deer, particularly neonates, can be significant (Cook et al. 1971; Whittaker and Lindzey 1999; Ballard et al. 2001; Vreeland et al. 2004). However, knowledge of the impact coyote predation has on white-tailed deer in the Southeast is limited, and warrants further investigation. Only three studies in the southeastern United States have directly assessed the effects of coyotes on neonate survival. Saalfeld and Ditchkoff (2007) reported 67% fawn mortality in an Alabama suburban population, with coyotes responsible for 41–63% of the mortalities. Kilgo et al. (2012) reported 78% mortality in a South Carolina population, with as much as 80% of mortalities resulting from coyote predation. In another Alabama population, of 12 fawns with known fate, only 3 survived to 180 d (75% mortality), with six out of seven predation events attributed to coyotes (Jackson and Ditchkoff 2013).

Further study of fawn survival in the southeastern United States is necessary to evaluate whether variability exists in coyote predation as well as to document cases of successful management response to declining deer numbers. Our objective in this study was to capture and monitor neonatal white-tailed deer to estimate survival, evaluate the causes and timing of mortalities, assess potential factors that influenced fawn survival in South Carolina, and present details of a management approach that appeared to successfully stabilize deer numbers amidst declining recruitment estimates.

Study Site

Our research was conducted at Brosnan Forest, a 5,830-ha tract of lower coastal plain habitat in Dorchester, South

Carolina (Figure 1). Brosnan Forest was owned by Norfolk Southern Railway and was maintained as a conference and recreation facility for the employees and customers of the company since the 1950s. The property was bisected by U.S. Highway 78, and all research activities took place on the 2,552-ha portion north of the highway. Habitat consisted mainly of open longleaf pine *Pinus palustris* stands, interspersed with bottomland hardwood drains, and mixed hardwoods. Dominant hardwood species in bottomland drains included oak *Quercus* spp., sweetgum *Liquidambar styraciflua*, black gum *Nyssa sylvatica*, and yellow poplar *Liriodendron tulipifera*. Mixed pine-hardwoods areas consisted of loblolly *P. taeda*, slash *P. elliotii*, and pond *P. serotina* pine, oak, sweetgum, and red maple *Acer rubrum*. Brosnan Forest was actively managed for wildlife and timber production, and most areas were burned on a 2–4-y rotation. About 1,000–1,400 ha were burned annually, and some understory vegetation was controlled mechanically and chemically as needed. Food plots ($n = 118$, 118.1 ha) comprised 4.6% of the study area, and ranged in size from 0.16 to 9.1 ha. Food plots were planted annually with a cool-season mix of various clovers *Trifolium* sp., grains (oats, *Avena fatua*; wheat, *Triticum aestivum*; rye, *Secale cereale*), chicory *Cichorium intybus*, and winter peas *Pisum sativum*.

Deer hunting on the property was restricted to invited guests of Norfolk Southern Railway, and hunters were encouraged to harvest males 3.5 y old or older and females of any age class. Since 2000, about 60% of harvested males were 3.5 y or older, which implies a significant degree of hunter selection. Since 2000, an average of 425 (range = 234–506) deer have been harvested each year, with females making up the majority of the harvest (65%).

Predator trapping was part of Brosnan Forest's management plan, and, starting in 2003, detailed trapping records (including number and species caught as well as the number of traps set each night) were available. The trapping season ran from January through April each year, with the exception of 2010, when trapping efforts were extended through June. We used these data to create an index of coyote and bobcat *Lynx rufus* abundance for each year of our study by dividing the number of each type of predator caught by the number of trap-nights.

From 2003 to 2010, trappers removed 858 predators: 447 (52.1%) bobcats, 313 (36.5%) coyotes, and 98 (11.4%) feral dogs *C. l. familiaris*. The yearly trends show that bobcat populations were relatively stable, where trappers caught an average of 9.5 bobcats/1,000 trap-nights. The number of feral dogs appeared to remain stable throughout the study as well, where trappers averaged 1.9 feral dogs caught per 1,000 trap-nights. The number of coyotes caught per trap-night appeared to increase over time. Trappers averaged 1.9 coyotes caught per 1,000 trap-nights from 2003 to 2005, but the number of coyotes caught per 1,000 trap-nights (number trapped) increased to 4.5 ($n = 31$) in 2006, 6.7 ($n = 45$) in 2007, and peaked at 14.4 ($n = 112$) in 2008. Trappers averaged 6.9 coyotes/1,000 trap-nights in 2009–2010.



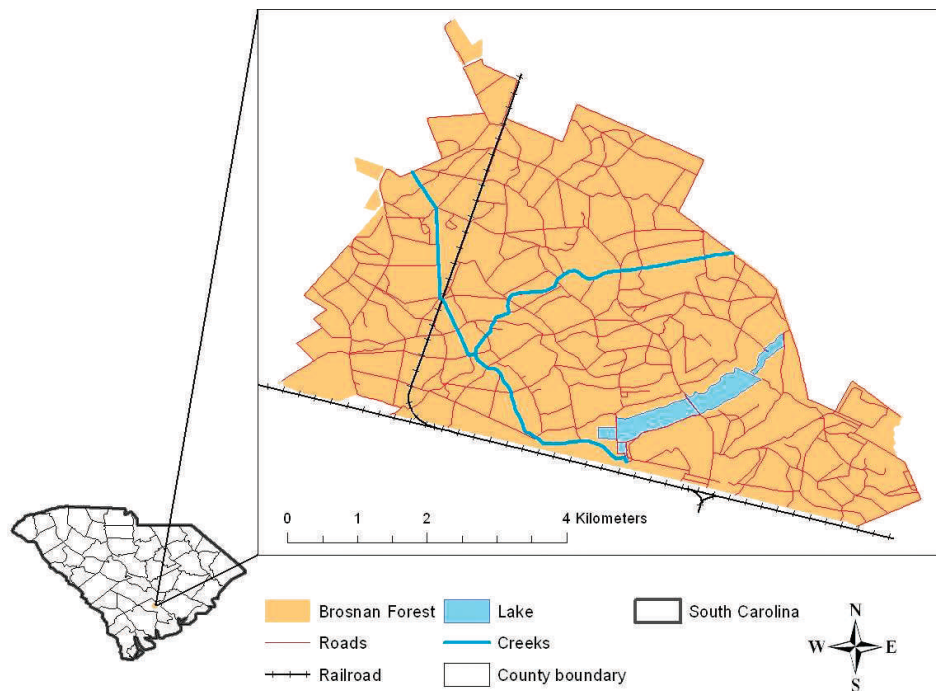


Figure 1. Location of Brosnan Forest, South Carolina, where white-tailed deer fawns *Odocoileus virginianus* were monitored from 2006 to 2010.

Methods

Locating and capturing fawns

We conducted our searches for fawns from approximately 10 April to 1 June each year, 2006–2010. Reproductive data from the study area indicated the median date of conception during past years was 9 October, with 80% of conceptions occurring between 19 September and 28 October. Assuming a 200-d gestation (Verme 1965), conception dates coincided with a median parturition date of 27 April, with 80% of the fawns born between 7 April and 16 May (J. Raglin, Norfolk Southern Railway, personal communication). The study area had 153 km of navigable roads, and we took advantage of this feature to capture fawns using a thermal-imaging camera (Figure 2; see Ditchkoff et al. 2005 for a detailed description of this method). Briefly, we mounted thermal-imaging cameras on fully adjustable swivels on each side of a truck so as to search both sides of the road as we drove through the study area. Searches were conducted between dusk and dawn (2000–0600 hours) to maximize the heat differential between animals and the surrounding environment (Galligan et al. 2003). We drove the truck at approximately 6.5 km/h (4 miles/h) to maximize area covered while maintaining the ability to detect fawns. The average distance from the vehicle to each captured fawn was 35 m (range = 3–96 m), and using this as a benchmark, we were able to survey approximately 44% of the entire study area. When a fawn was located, one observer approached the fawn with a red headlamp, while the others guided him to the fawn's location using the thermal imager. Fawns were captured using a standard 1-m-diameter fishing dip net attached to a 4.2-m handle.

For each captured fawn, we recorded weight, body length, skull, and hind foot measurements, as well as measurements of hoof growth to estimate fawn age in days (Sams et al. 1996a; Haskell et al. 2007). We applied numbered, self-piercing ear tags (National Band and Tag Co., Newport, KY) to each ear, and inserted PIT tags (EZid Animal Identification Systems, Greeley, CO; the livestock, fish, and wildlife division of AVID Identification Systems, Inc., Norco, CA) in the right ear and at the base of the tail to aid identification in the instance of future capture or harvest. Finally, we fitted each fawn with an expandable very high frequency collar (M4200; Advanced Telemetry



Figure 2. Female white-tailed deer *Odocoileus virginianus* (bedded) with fawn (standing) as viewed through a thermal-imaging camera during a search in April 2009 at Brosnan Forest, South Carolina.

Systems, Isanti, MN) designed to fall off at approximately 6 mo of age. Handling time was approximately 8–10 min/fawn.

Monitoring and classification of mortalities

We monitored survival of all collared fawns daily for the first month, and 3–4 times/wk thereafter. Mortality was detected by changes in the collar's pulse rate from 60 beats to 120 beats/minute. We investigated all fawn mortalities immediately upon signal detection, and evaluated each site for evidence of cause of death. We used visual clues such as fawn condition, tracks, bite marks, trauma (subcutaneous bleeding, bruising, broken bones, etc.), hair, and signs of a struggle to determine cause of death. Coyote and bobcat predation events were distinguished by an examination of trauma and a description of the remains. Bobcat caching behavior was the most distinguishing aspect among predation events (Smith 1945; Dill 1947; and Beale and Smith 1973), whereas coyote kills were recognized by the scattering of remains and crushed bones (White 1973; Garner et al. 1976). Additionally, we assigned coyote predation as the cause of death when evidence indicated predation, but 1) the carcass was not cached, 2) examination of the kill site revealed only the radio-collar, bone fragments, and/or blood (consumption of whole carcasses is more typical of coyote than bobcat predation; White 1973; Garner et al. 1976), or 3) the carcass was found considerable distance from the fawn's previous locations (coyotes may carry carcasses considerable distances after a kill; Harrison and Gilbert 1985). It was possible that a scavenger reached the remains prior to our arrival; therefore, we conservatively assigned predation as the cause of death rather than a scavenging event only when we recovered sufficient evidence of a kill (hemorrhaging and/or crushed skull, or bobcat cache). There is also the possibility that we incorrectly assigned coyote predation as the cause of death if feral dogs were the ultimate cause. Though distinguishing between coyote and feral dog predation can be difficult without the aid of DNA analysis, the occurrence of feral dogs on our study site was low compared with other predators. Though confident that using these procedures to assign cause of death was sufficient in most cases, we did not collect DNA evidence from carcasses; therefore, we acknowledge that we could not be absolutely certain of the cause of death in every case. However, when using similar procedures to assess causes of mortality, Kilgo et al. (2012) submitted swab samples for DNA testing, and found that the results confirmed their field determination in 36 of 37 cases. When evidence could not identify a specific predator, but predation was determined to be the cause of death, we classified the cause of death as "unknown predator." Fawns that were clearly emaciated were classified as malnourished, though the cause of emaciation was often unknown (natural abandonment, mortality of mother, inability to nurse, etc.). If we were unable to determine cause of death by these procedures, we classified mortality as unknown.

Population surveys

In order to link yearly survival estimates with trends in recruitment and to track deer abundance over time, we

used standard methods for road side surveys (Mitchell 1986) to estimate herd demographics at Brosnan Forest. Surveys were conducted between 25 July and 12 August each year, beginning at dusk and lasting 2–3.5 h. There were four survey transects that consisted of nonoverlapping roads within the forest's boundaries, and they ranged from 12.6 km to 14.8 km in length. We used two spotlights (Lightforce SL240; Lightforce USA, Inc., Orofino, ID) and two thermal imagers (Raytheon PalmIR 250; Raytheon Commercial Infrared, Dallas, TX), one mounted to each side of the vehicle, to survey for white-tailed deer along each transect (Collier et al. 2007, 2013). Thermal imager and spotlight observers independently classified deer into classes (adult male, adult female, fawn, unknown) based on antler and body characteristics.

Statistical analysis

We performed survival analysis using the nest survival approach (Dinsmore et al. 2002) in Program MARK version 6.1 (White and Burnham 1999). This approach to analyzing known-fate data has increased in recent years (Hartke et al. 2006; Mong and Sandercock 2007; Collier et al. 2009). We defined the start of the season as the earliest estimated date of birth, as determined by hoof-growth measurements (Haskell et al. 2007). We estimated fawn survival from birth through 180 d, where fawns entered the sample at their estimated date of birth, and individuals with an unknown fate were censored. We created encounter histories of each individual by recording the date of birth for each captured fawn (*k*), the last day each fawn was known to be alive (*l*), the final date that either a) we checked the fawn and found mortality occurred, b) a transmitter failed or a fawn disappeared (censoring), or c) the fawn was alive at the end of the study (*m*), the fate of the fawn where 1 = mortality and 0 = survived to the end of the study or was censored (*f*), and the number of fawns that had the same exact encounter history (*n*). We used date of birth, mass, sex, age, and year as predictor variables in our models (Table S1, *Supplemental Material*). Date of birth was used to determine at which point during fawning season the fawn was born, where the first fawn born would have a value of 1. Mass was standardized based on a linear growth curve of age vs. mass for captured fawns. We determined an average mass for fawns at each age, and determined whether each fawn was above or below average mass for its given age.

Results

We captured and monitored 39, 40, 48, 52, and 31 fawns in the 5 y from 2006 to 2010, respectively, for 210 total fawns. Estimated average age (in days) of fawns at the time of capture was 7.24 ± 0.16 . We recorded 68 mortalities (32.4%) with 5 mortalities each in 2006 (12.8%) and 2007 (12.5%), 18 in 2008 (37.5%), 28 in 2009 (53.8%), and 12 in 2010 (38.7%). Predation was the leading cause of mortality across all years ($n = 29$, 42.6%), followed by unknown and/or natural causes ($n = 22$, 32.4%) and malnutrition ($n = 15$, 22.1%). Two mortalities (2.9%) were attributed to collar malfunctions



Table 1. Summary data of the number captured and causes of death for white-tailed deer fawns *Odocoileus virginianus* at Brosnan Forest, South Carolina, for the years 2006–2010.

Year	Sex	No. captured	No. deaths	%mortality	Cause-specific mortality					
					Malnourished and/or abandoned	Bobcat	Coyote	Unknown predator	Unknown cause	Other
2006	M	18	2	0.11	2	—	—	—	—	—
	F	21	3	0.14	2	—	—	—	1	—
2007	M	23	0	0.00	—	—	—	—	—	—
	F	17	5	0.29	—	1	—	1	3	—
2008	M	24	7	0.29	2	—	1	—	3	1 ^a
	F	24	11	0.46	4	1	1	3	2	—
2009	M	28	13	0.46	2	—	4	1	5	1 ^b
	F	24	15	0.63	2	3	3	1	6	—
2010	M	23	7	0.30	—	2	3	—	2	—
	F	8	5	0.63	1	—	2	2	—	—

^a Fawn had one leg caught through collar and the stitching did not break loose.

^b Collar stitching did not allow expansion of collar due to growth.

(one collar did not expand, leading to possible strangulation; another did not completely separate and the fawn had a leg stuck through the collar). As unnatural events, these two mortalities were not counted in the nest survival analysis (i.e., censored). Of 29 confirmed predation events, 14 were attributed to coyotes, 7 to bobcats, and 8 were unknown (Table 1). The percentage of mortalities due to coyote predation steadily increased through the course of our study. In the first 2 y of the study there were no mortalities attributed to coyote predation, but the percentage increased in 2008 ($n = 2$, 11.1%), 2009 ($n = 7$, 25%), and 2010 ($n = 5$, 41.7%).

We developed two model sets, one incorporating all mortalities regardless of the cause of death (Table 2; Table S2, *Supplemental Material*), and one where only predation events were counted as mortalities (Table 3; Table S3, *Supplemental Material*). In the all-encompassing mortality model, the best model indicated that survival varied according to day of birth, mass, and sex, with model-averaged beta estimates (with standard errors) of -0.013 (0.013), 0.202 (0.173), and 0.871 (0.278) for each of these parameters, respectively. A fawn born on the first day of the fawning season was 1.65 (95% CI = 0.60–4.55) times as likely to survive as a fawn born on the 40th day of fawning season. Male fawns were 2.39 (95% CI = 1.37–4.17) times as likely to survive as female fawns. Though year was not included in the top 3 models, we generated daily survival estimates for each year according to the best model that included year as a variable and extrapolated to 180 d to determine the probability of survival to 6 mo of age. The probability of a fawn surviving the entire 180-d study period each year was 0.67 (95% CI = 0.34–0.85), 0.56 (95% CI = 0.25–0.79), 0.56 (95% CI = 0.38–0.72), 0.28 (95% CI = 0.15–0.42), and 0.49 (95% CI = 0.28–0.68), for the years 2006–2010, respectively (Figure 3).

Using the model that included only predation events as mortalities, the covariates sex, age, and year appeared to best explain variation in probability of predation. Year and sex were included in the top eight models, and,

using the best-approximating model, the probability of a fawn being depredated within the first 180 d was 0 (no predation events in 2006), 0.17 (95% CI = 0.04–0.45), 0.14 (95% CI = 0.04–0.30), 0.31 (95% CI = 0.12–0.51), and 0.31 (95% CI = 0.12–0.55) for the years 2006–2010, respectively. Female fawns were 3.89 (95% CI = 1.59–9.47) times as likely to be depredated as male fawns. When accounting for all mortality factors (malnourishment, abandonment, disease, predation, and unknown causes), fawns were most susceptible during the first 30 d of life ($n = 36$, 52.9%). However, the age effect in our predator-only model suggests a slight negative relationship (model-averaged beta estimate = -0.0045 ± 0.0051) between fawn age and probability of being

Table 2. Results of all-encompassing mortality model from nest survival analysis used to investigate factors that influenced fawn survival of white-tailed deer *Odocoileus virginianus* at Brosnan Forest, South Carolina, from 2006 to 2010.

Model	No. parameters	ΔAIC_c^a	AIC_w^b
S (dob ^c + mass + sex)	4	0.000	0.183
S (dob + mass + sex + age)	5	0.151	0.169
S (mass + sex)	3	0.988	0.111
S (mass + sex + age)	4	1.185	0.101
S (dob + sex + age + year)	8	1.449	0.088
S (dob + sex + year)	7	2.239	0.060
S (dob + mass + sex + age + year)	9	2.257	0.059
S (dob + mass + sex + year)	8	2.679	0.048
S (sex + age + year)	7	2.805	0.045
S (sex + year)	6	3.745	0.025
S (constant) ^d	1	17.303	0.000

^a Difference between model's Akaike's Information Criterion (AIC) corrected for small sample size and the lowest AIC_c value.

^b AIC_c relative weight attributed to model.

^c Date of birth calculated as the number of days since beginning of fawning season.

^d Model of no effects on survival.



Table 3. Results of predation-only model from nest survival analysis used to investigate factors that influenced predation of white-tailed deer fawns *Odocoileus virginianus* at Brosnan Forest, South Carolina, from 2006 to 2010.

Model	No. parameters	ΔAIC_c^a	AIC_w^b
S (sex + age + year)	7	0.000	0.223
S (sex + year)	6	0.536	0.171
S (dob ^c + sex + age + year)	8	0.948	0.139
S (dob + sex + year)	7	1.592	0.101
S (mass + sex + age + year)	8	1.636	0.097
S (mass + sex + year)	7	2.284	0.071
S (dob + mass + sex + age + year)	9	2.456	0.065
S (mass + sex + age)	4	4.163	0.028
S (dob + mass + sex + age)	5	5.036	0.018
S (mass + sex)	3	6.207	0.010
S (constant) ^d	1	16.13	0.000

^a Difference between model's Akaike's Information Criterion (AIC) corrected for small sample size and the lowest AIC_c value.
^b AIC_c relative weight attributed to model.
^c Date of birth calculated as the number of days since beginning of fawning season.
^d Model of no effects on survival.

depredated. Specifically, a 90-d-old fawn was 1.43 times as likely to be depredated as a 10-d-old fawn. Additionally, we recorded 15 mortalities (22.1%) when fawns were >90 d old. Of these mortalities occurring after the fawns reached 3 mo of age, 9 (60%) were attributed to coyote predation (Figure 4).

Population and harvest trends

Yearly spotlight surveys yielded a recruitment estimate (fawns : doe) of 0.95, 1.1, 0.95, and 0.9 for the years 2005–2008, respectively. However, shadowing the results of our fawn survival estimation, recruitment declined to 0.57 in 2009. Because only thermal-imaging equipment was used for the survey in 2010, the recruitment estimate

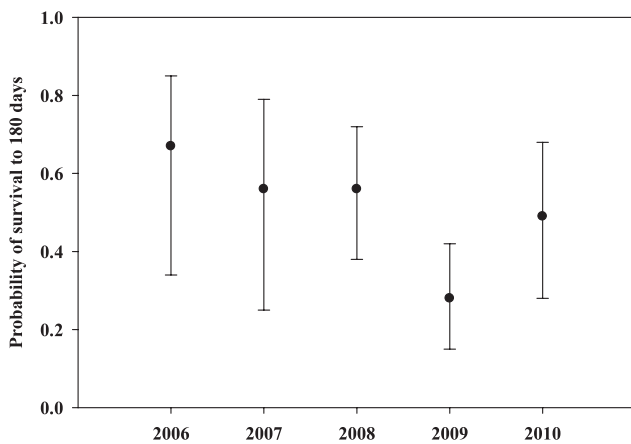


Figure 3. Survival probabilities of neonate white-tailed deer *Odocoileus virginianus* at Brosnan Forest, South Carolina, for the years 2006–2010. Daily survival rates (from nest survival analysis in Program MARK) were raised to the power of 180 to determine the probability of surviving to 180 d.

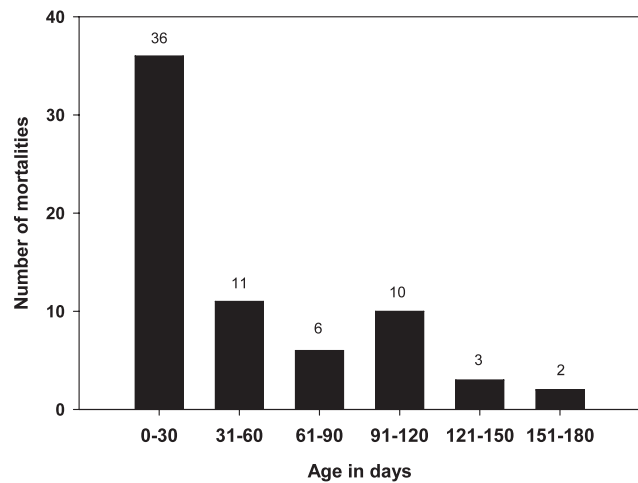


Figure 4. Timing, in days, of fawn *Odocoileus virginianus* mortalities that occurred during the years 2006–2010 at Brosnan Forest, South Carolina. Numbers above the bars represent the number of mortalities recorded during that particular time period.

could not be reliably compared to that of previous years when spotlights were primarily used to distinguish between adult antlerless deer and fawns. Total deer harvest averaged 358 (95% CI = 297.4–418.6) deer/y for the years 2005–2008. In response to declining recruitment, hunting pressure was reduced and the total deer harvest declined to 252 and 234 for the years 2009–2010, respectively. Though less than previous years, the population estimate of 5.86 (95% CI = 4.04–7.68) deer encountered/survey km in 2010, did not appear to substantially deviate from the previous 5-y average of 7.36 (95% CI = 6.71–8.01) deer/survey km.

Discussion

Fawn survival for the years 2006–2010 was 67.6% and ranged from a low of 46.2% in 2009 to a high of 87.5% in 2007. Overall, survival estimates in our study were greater than those previously reported in the literature (29%, Cook et al. 1971; 14%, Epstein et al. 1985; 26%, Long et al. 1998; 47%, Carstensen et al. 2009; 33%, Saalfeld and Ditchkoff 2007; 22%, Kilgo et al. 2012; 26%, Jackson and Ditchkoff 2013). Similar estimates of survival were found in Nelson and Woolf (70%, 1987), Carroll and Brown (59%, 1977), and Huegel et al. (76%, 1985). It is likely, though, that we overestimated fawn survival to some extent because of the manner in which we captured fawns. Because we captured neonates opportunistically during searches, we likely did not detect those mortalities that occur at birth (stillborn or soon after parturition). More recent studies using vaginal implant transmitters to capture fawns accounted for this additional mortality factor (Saalfeld and Ditchkoff 2007; Carstensen et al. 2009; Kilgo et al. 2012; Jackson and Ditchkoff 2013). According to Kilgo et al. (2012), survival was lowest during the first week of life, as 27 of 70 (38.6%) mortalities occurred during that time period. The age of captured fawns in our study averaged 7 d, so our survival estimates are likely biased because we only had

the ability to monitor fawns that, on average, had already survived their first week of life. Using the nest survival approach in Program MARK (Dinsmore et al. 2002), we generated survival probabilities using daily survival rates and extrapolated to 180 d. Large confidence intervals for the survival probabilities during 2006 and 2007 are indicative of the censoring that took place due to collar failures. Specifically, the expanding collars were not stitched strongly enough to last the entire study period. In 2008, the problem was rectified, and the collars were more reliable, staying on the study animals for the length of the study period.

Predation was the leading cause of mortality in our study, and coyotes were responsible for the majority of predation events. Coyotes have been cited as the leading predator of white-tailed deer fawns in numerous fawn-survival studies (Cook et al. 1971; Carroll and Brown 1977; Huegel et al. 1985; Sams et al. 1996b; Long et al. 1998; Ballard et al. 1999; Vreeland et al. 2004; Saalfeld and Ditchkoff 2007; Kilgo et al. 2012; Jackson and Ditchkoff 2013). Kilgo et al. (2010) speculated that coyotes were affecting deer recruitment in South Carolina, because of the correlation between the decline in the statewide deer population and the coincident increase in coyote numbers, as well as data they have collected at the Savannah River Site.

Because of the trapping efforts on our study area, we were able to index predator populations across the 5 y of the study. The index should have provided information concerning population trends, assuming that trapper efficiency was consistent each year. Bobcat populations appeared to remain stable throughout the study, but the general trend for coyotes increased over time. Comparing fawn survival estimates and general trends in the predator populations shows that fawn survival decreased while coyote populations increased. Trapping efforts were extended until June during 2010 in order to continue removing predators throughout the entire fawning season, and coincidentally we noted a slight increase in fawn survival estimates from 2009 to 2010. We hypothesize that the extended trapping season may have aided fawn survival estimates for that year.

Predator removal efforts on our study area likely contributed to survival rates that exceeded those reported in recent work (33%, Saalfeld and Ditchkoff 2007; 22%, Kilgo et al. 2012; 26%, Jackson and Ditchkoff 2013). Recent research in the Southeast has documented the positive effect of predator removal on fawn survival. Howze et al. (2009) found greater recruitment estimates on a predator removal site (0.97 fawns/doe) than on a control site (0.45 fawns/doe), and VanGilder et al. (2009) found that following predator removal, recruitment estimates increased from 0.41 to 1.20 fawns/doe. However, it is interesting to note that, in our study, fawn survival declined in spite of the consistent, large-scale predator-removal program implemented each year. It is apparent that these control activities could not prevent an increase in predation levels (and subsequent decline in fawn survival) over the course of the study.

Similar to previous studies, we found that most mortality occurred during the first 30 d of life (Cook

et al. 1971; Bartush and Lewis 1981). Fawns are generally thought to be most susceptible to predation between 2 and 9 wk of age. Bartush and Lewis (1981) reported predation events occurring at an average age of 21 d and ranging from 3 to 78 d, and Nelson and Woolf (1987) found that 73% of depredated fawns were <47 d old. Fawns are generally thought to be able to evade predators when they reach 3 mo of age; however, we found that 22% of mortalities occurred after the fawns had reached 90 d of age. Of these older age mortalities, 60% were attributed to coyote predation. It is important to consider the implications this may have on management efforts with regards to the timing of population surveys. Prehunting season surveys (occurring in late summer–early autumn) are useful in determining buck age structure, sex ratio, population size, and recruitment so that proper harvest prescriptions and an assessment of the health of the deer population can be made for the coming year. Late-stage fawn mortality could affect the interpretation of recruitment estimates in these surveys, and thus alter harvest prescriptions, due to the fact that fawn survival may continue to drop after the surveys have taken place. For example, fawning does not occur until late July or August in parts of Alabama (Causey 1990), so accurate recruitment estimates may not be possible prior to hunting season (McCoy et al. 2011). Additionally, similar to Kilgo et al. (2012), we found that the probability of survival declined for neonates born later in the fawning season, which may further compound the problem for prehunting-season surveys in those regions where fawning season occurs in late summer. In these situations, young fawns (i.e., late-born) that are counted in preseason surveys have lower survival probabilities according to our model results, and could lead to an overestimate of the recruitment rate. In these instances, we suggest recruitment be estimated from hunter observations, or postseason surveys.

Interestingly, we found sex-specific differences in fawn survival. Specifically, female fawns displayed lower survival than males for all years. A difference in neonate survival between sexes is rare according to previous research (Cook et al. 1971; Bartush and Lewis 1981; Nelson and Woolf 1987; Decker et al. 1992; Sams et al. 1996b; Ricca et al. 2002), though a few studies have reported a male bias in mortality rates (Mahoney et al. 1990; Carstensen et al. 2009). Carstensen et al. (2009) found that 3 times as many males as females died between the ages of 5–12 wk. It has been suggested that male fawns are more susceptible to predation because they are more active than females, thus making them more visible to predators (Jackson et al. 1972). However, our results show a consistent trend of lower female survival, which contradicts previous findings. Research has shown that in sexually dimorphic ungulates, younger, less experienced mothers tend to give birth to a greater percentage of females (Thomas et al. 1989; Alados and Escós 1994; Wauters et al. 1995; Côté and Festa-Bianchet 2001), presumably because female young are less costly to wean (Clutton-Brock et al. 1981; Hogg et al. 1992). Though speculative, it is possible that we



observed greater female mortality because female fawns are more likely to be born to inexperienced mothers that may be attempting to rear young for the first time, and may not have access to the best quality fawning habitat.

Population trends

Not surprisingly, recruitment estimates gathered from yearly spotlight and/or thermal imaging surveys depicted a similar pattern to that of fawn survival estimates. Recruitment appeared to decline significantly from 2008 (0.9 fawns : doe) to 2009 (0.57 fawns : doe). Equipped with research and survey data that both indicated a decline in the number of fawns reaching adulthood, forest managers reduced the target harvest for the 2009 hunting season in hopes of offsetting the subpar recruitment. Harvest prescriptions were successfully implemented, and total harvest in 2009 and 2010 was reduced to 252 (151 antlerless) and 234 deer (131 antlerless), respectively, signifying a 30–40% decline from the previous 4-y average of 358 (217 antlerless). Survey data from 2009 and 2010 showed that population size (deer/survey km) remained relatively constant despite declining recruitment. It appeared that close monitoring of the Brosnan deer herd allowed managers to act quickly and avoid population-level declines by considerably reducing harvest pressure.

Supplemental Material

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Table S1. Encounter histories and covariates for white-tailed deer *Odocoileus virginianus* neonates included in survival analysis from 2006 to 2010 at Brosnan Forest, South Carolina. Includes information on day of birth, last day known alive, last day checked, and fate of each fawn. Covariates in the table include day of birth, mass, sex, year, and age.

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Table S2. List of all candidate models, respective AIC tables, and model-averaged coefficient estimates used for the all-encompassing survival analysis of white-tailed deer *Odocoileus virginianus* neonates from 2006 to 2010 at Brosnan Forest, South Carolina.

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Table S3. List of all candidate models, respective AIC tables, and model-averaged coefficient estimates used for predation-only survival analysis of white-tailed deer *Odocoileus virginianus* neonates from 2006 to 2010 at Brosnan Forest, South Carolina.

Found at DOI: <http://dx.doi.org/10.3996/032013-JFWM-026.S1> (223 KB XLSX)

Reference S1. Adams K, Hamilton J, Ross M. 2012. QDMA's whitetail report 2012. Bogart, Georgia: Quality Deer Management Association.

Found at DOI: <http://dx.doi.org/10.3996/032013-JFWM-026.S2>; also available at <http://www.qdma.com/uploads/pdf/WR2012.pdf> (6.0 MB PDF)

Reference S2. Mitchell WA. 1986. Deer spotlight census. U.S. Army Corp of Engineers wildlife resources management manual. U.S. Army Engineer Waterways Experiment Station Technical Report EL-86-53.

Found at DOI: <http://dx.doi.org/10.3996/032013-JFWM-026.S3>; also available at http://el.erdc.usace.army.mil/elpubs/pdf/EL86_53.pdf (934 KB PDF)

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Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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