

## RESEARCH ARTICLE



# Survival of white-tailed deer fawns on Marine Corps Base Quantico

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## Abstract

Some jurisdictions in the eastern United States have reduced harvest of white-tailed deer (*Odocoileus virginianus*) because of perceived declines in recruitment and population size over the last decade. Although the restoration of American black bears (*Ursus americanus*) and the colonization of coyotes (*Canis latrans*) have increased fawn predation in some areas, limited information exists on how temporally dynamic resources and weather influence fawn survival. Therefore, we evaluated fawn survival probability, cause specific mortality, and if factors such as oak (*Quercus* spp.) mast abundance, winter severity, precipitation, and landscape composition influenced mortality risk on Marine Corps Base Quantico in northern Virginia, USA, from 2008 to 2019. We tracked 248 fawns outfitted with very high frequency radio-collars and predation was the leading cause of mortality ( $n = 42$ ; 45%). We estimated survival to 133 days and survival pooling all years (2008–2019) was 0.50 (95% CI = 0.42–0.60). Increased annual red oak (*Quercus* spp.) mast abundance from the previous fall reduced mortality hazard for fawns. The longevity of our study revealed a link between fawn survival and a specific maternal resource (red oak mast) only available during gestation. Our results highlight the importance of oak mast in eastern deciduous forests and, more broadly, overwinter maternal condition on white-tailed deer recruitment.

## KEYWORDS

fawn, oak mast, *Odocoileus virginianus*, predator, prey, survival, Virginia, white-tailed deer



A central tenet of wildlife management is the need to understand factors influencing population dynamics over time. In large mammals, adult survival and fecundity are less sensitive to environmental conditions than neonate survival (Gaillard et al. 1998, 2000). Ungulate recruitment can vary considerably in space and time (Linnell et al. 1995) and is often influenced by factors including predation, weather, food availability, and landscape composition and configuration (Garroway and Broders 2005, Farmer et al. 2006, Gulsby et al. 2017, Shuman et al. 2017, Wright et al. 2019). These factors can vary spatially and temporally and may interact in complex ways to influence neonatal ungulate recruitment (Wentworth et al. 1992, Gingery et al. 2018). Understanding complex relationships is important for predicting effects of changing conditions on ungulate populations and for sound management.

Kilgo et al. (2010) offered long-term correlative evidence suggesting coyote (*Canis latrans*) range expansion could be causing declines in white-tailed deer (*Odocoileus virginianus*) recruitment and abundance in portions of the southeastern United States. Subsequently, numerous relatively short-term studies across the southeastern United States reported that coyotes can be a significant source of mortality for white-tailed deer fawns and may reduce recruitment (Kilgo et al. 2012 [4 yr], Chitwood et al. 2015 [2 yr], Nelson et al. 2015 [4 yr], Watine and Giuliano 2016 [2 yr]). Coyote predation of fawns fluctuates with variation in occurrence and density of American black bears (*Ursus americanus*) and bobcats (*Lynx rufus*; Shuman et al. 2017, Kautz et al. 2019). Coyote predation can be an additive mortality source for deer populations (Kilgo et al. 2014). Fawn survival, however, can be low in the absence of fawn predators because of disease, malnutrition, and vehicle collisions (Dion et al. 2020, McGovern et al. 2020).

Nutritional condition of adult females during gestation influences fawn survival. Hard mast availability in eastern deciduous forests is a primary influence of white-tailed deer nutritional condition and population dynamics (Feldhamer et al. 1989, Wentworth et al. 1992). Hard mast production, however, can be highly variable, thereby creating stochastic resource availability for mast-dependent wildlife species (Diamond et al. 2000, Greenberg 2000). White-tailed deer diets in deciduous forests of eastern North America can be largely composed of oak (*Quercus* spp.) mast (acorns) during fall (Harlow et al. 1975, Pekins and Mautz 1987, McShea and Schwede 1993). Mast availability is important for deer energetic reserves during gestation (Harlow et al. 1975) because acorns have higher energy content than most other available resources (Pekins and Mautz 1988). Oak mast abundance the preceding fall and after a fawn's birth positively influences fawn body mass (Feldhamer et al. 1989, Wentworth et al. 1992), and body mass has often been linked to increased fawn survival (Saalfeld and Ditchkoff 2007, Shuman et al. 2017, Dion et al. 2020).

Landscape attributes can also influence fawn survival by altering the distribution and quality of forage resources, concealment cover, and predators. At the bed-site scale, fawns often select areas that provide adequate thermal and concealment cover (Huegel et al. 1986, Van Moorter et al. 2009) and bed sites typically have greater visual obstruction than the surrounding area, to provide protection from predators (Huegel et al. 1986, Shuman et al. 2018). At a broader scale, landscape composition and configuration also may influence fawn survival. For example, a recent meta-analysis revealed fawn survival probabilities increased with increasing agricultural land cover (Gingery et al. 2018). The results of Gingery et al. (2018) may be related to regional differences that co-vary with agricultural land cover (Kilgo et al. 2019) as some studies have reported contrary results such as increasing fawn survival with distance to croplands (Shuman et al. 2017) and increasing amount of woodland cover (McGovern et al. 2020). Rohm et al. (2007) reported landscape configuration can affect fawn survival where edge density and larger irregular forest patches adjacent to multiple smaller non-forest patches increased fawn survival. Furthermore, fawn survival increased with greater patch heterogeneity in South Carolina (Gulsby et al. 2017), potentially because coyote abundance often decreases with increasing patch diversity (Crooks 2002, Cherry et al. 2017).

Coyote colonization occurred in the Mid-Atlantic during the 1990s and early 2000s (Hody and Kays 2018). Observations of coyotes on Marine Corps Base Quantico, Virginia, USA (i.e., Quantico), were exceedingly rare before 1995; however, coyote abundance increased rapidly thereafter. From 1990–2003, an average of 1,317 deer were harvested annually on Quantico, and from 2004–2007 an average of 755 deer were harvested. By 2008, increased observations of coyotes and decreased observations of fawns by hunters generated questions regarding the effect of predation on the local deer population relative to other factors such as weather and resource

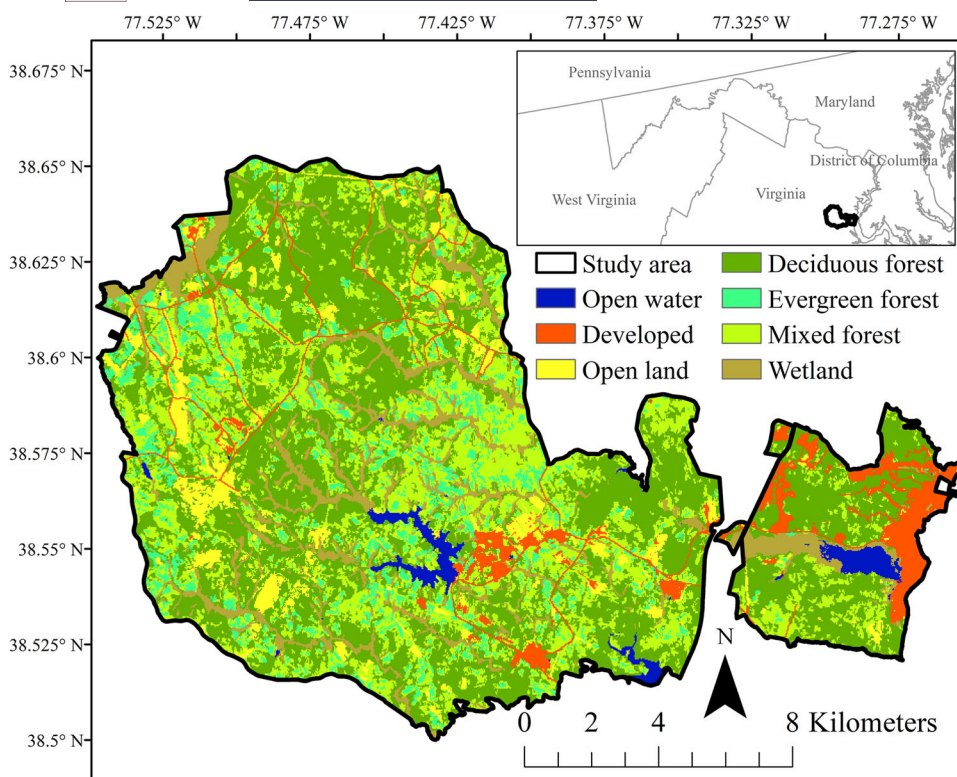


availability. Although fawn survival is a highly stochastic vital rate that is influenced by temporally dynamic forces, many studies of fawn survival occurred at short temporal scales (e.g., <5 yr; Huegel et al. 1985, Vreeland et al. 2004, Nelson et al. 2015, Shuman et al. 2017, Wright et al. 2019). As such, how temporally dynamic variables influence fawn recruitment remains largely unaddressed.

We evaluated fawn survival, cause-specific mortality, and factors influencing fawn mortality by integrating 12 years of known fate survival data from individual fawns with hard mast field survey data, land cover data, and weather data. We tested the hypothesis that fawn survival would be influenced by temporally dynamic variables that affect nutritional condition during gestation and fawning. We hypothesized nutritional condition of females during gestation and lactation would influence fawn survival at Quantico. We predicted fawn survival would increase with greater yearling body mass (i.e., female deer overwinter nutritional condition). We predicted fawn survival would increase with greater hard mast availability during gestation and decrease with increased winter severity during gestation. Furthermore, we predicted fawn survival would increase with increased growing season precipitation, which is an important influence of forage growth and availability and concealment cover. We tested the hypothesis that spatial variation in landscape conditions (i.e., availability of food and concealment cover resources), distance to land cover types, and road density at the home range scale would influence fawn survival. We predicted fawn survival would increase with increasing habitat patch diversity, complexity, and total edge. We predicted survival would vary as a function of distance to land cover types because different land cover types are influencing the susceptibility to predation for fawns (Shuman et al. 2017). Specifically, we predicted mortality risk would decrease near development because of the human shield effect, where predators avoid areas of high human activity (Berger 2007). We predicted mortality risk would increase near open areas if coyotes were the most important predators and near deciduous, mixed, and evergreen forests if black bears were the most important source of mortality. We predicted mortality hazard would increase near wetlands and open water if the distribution of water governs the distribution of fawn predators. Finally, because this system experienced recent colonization of coyotes and black bears, we predicted survival rates would decrease through time.

## STUDY AREA

We conducted our research on fawn survival from 2008 to 2019 in northern Virginia on Quantico, a 23,888-ha military installation at the interface of the Piedmont and Coastal Plain physiographic provinces in Stafford, Prince William, and Fauquier counties (Figure 1). Elevation ranges from 142 m to near sea level at the Potomac River and the topography is rolling to hilly (Stamps 2015). Four seasons occurred on Quantico (summer: Jun–Aug, fall: Sep–Nov, winter: Dec–Feb, spring: Mar–May). During the study, Quantico experienced hot, humid summers and generally mild winters with a relatively long growing period from mid-March to mid-November. January was the coldest month with an average low of  $-4^{\circ}\text{C}$  and July was the warmest month with an average high of  $32^{\circ}\text{C}$ . Average annual precipitation was 103 cm with only occasional snow in winter. Although the primary mission of Quantico was to provide a site for military and law enforcement training, active natural resource management did occur on most of the landscape. Active land management included prescribed fire, food plot maintenance, and timber harvesting. Deer hunting, both archery and firearm, occurred on portions of Quantico from late September through January (Stamps 2015). Cover types included deciduous forests (42.51%), mixed forests (26.93%), evergreen forests (7.47%), wetlands (9.06%), open lands (5.60%), developed lands (6.56%), and open water (1.87%). Deciduous species included oaks, American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), yellow poplar (*Liriodendron tulipifera*), and hickories (*Carya* spp.). Evergreens included Virginia pine (*Pinus virginiana*) and loblolly pine (*Pinus taeda*). Wetlands included riverine, lacustrine, estuarine, and palustrine wetlands. Ground cover in open lands included grasses such as fescue (*Festuca* spp.), Indiangrass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and clover (*Trifolium* spp.). Average white-tailed deer density on Quantico from 1992 to 2019 was  $26.40 \pm 19.67$  ( $\bar{x} \pm \text{SD}$ ) deer/km<sup>2</sup> (Cook 2019). This deer density is within the range of other



**FIGURE 1** Marine Corps Base Quantico in northern Virginia, USA, 2008–2019, with land cover types, which included open water, developed, open land, deciduous forest, evergreen forest, mixed forest, and wetland with latitude and longitude indicated on the left and top, respectively

density estimates for Virginia (McShea et al. 2008) and slightly higher than estimates from Pennsylvania, USA (Lutz et al. 2015). White-tailed deer predators on Quantico included black bears, coyotes, and bobcats. Coyotes were the most frequently observed fawn predator on Quantico during the deer hunting season with hunters reporting  $0.82 \pm 0.30$  observations/100 hours. Bobcats ( $0.03 \pm 0.05$ ) and black bears ( $0.05 \pm 0.05$ ) were rarely observed and black bear observation rates were far lower than other regions of Virginia such as the Appalachian Mountains ( $1.25 \pm 0.65/100$  hr; Fies 2019, Nocera 2019).

## METHODS

### Data collection

During 2008–2019, we captured female deer  $\geq 1.5$  years old, as determined via tooth wear and eruption (Severinghaus 1949), via free darting and drop-netting (Pneu-Dart, Williamsport, PA, USA; 12.19 m  $\times$  12.19 m, Wildlife Capture Services, Flagstaff, AZ, USA). We darted females from vehicles and over bait sites with 2.0-cc disposable darts (Pneu-Dart) that delivered BAM (1.1 mg/kg butorphanol tartrate; 0.37 mg/kg azaperone tartrate; 0.44 mg/kg medetomidine hydrochloride; ZooPharm, Laramie, WY, USA) or xylazine hydrochloride (3.3 mg/kg; Henry Schein, Melville, NY, USA; Lloyd, Shenandoah, IA, USA) and Telazol (5.1 mg/kg; Pfizer, New York, NY, USA; Zoetis, Parsippany-Troy Hills, NJ, USA). We intramuscularly injected deer captured in drop nets with Telazol



(5.1 mg/kg; Pfizer; Zoetis) and xylazine hydrochloride (3.3 mg/kg; Henry Schein; Lloyd). After anesthetization, we inserted motion or motion and temperature-activated vaginal implant transmitters (VITs; Series M3900, Advanced Telemetry Systems, Isanti, MN, USA; Model TVIT-200, Telonics, Mesa, AZ, USA) into pregnant females using a lubricated 2.6-cm diameter plastic applicator. We fit all captured deer with unique ear tags. Upon completion of processing, we intramuscularly administered naltrexone hydrochloride (0.51 mg/kg; ZooPharm) and atipamezole hydrochloride (4.08 mg/kg; ZooPharm) to reverse BAM. To reverse xylazine hydrochloride, we administered tola-zoline hydrochloride (2.0 mg/kg; Lloyd) intramuscularly.

We captured fawns by conducting roadside surveys using long-range thermal imagers (Thermal-Eye 250D, Raytheon Technologies, Dallas, TX, USA; Mini Thermal Monoculars, Insight Technology, Londonderry, NH, USA), monitoring females fit with VITs, and responding to reports of fawn sightings. Every fawn capture season we initiated roadside surveys based on whichever of the following 3 criteria came first: a VIT was expelled, reported sightings of fawns, or the beginning of May. We searched all accessible roads across the base  $\geq 1$  time/capture season with 1 driver and 1–3 surveyors with thermal imagers. We also conducted ground searches by foot to cover areas not accessible by vehicle. We stopped road and ground searches when the majority of fawns encountered would flee too quickly to pursue when approached. We monitored females carrying VITs once weekly from February to April and then daily from May to August until the VIT was recovered. When we located a VIT, we would search the area within 200 m from where we found the VIT with thermal imagers. Upon capture we blindfolded, weighed, ear tagged, and fit fawns with very high frequency (VHF) expandable collars (Model MOD-205, Telonics; Model M4210, Advanced Telemetry Systems) equipped with a 4-hour mortality sensor. We recorded the sex, determined age through inspection of the umbilicus, dewclaws, and gelatinous pads, and recorded the location of capture (Haugen and Speake 1958, Sams et al. 1996).

Using ground-based VHF telemetry, we monitored each fawn once daily through August and 3 times/week until 1 October when fawns were considered recruited into the harvestable population. When we detected a mortality signal, we conducted an investigation to ascertain the cause of the signal (e.g., dropped collar, dead individual) and determined the time and date when the signal began. Upon arrival at the site, we described notable features of the area, collected remains of carcass if present, and recorded tracks, scat, or hair of potential predators. We spent  $\geq 20$  minutes at the site investigating the cause of the signal, and searched 100% of the area first within a 30-m radius of the collar for predator sign, then if necessary, we expanded out to 60 m.

If predation appeared to be the cause of death based on the presence of hemorrhaging and signs of trauma, we followed a modified version of Vreeland et al. (2004) to classify the mortality to a species based on field evidence (e.g., tracks, scat, hair, puncture wound location and diameter, cache site characteristics, predator feeding behavior). When we observed hemorrhaging and puncture wounds but did not have adequate data to assign the event to a given species, we categorized the cause of death as unknown predator. If we found evidence of caching but no signs of hemorrhaging, we assigned the cause of death as unknown because of the possibility that the individual had been scavenged. We delivered intact carcasses with no obvious signs of trauma to the Virginia Department of Wildlife Resources for necropsy and sent tissue samples to the Southeastern Cooperative Wildlife Disease Study (Athens, GA, USA) for further examination.

## Data analysis

We used the non-parametric Kaplan-Meier estimator, a class of time-to-event model, to estimate probability of survival for fawns captured from 2008 to 2019. We used the age of fawns ( $n = 175$ ) in days to estimate survival probability to 133 days old based on age at capture. The average age of fawns was 133 days on 1 October when monitoring stopped each year and the fawns were considered recruited into the harvestable population. In addition, we estimated annual survival for years containing sample sizes with  $\geq 18$  fawns that had recorded ages, which included 2013, 2015, 2016, 2017, 2018, and 2019 and pooled fawns from all years of the study





(2008–2019) to estimate overall survival probability. We fit models using the survival package in program R (R Core Team 2018).

To evaluate factors affecting survival, we used Cox proportional hazards models. We fit Cox proportional hazards models using the same age method as the Kaplan-Meier estimator models. We developed models based on our hypotheses that fawn survival would be influenced by temporally dynamic variables that affect nutritional condition during gestation and lactation, and spatial variation in landscape conditions.

We created 3 variables (average yearling female body mass, white oak [*Quercus* spp.] mast abundance index, red oak [*Quercus* spp.] mast abundance index) to represent nutritional condition during gestation. First, we calculated the average yearling female body mass at harvest for each hunting season prior to fawning to represent nutritional condition of the deer population during early winter. We chose to use yearling mass because yearlings are more sensitive to environmental changes and population density than adult deer (Strickland et al. 2008). Because hard mast affects many aspects of deer biology, including body mass and reproduction (Feldhamer et al. 1989, Wentworth et al. 1992), we created 2 variables to represent temporal variability in oak mast abundance, an annual red oak mast abundance index and white oak mast abundance index. During late August and early September, biologists obtained an oak mast abundance index for red and white oaks following the Whitehead method (Whitehead 1969). White oak surveys included white oak (*Q. alba*) and chestnut oak (*Q. montana*), whereas red oak surveys included northern red (*Q. rubra*), southern red (*Q. falcata*), willow (*Q. phellos*), scarlet (*Q. coccinea*), and black oak (*Q. velutina*). Oaks were separated into these 2 groups because red oaks included the majority of the oak trees on Quantico and by extension would represent greater variation in resource abundance for deer, while white oaks included the most preferred oak mast to deer on the study site. We assigned the annual white oak and red oak mast abundance index values to each fawn from the fall prior to their birth.

Winter severity can also influence the condition of females and subsequent fawn survival (Mech et al. 1987, 1991; Garroway and Broders 2005). As such, we created a winter severity index, by totaling the number of days from 1 December to 31 March with a maximum temperature under 0°C. We assigned the winter severity index to each fawn from the winter prior to birth. Precipitation can also influence food availability during late gestation and fawn rearing, a factor that can also affect a female's nutritional condition and fawn survival (Mech et al. 1987, 1991; Michel et al. 2018). Therefore, we created a precipitation variable by averaging daily precipitation from 1 March to 30 September for each year of the study. We obtained weather data from the National Oceanic and Atmospheric Administration Station, in Fredericksburg, Virginia.

Because landscape composition and configuration can influence female nutrition and fawn survival (Rohm et al. 2007, Gulsby et al. 2017, Shuman et al. 2017, Gingery et al. 2018), we created relevant land cover variables using the 2011 National Land Cover Database (NLCD; U.S. Geological Survey, Sioux Falls, SD, USA). We used ArcMap 10.6 (Esri, Redlands, CA, USA) to reclassify the NLCD for the area of inference into 7 classes (wetland, mixed forest, evergreen forest, deciduous forest, open land, open water, developed; Table S1, available in Supporting Information) that we *a priori* thought would be important to fawn survival. We used the Euclidean distance tool in ArcMap 10.6 to create distance raster layers, which populated each cell with the distance to each cover type (Figure S1, available in Supporting Information). We also created a road density variable by creating a road layer for the study area by merging road data managed by Quantico, the Virginia Geographic Information Network, and Virginia Department of Transportation. We used this road layer in the line density tool in ArcMap 10.6 with a search radius of 304.35 m. We selected this buffer size to represent the area used by fawns during their first 3 weeks of life (29.1 ha; Gulsby et al. 2017). We created landscape metrics including: Shannon's diversity index, a measure of patch richness and evenness; mean fractal dimension index, a measure of the complexity of the patch shapes with simpler shapes such as circles having a lower index number than a more complex shape; and total forested edge. We calculated Shannon's diversity index and mean fractal dimension index using the reclassified NLCD (Table S1) in FRAGSTATS 4.2 (McGarigal et al. 2012). We created total forested edge by reclassifying the 2011 NLCD into forested and non-forested (Table S2, available in Supporting Information) in ArcMap 10.6 and then used the binary forested layer in FRAGSTATS 4.2. We calculated landscape metrics (Figure S2, available in Supporting Information)



in FRAGSTATS 4.2 using a moving window analysis with a 4-cell rule and a 304.35-m radius window size. We then extracted spatial metric values for each fawn's capture location using the extract multi values to points tool in ArcMap 10.6.

To standardize each variable, we subtracted the mean and divided by the standard deviation of each in program R and then tested for multicollinearity by creating a Pearson's correlation coefficient matrix to identify correlated variables ( $|r| \geq 0.7$ ). We used the following variables in the Cox proportional hazards models: sex, annual red oak mast abundance index, annual white oak mast abundance index, yearling female mass, winter severity, precipitation, distance to land cover (wetland, mixed forest, deciduous forest, evergreen forest, open land, open water, developed), road density, total edge, Shannon's diversity index, and mean fractal dimension index (Tables 1 and 2). We conducted the Cox proportional hazards analysis in program R using the survival package (Therneau and Grambsch 2000) and the dredge function in package MuMIn (Bartoń 2019) to develop all possible linear combinations of the

**TABLE 1** Category, variable name, and variable description used in the Cox proportional hazards models to assess factors affecting white-tailed deer fawn survival of fawns with recorded ages ( $n = 175$ ) on Marine Corps Base Quantico, Virginia, USA, 2008–2019

Category	Variable name	Description
Weather	Winter severity	Number of days with a maximum temperature under zero degrees Celsius
	Precipitation	Average daily precipitation during the growing season
Landscape configuration	Total edge	Amount of edge <sup>a</sup>
	Shannon's diversity index	A measure of land cover patch types <sup>a</sup>
	Mean fractal dimension index	Measures the complexity of the land cover patch shapes <sup>a</sup>
Landscape features	Distance to wetland	Distance from capture location to nearest wetland
	Distance to mixed forest	Distance from capture location to nearest mixed forest
	Distance to deciduous forest	Distance from capture location to nearest deciduous forest
	Distance to evergreen forest	Distance from capture location to nearest evergreen forest
	Distance to open land	Distance from capture location to nearest open land
	Distance to open water	Distance from capture location to nearest open water
	Distance to developed	Distance from capture location to nearest developed area
	Road density	Density of roads <sup>a</sup>
Nutritional condition	Annual red oak mast abundance index	Average red oak acorn index count/tree
	Annual white oak mast abundance index	Average white oak acorn index count/tree
	Yearling female mass	Average yearling female mass at harvest
Biological	Sex	Sex of the fawn as determined at capture

<sup>a</sup>We calculated landscape configuration and road density variables for each individual within a 29.1-ha buffered capture location as this area represents a fawn's home range during the first 3 weeks of life.



**TABLE 2** Variables, their means, standard deviations, and minimum and maximum of the ranges included in the Cox proportional hazards models for Marine Corps Base Quantico, Virginia, USA, 2008–2019, of risk to white-tailed deer fawns with recorded ages ( $n = 175$ )

Variables <sup>a</sup>	$\bar{x}$	SD	Min.	Max.
Wetland	393.45	296.79	0.00	1,494.59
Open	220.94	209.77	0.00	1,235.84
Mixed	78.14	103.67	0.00	550.73
Deciduous	50.88	71.55	0.00	379.47
Evergreen	380.39	505.28	0.00	2,047.49
Water	1,474.40	1,031.65	60.00	4,080.00
Developed	133.21	207.65	0.00	1,387.16
Road	3.92	2.77	0.00	18.41
Edge	2,322.17	995.54	0.00	4,680.00
Fractal	1.04	0.01	1.01	1.08
Diversity	1.14	0.33	0.05	1.67
Mass	29.62	1.51	26.81	31.71
Precipitation	3.56	0.66	2.59	6.09
Winter	6.49	2.59	2.00	11.00
Red	20.27	9.00	4.10	36.48
White	28.03	18.94	0.75	58.90

<sup>a</sup>Wetland = distance to wetland (m), open = distance to open land (m), mixed = distance to mixed forest (m), deciduous = distance to deciduous forest (m), evergreen = distance to evergreen forest (m), water = distance to open water (m), developed = distance to developed (m), road = road density (km/km<sup>2</sup>), edge = total edge (m), fractal = mean fractal dimension index, diversity = Shannon's diversity index, mass = yearling female mass (kg), precipitation = precipitation (mm), winter = winter severity (day), red = annual red oak mast abundance index, white = annual white oak mast abundance index.

variables. We chose to fit models with all possible combinations of our variables because our hypotheses, represented by our variables, were not mutually exclusive. We considered models within 2 Akaike's Information Criterion corrected for small sample size (AIC<sub>c</sub>; Burnham and Anderson 2002) of the top model as having support. We verified that supported models and the global model met the proportional hazards assumption by using Schoenfeld residuals (Schoenfeld 1982) and assessed variables via hazard ratios and their 95% confidence intervals to determine if they were informative.

## RESULTS

During 2008–2019, we captured and collared 248 (116 females, 132 males) fawns between 29 April and 14 August (Table 3). Of those 248 fawns, we captured 28 fawns by monitoring VITs and 220 opportunistically. Of the 175 fawns with recorded ages (Table 3; 85 females, 90 males), we captured 15 fawns by monitoring VITs and 160 opportunistically between 2 May and 14 August. Average age at capture for the 175 fawns was  $4.39 \pm 3.33$  days old, with VIT captured fawns and opportunistically captured fawns averaging  $1.67 \pm 0.82$  days and  $4.65 \pm 3.36$  days old at capture, respectively.





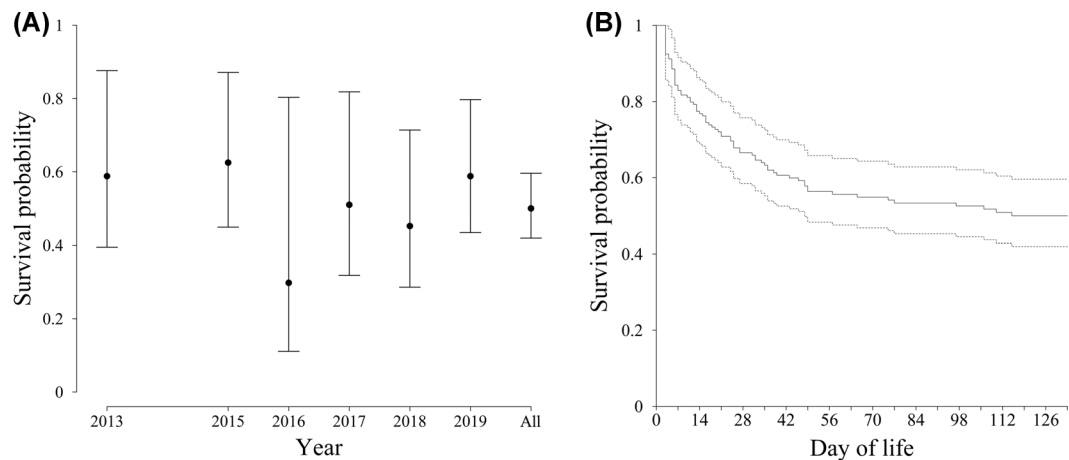
**TABLE 3** Total number of white-tailed deer fawns captured ( $n = 248$ ) and number of fawns with recorded ages ( $n = 175$ ) at capture by year used in the study on Marine Corps Base Quantico, Virginia, USA, 2008–2019

Year	Number of fawns captured	Number of fawns with ages
2008	14	2
2009	18	3
2010	14	0
2011	10	2
2012	13	0
2013	19	18
2014	12	12
2015	28	25
2016	23	21
2017	31	30
2018	33	29
2019	33	33
Total	248	175

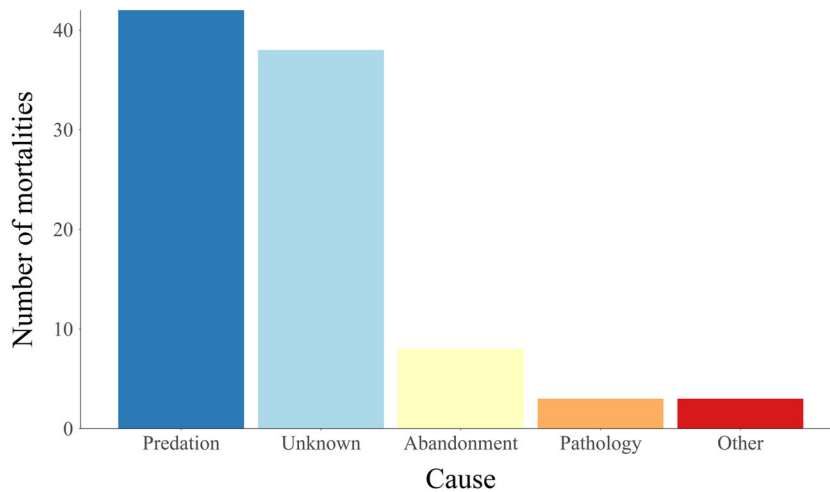
Combining all 175 fawns, survival probability of females and males to 133 days did not differ (females: 0.54, 95% CI = 0.43–0.69, males: 0.47, 95% CI = 0.36–0.60) as the confidence intervals overlapped the estimates. We found no support for a difference based on comparing confidence intervals in annual survival estimates among individual years 2013 (0.59, 95% CI = 0.40–0.88,  $n = 18$ ), 2015 (0.63, 95% CI = 0.45–0.87,  $n = 25$ ), 2016 (0.30, 95% CI = 0.11–0.80,  $n = 21$ ), 2017 (0.51, 95% CI = 0.32–0.82,  $n = 30$ ), 2018 (0.45, 95% CI = 0.29–0.71,  $n = 29$ ), and 2019 (0.59, 95% CI = 0.43–0.80,  $n = 33$ ; Figure 2A). From 175 fawns with ages, pooled survival was 0.50 (95% CI = 0.42–0.60) to 133 days (Figure 2B). Fawn survival to 2 weeks was 0.77 (95% CI = 0.69–0.86).

We recorded 94 fawn mortalities out of the 248 fawns captured and predation was the leading cause of mortality ( $n = 42$ ; 45%), with 10 predation events attributed to coyotes and 2 to bobcats (Figure 3). Other predation events ( $n = 30$ ) could not be assigned to a predator species. Unknown causes accounted for 40% ( $n = 38$ ) of mortalities and remaining mortalities (15%) were due to abandonment ( $n = 8$ ; 9%); pathology ( $n = 3$ ; 3%), which included an abnormality and infections; and other ( $n = 3$ ; 3%), which included a fence entanglement and vehicle collisions. Of the 94 deaths, 40 were females and 54 were males. Of the remaining fawns, 82 were considered recruited and 72 had unknown fates due to dropped collars, collar failure, and lost contact. Of the 175 fawns with recorded ages, 66 died; more than half of the mortalities occurred within the first 3 weeks of life and the latest mortality occurred at 17 weeks (Figure 4). Of the 66 deaths, 29 were females and 37 were males. Of the remaining fawns, 53 were considered recruited and 56 had unknown fates due to dropped collars, collar failure, and lost contact.

Cox proportional hazards models revealed red oak mast abundance was a parameter in all of the 9 models  $\leq 2 \Delta AIC_c$  (Table 4) and the null ( $\Delta AIC_c = 2.454$ ) and global models ( $\Delta AIC_c = 35.510$ ) were not included in the aforementioned model set. Therefore, of the 9 models, we selected the one with the least parameters to be our top model (Arnold 2010). Models containing red oak mast abundance received 69% of the model weight from the complete model set. Our top model contained only red oak mast abundance, an informative parameter, and indicated that for every unit (SD) increase in annual red oak mast abundance, the hazard is reduced by 24% ( $\beta = -0.272$ , hazard ratio = 0.762, 95% CI = 0.593–0.980; Figure 5). The red oak mast abundance index from 2007 to 2018 varied considerably among years with a mean of  $20.06 \pm 9.90$  and a range of 4.10–36.48.



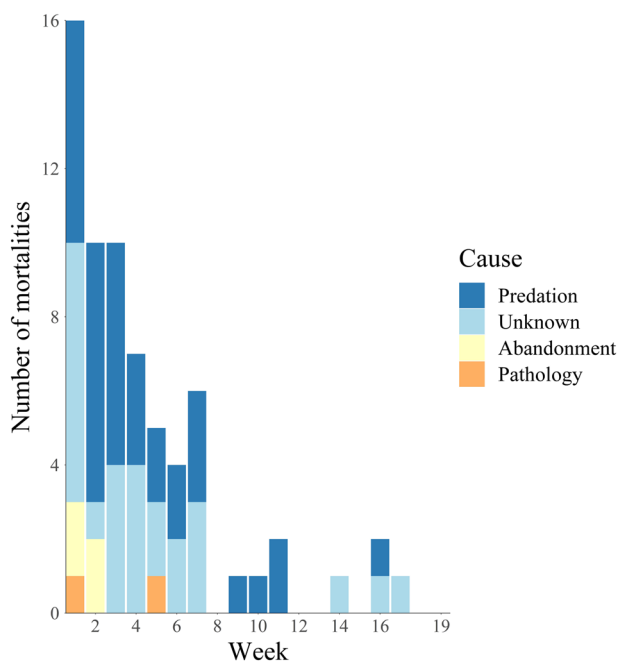
**FIGURE 2** A) Survival estimates with 95% confidence intervals to 133 days by year for years 2013, 2015, 2016, 2017, 2018, 2019, and for all white-tailed deer fawns with recorded ages ( $n = 175$ ) on Marine Corps Base Quantico, Virginia, USA, 2008–2019. B) Survival curve to 133 days with 95% confidence intervals for all fawns with recorded ages ( $n = 175$ ) on Marine Corps Base Quantico, Virginia, USA, 2008–2019



**FIGURE 3** Number of mortalities ( $n = 94$ ) by cause from all 248 white-tailed deer fawns collared with very high frequency collars on Marine Corps Base Quantico, Virginia, USA, 2008–2019. Predation accounted for 42 mortalities with 10 predation events ascribed to coyotes and 2 to bobcats. Thirty predation events could not be assigned to a predator species. Thirty-eight of the mortalities were due to unknown causes, 8 were due to abandonment, 3 were due to pathology which included an abnormality and infections, and 3 were due to other causes, which included a fence entanglement and vehicle collisions

## DISCUSSION

Our examination of annual variation in fawn survival and factors affecting survival over 12 years revealed red oak mast abundance the previous fall was the most important predictor of fawn survival the following summer. This result supported our hypothesis that nutritional condition during gestation is a strong predictor of reproductive success in deer. We acknowledge mast abundance may influence survival through other pathways such as

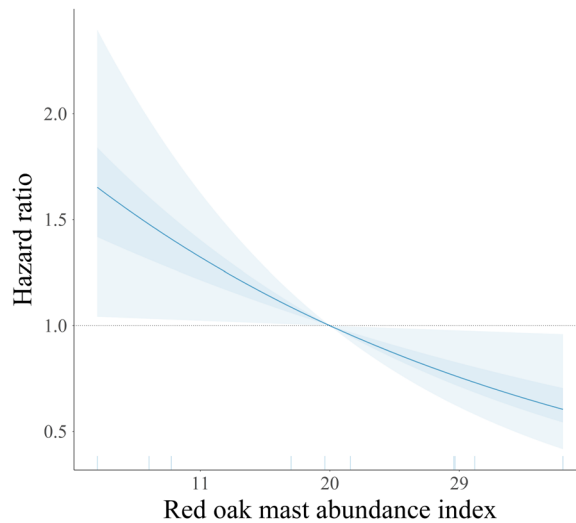


**FIGURE 4** Number of fawn mortalities ( $n = 66$ ) from the 175 white-tailed deer fawns with recorded ages by cause and week of life on Marine Corps Base Quantico, Virginia, USA, 2008–2019. Predation included coyote ( $n = 10$ ), bobcat ( $n = 2$ ), and unknown predator ( $n = 22$ ). Pathology ( $n = 2$ ) included an infection and an abnormality. The remainder of mortalities were unknown ( $n = 26$ ) and abandonment ( $n = 4$ )

**TABLE 4** Model components (model), number of parameters ( $K$ ), Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ), difference in  $AIC_c$  ( $\Delta AIC_c$ ), and model weights ( $w_i$ ) for competitive Cox proportional hazards models ( $\Delta AIC_c \leq 2$ ) examining the factors that affect white-tailed deer fawn survival of fawns with recorded ages ( $n = 175$ ) on Marine Corps Base Quantico, Virginia, USA, 2008–2019

Model <sup>a</sup>	<i>K</i>	<i>AIC<sub>c</sub></i>	$\Delta AIC_c$	<i>w<sub>i</sub></i>
Red	1	605.132	0.000	0.004
Red + road	2	606.208	1.076	0.002
Red + evergreen	2	606.404	1.272	0.002
Red + sex	2	606.633	1.502	0.002
Red + winter	2	606.652	1.520	0.002
Red + diversity	2	606.942	1.811	0.001
Red + wetland	2	606.972	1.840	0.001
Red + open	2	607.020	1.889	0.001
Red + mass	2	607.037	1.906	0.001

<sup>a</sup>Red = annual red oak mast abundance index, road = road density, evergreen = distance to evergreen forest, sex = sex of the fawn, winter = winter severity, diversity = Shannon's diversity index, wetland = distance to wetland, open = distance to open land, mass = yearling female mass.



**FIGURE 5** Influence of annual red oak mast abundance index on the hazard ratio of white-tailed deer fawns with recorded ages ( $n = 175$ ) on Marine Corps Base Quantico, Virginia, USA, 2008–2019, with 50% and 95% confidence intervals with a rug plot indicating annual observed red oak mast abundance index values

increasing the abundance of small mammals, thereby creating diversionary food items for fawn predators (Wolff 1996, McShea 2000). Although many researchers have demonstrated the link between female condition and fawn survival (Mech et al. 1987, 1991; Long et al. 2016), few studies have linked survival to a specific resource. Predation was the single most important source of mortality and coyotes were responsible for most of the predation events assigned to species.

Mast has been linked to both adult female and fawn body condition of many cervids, including white-tailed deer (Harlow et al. 1975, Feldhamer et al. 1989, Wentworth et al. 1992, Kjellander et al. 2006). In the southern Appalachians, Wentworth et al. (1992) reported the percentage of yearlings harvested declined 2 years after a poor oak mast event, suggesting a poor mast crop may lower recruitment. We link red oak acorn abundance, a specific maternal resource only available before parturition, to fawn survival. This finding suggests females were in better condition during gestation after good red oak mast years. Therefore, their fawns were likely born in better condition, received greater maternal investment, or were better defended by their mothers or a combination thereof. Annual red oak mast abundance was important, but annual white oak mast abundance was not, which may be due in part to a greater abundance of red oaks on Quantico. Also, red oak mast persists longer on the landscape than white oak mast and, therefore, may be available to females later in gestation (Fox 1982).

We also examined if winter severity and precipitation, which we believed would be linked with resource availability and quality, would influence fawn survival. Researchers have demonstrated winter severity and precipitation can influence the condition of females and subsequently fawn survival (Mech et al. 1987, 1991; Garroway and Broders 2005). We failed to detect these effects, undoubtedly because Quantico experiences a relatively mild winter in most years and potentially the effects of severe winters are only relevant when coupled with poor mast abundance. Contrary to others (Rohm et al. 2007, Gulsby et al. 2017, Shuman et al. 2017, Gingery et al. 2018), our analysis of landscape variables produced no support for our prediction that spatially explicit landscape conditions would influence fawn survival.

Predation was the most common cause of mortality and coyotes were responsible for most of the predation events assigned to species. Our monitoring protocols resulted in numerous mortalities that could not be assigned a cause and caution should be given when considering these cause-specific mortality data. Most mortalities occurred within the first 10 weeks of life, which is similar to other studies (Vreeland et al. 2004, Rohm et al. 2007, Shuman



et al. 2017). Unlike in the Gulf Coastal Plain, where most mortalities occurred during the first week of life (Shuman et al. 2017), in our study >50% of mortalities occurred within the first 3 weeks of life. We did not detect black bear predation of fawns.

Pooling all years of data, fawn survival was 50%, which is slightly higher than the modeled survival rate for completely forested areas in the meta-analysis conducted by Gingery et al. (2018). Our overall survival probability is more similar to studies conducted in the Midwest and Northeast (e.g., IL [59%; Rohm et al. 2007], MI [36%; Kautz et al. 2019], PA [53% and 38%; Vreeland et al. 2004], and NB, Canada [47%; Ballard et al. 1999]) than the Southeast (e.g., AL [33% and 26%; Saalfeld and Ditchkoff 2007, Jackson and Ditchkoff 2013], GA [29%; Nelson et al. 2015], LA [27%; Shuman et al. 2017], NC [14%; Chitwood et al. 2015], and SC [23%; Kilgo et al. 2012]), where coyote predation appears to be a major source of fawn mortality.

In our study, most fawns were captured via field searches. Therefore, fewer deer were monitored during their first days of life relative to other survival intervals. This can introduce a substantial bias and overestimated survival rates (Gilbert et al. 2014, Chitwood et al. 2017). Despite there being fewer deer in their first days of life in our study compared to others, our approach included some individuals captured on their first day of life ( $n = 24$ ). Therefore, our estimates can be considered reflective of fawn survival from birth to 133 days. We concede that the limited number of fawns included in the first days of life may have resulted in larger error estimates for those daily survival rates.

We found evidence that hard mast, a temporally dynamic resource, can influence fawn survival. Other research has reported the effect of female maternal nutritional condition, but the longevity of our study revealed a link between fawn survival and a specific maternal resource only available during gestation. Our finding that red oak mast influenced survival suggests a single resource may be critical in influencing population dynamics in some areas and more broadly that nutritional condition of females during gestation can influence subsequent fawn survival.

## MANAGEMENT IMPLICATIONS

In areas of eastern deciduous forests where white-tailed deer recruitment is lower than desired, increasing the amount of red oak acorn production may increase recruitment. This could be achieved by increasing red oak abundance in the canopy via prescribed burning and crown releases and using silvicultural approaches that enhance oak regeneration following timber harvest. These techniques would likely also increase fawn concealment cover and forage availability by promoting a flush of understory vegetation. Nonetheless, some facet of this will remain as a stochastic factor as mast crops are largely dependent on factors out of the control of managers. Managers could also increase resources available during gestation by providing supplemental feed, maintaining food plots, or increasing early successional habitat. Improving habitat conditions such that the relative importance of acorns declines would likely increase stability in fawn survival and population resilience to stochastic environments. Nonetheless, managing fawn survival is more challenging than managing adult survival and antlerless harvest restrictions may be the most viable means for increasing recruitment. The use of multiple long-term surveys (e.g., fawn survival and mast index) can provide managers important information about herd dynamics, which can aid in setting antlerless harvest objectives.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## ETHICS STATEMENT

Our handling and capture methods followed guidelines of the American Society of Mammalogists (Sikes et al. 2016) and a Virginia Scientific Collection Permit (permit 064873).

## REFERENCES

- Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. *Journal of Wildlife Management* 74:1175–1178.
- Ballard, W. B., H. A. Whitlaw, S. J. Young, R. A. Jenkins, and G. J. Forbes. 1999. Predation and survival of white-tailed deer fawns in Northcentral New Brunswick. *Journal of Wildlife Management* 63:574–579.
- Bartoń, K. 2019. MuMIn: multi-model inference. Version 1.43.6. <https://www.rdocumentation.org/packages/MuMIn/versions/1.43.6>
- Berger, J. 2007. Fear, human shields and the redistribution of prey and predators in protected areas. *Biology Letters* 3: 620–623.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer-Verlag New York, New York, USA.
- Cherry, M. J., P. E. Howell, C. D. Seagraves, R. J. Warren, and L. M. Conner. 2017. Effects of land cover on coyote abundance. *Wildlife Research* 43:662–670.
- Chitwood, M. C., M. A. Lashley, C. S. DePerno, and C. E. Moorman. 2017. Considerations on neonatal ungulate capture method: potential for bias in survival estimation and cause-specific mortality. *Wildlife Biology* 17:wlb.00250.
- Chitwood, M. C., M. A. Lashley, J. C. Kilgo, K. H. Pollock, C. E. Moorman, and C. S. DePerno. 2015. Do biological and bedsite characteristics influence survival of neonatal white-tailed deer? *PLoS One* 10:e0119070.
- Cook, C. E. 2019. 2019 Marine Corps Base, Quantico white-tailed deer spotlight census addendum. Final report to the Marine Corps Base Quantico Natural Resources Section, Conservation Management Institute, Blacksburg, Virginia, USA.
- Crooks, K. R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. *Conservation Biology* 16: 488–502.
- Diamond, S. J., R. H. Giles, Jr., R. L. Kirkpatrick, and G. J. Griffin. 2000. Hard mast production before and after the chestnut blight. *Southern Journal of Applied Forestry* 24:196–201.
- Dion, J. R., J. M. Haus, J. E. Rogerson, and J. L. Bowman. 2020. White-tailed deer neonate survival in the absence of predators. *Ecosphere* 11:e03122.
- Farmer, C. J., D. K. Person, and R. T. Bowyer. 2006. Risk factors and mortality of black-tailed deer in a managed forest landscape. *Journal of Wildlife Management* 70:1403–1415.
- Feldhamer, G. A., T. P. Kilbane, and D. W. Sharp. 1989. Cumulative effect of winter on acorn yield and deer body weight. *Journal of Wildlife Management* 53:292–295.
- Fies, M. L. 2019. 2018 bowhunter survey. Virginia Department of Game and Inland Fisheries, Verona, Virginia, USA.
- Fox, J. F. 1982. Adaptation of gray squirrel behavior to autumn germination by white oak acorns. *Evolution* 36:800–809.
- Gaillard, J.-M., M. Festa-Bianchet, and N. G. Yoccoz. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. *Trends in Ecology & Evolution* 13:58–63.
- Gaillard, J.-M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toigo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. *Annual Review of Ecology and Systematics* 31:367–393.
- Garroway, C. J., and H. G. Broders. 2005. The quantitative effects of population density and winter weather on the body condition of white-tailed deer (*Odocoileus virginianus*) in Nova Scotia, Canada. *Canadian Journal of Zoology* 83:1246–1256.
- Gilbert, S. L., M. S. Lindberg, K. J. Hundertmark, and D. K. Person. 2014. Dead before detection: addressing the effects of left truncation on survival estimation and ecological inference for neonates. *Methods in Ecology and Evolution* 5: 992–1001.
- Gingery, T. M., D. R. Diefenbach, B. D. Wallingford, and C. S. Rosenberry. 2018. Landscape-level patterns in fawn survival across North America. *Journal of Wildlife Management* 82:1003–1013.
- Greenberg, C. H. 2000. Individual variation in acorn production by five species of southern Appalachian oaks. *Forest Ecology and Management* 132:199–210.





- Gulsby, W. D., J. C. Kilgo, M. Vukovich, and J. A. Martin. 2017. Landscape heterogeneity reduces coyote predation on white-tailed deer fawns. *Journal of Wildlife Management* 81:601–609.
- Harlow, R. F., J. B. Whelan, H. S. Crawford, and J. E. Skeen. 1975. Deer foods during years of oak mast abundance and scarcity. *Journal of Wildlife Management* 39:330–336.
- Haugen, A. O., and D. W. Speake. 1958. Determining age of young fawn white-tailed deer. *Journal of Wildlife Management* 22:319–321.
- Hody, J. W., and R. Kays. 2018. Mapping the expansion of coyotes (*Canis latrans*) across North and Central America. *ZooKeys* 759:81–97.
- Huegel, C. N., R. B. Dahlgren, and H. L. Gladfelter. 1985. Mortality of white-tailed deer fawns in South-Central Iowa. *Journal of Wildlife Management* 49:377–380.
- Huegel, C. N., R. B. Dahlgren, and H. L. Gladfelter. 1986. Bedsite selection by white-tailed deer fawns in Iowa. *Journal of Wildlife Management* 50:474–480.
- Jackson, A. M., and S. S. Ditchkoff. 2013. Survival estimates of white-tailed deer fawns at Fort Rucker, Alabama. *American Midland Naturalist* 170:184–190.
- Kautz, T. M., J. L. Belant, D. E. Beyer, Jr., B. K. Strickland, T. R. Petroelje, and R. Sollmann. 2019. Predator densities and white-tailed deer fawn survival. *Journal of Wildlife Management* 83:1261–1270.
- Kilgo, J. C., M. J. Cherry, S. S. Ditchkoff, W. D. Gulsby, and K. V. Miller. 2019. Coyotes and white-tailed deer populations in the east: a comment on Bragina et al. (2019). *Journal of Wildlife Management* 83:1636–1640.
- Kilgo, J. C., H. S. Ray, C. Ruth, and K. V. Miller. 2010. Can coyotes affect deer populations in southeastern North America? *Journal of Wildlife Management* 74:929–933.
- Kilgo, J. C., H. S. Ray, M. Vukovich, M. J. Goode, and C. Ruth. 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. *Journal of Wildlife Management* 76:1420–1430.
- Kilgo, J. C., M. Vukovich, H. S. Ray, C. E. Shaw, and C. Ruth. 2014. Coyote removal, understory cover, and survival of white-tailed deer neonates. *Journal of Wildlife Management* 78:1261–1271.
- Kjellander, P., J.-M. Gaillard, and A. J. M. Hewison. 2006. Density-dependent responses of fawn cohort body mass in two contrasting roe deer populations. *Oecologia* 146:521–530.
- Linnell, J. D. C., R. Aanes, and R. Andersen. 1995. Who killed Bambi? The role of predation in the neonatal mortality of temperate ungulates. *Wildlife Biology* 1:209–223.
- Long, R. A., R. T. Bowyer, W. P. Porter, P. Mathewson, K. L. Monteith, S. L. Findholt, B. L. Dick, and J. G. Kie. 2016. Linking habitat selection to fitness-related traits in herbivores: the role of the energy landscape. *Oecologia* 181:709–720.
- Lutz, C. L., D. R. Diefenbach, and C. S. Rosenberry. 2015. Population density influences dispersal in female white-tailed deer. *Journal of Mammalogy* 96:494–501.
- McGarigal, K., S. A. Cushman, and E. Ene. 2012. FRAGSTATS v4: spatial pattern analysis program for categorical and continuous maps. University of Massachusetts, Amherst, USA.
- McGovern, P. G., S. J. Dinsmore, and J. A. Blanchong. 2020. Survival of white-tailed deer fawns in central Iowa. *PLoS ONE* 15:e0229242.
- McShea, W. J. 2000. The influence of acorn crops on annual variation in rodent and bird populations. *Ecology* 81:228–238.
- McShea, W. J., and G. Schwede. 1993. Variable acorn crops: responses of white-tailed deer and other mast consumers. *Journal of Mammalogy* 74:999–1006.
- McShea, W. J., C. M. Stewart, L. J. Kearns, S. Liccioli, and D. Kocka. 2008. Factors affecting autumn deer–vehicle collisions in a rural Virginia county. *Human-Wildlife Conflicts* 2:110–121.
- Mech, L. D., R. E. McRoberts, R. O. Peterson, and R. E. Page. 1987. Relationship of deer and moose populations to previous winters' snow. *Journal of Animal Ecology* 56:615–627.
- Mech, L. D., M. E. Nelson, and R. E. McRoberts. 1991. Effects of maternal and grandmaternal nutrition on deer mass and vulnerability to wolf predation. *Journal of Mammalogy* 72:146–151.
- Michel, E. S., J. A. Jenks, K. D. Kaskie, R. W. Klaver, and W. F. Jensen. 2018. Weather and landscape factors affect white-tailed deer neonate survival at ecologically important life stages in the Northern Great Plains. *PLoS ONE* 13:e0195247.
- Nelson, M. A., M. J. Cherry, M. B. Howze, R. J. Warren, and L. M. Conner. 2015. Coyote and bobcat predation on white-tailed deer fawns in a longleaf pine ecosystem in Southwestern Georgia. *Journal of the Southeastern Association of Fish and Wildlife Agencies* 2:208–213.
- Nocera, T. 2019. 2019 Marine Corps Base Quantico archery survey report. Final report to the Marine Corps Base Quantico Natural Resources Section, Conservation Management Institute, Blacksburg, Virginia, USA.
- Pekins, P. J., and W. W. Mautz. 1987. Acorn usage by deer: significance of oak management. *Northern Journal of Applied Forestry* 4:124–128.
- Pekins, P. J., and W. W. Mautz. 1988. Digestibility and nutritional value of autumn diets of deer. *Journal of Wildlife Management* 52:328–332.



- R Core Team. 2018. R: a language and environment for statistical computing. Version 3.5.1. R Foundation for Statistical Computing, Vienna, Austria.
- Rohm, J. H., C. K. Nielsen, and A. Woolf. 2007. Survival of white-tailed deer fawns in Southern Illinois. *Journal of Wildlife Management* 71:851–860.
- Saalfeld, S. T., and S. S. Ditchkoff. 2007. Survival of neonatal white-tailed deer in an exurban population. *Journal of Wildlife Management* 71:940–944.
- Sams, M. G., R. L. Lochmiller, E. C. Hellgren, W. D. Warde, and L. W. Varner. 1996. Morphometric predictors of neonatal age for white-tailed deer. *Wildlife Society Bulletin* 24:53–57.
- Schoenfeld, D. 1982. Partial residuals for the proportional hazards regression model. *Biometrika* 69:239–241.
- Severinghaus, C. W. 1949. Tooth development and wear as criteria of age in white-tailed deer. *Journal of Wildlife Management* 13:195–216.
- Shuman, R. M., M. J. Cherry, E. A. Dutoit, T. N. Simoneaux, K. V. Miller, and M. J. Chamberlain. 2018. Resource selection by parturient and post-parturient white-tailed deer and their fawns. *Journal of the Southeastern Association of Fish and Wildlife Agencies* 5:78–84.
- Shuman, R. M., M. J. Cherry, T. N. Simoneaux, E. A. Dutoit, J. C. Kilgo, M. J. Chamberlain, and K. V. Miller. 2017. Survival of white-tailed deer neonates in Louisiana. *Journal of Wildlife Management* 81:834–845.
- Sikes, R. S., and the Animal Care and Use Committee of the American Society of Mammalogists. 2016. 2016 Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. *Journal of Mammalogy* 97:663–688.
- Stamps, R. T. 2015. Integrated natural resources management plan 2015–2019 for Marine Corps Base, Quantico, Virginia. United States Marine Corps, Quantico, Virginia, USA.
- Strickland, B. K., S. Demarais, and P. D. Gerard. 2008. Variation in mass and lactation among cohorts of white-tailed deer *Odocoileus virginianus*. *Wildlife Biology* 14:263–271.
- Therneau, T. M., and P. M. Grambsch. 2000. Modeling survival data: extending the Cox model. Springer, New York, New York, USA.
- Van Moorter, B., J.-M. Gaillard, P. D. McLoughlin, D. Delorme, F. Klein, and M. S. Boyce. 2009. Maternal and individual effects in selection of bed sites and their consequences for fawn survival at different spatial scales. *Oecologia* 159: 669–678.
- Vreeland, J. K., D. R. Diefenbach, and B. D. Wallingford. 2004. Survival rates, mortality causes, and habitats of Pennsylvania white-tailed deer fawns. *Wildlife Society Bulletin* 32:542–553.
- Watine, L. N., and W. M. Giuliano. 2016. Coyote predation effects on white-tailed deer fawns. *Natural Resources* 7: 628–643.
- Wentworth, J. M., A. S. Johnson, P. E. Hale, and K. E. Kammermeyer. 1992. Relationships of acorn abundance and deer herd characteristics in the southern Appalachians. *Southern Journal of Applied Forestry* 16:5–8.
- Whitehead, C. J. 1969. Oak mast yields on wildlife management areas in Tennessee. Tennessee Game and Fish Commission, Nashville, USA.
- Wolff, J. O. 1996. Population fluctuations of mast-eating rodents are correlated with production of acorns. *Journal of Mammalogy* 77:850–856.
- Wright, C. A., J. T. McRoberts, K. H. Wiskirchen, B. J. Keller, and J. J. Millsaugh. 2019. Landscape-scale habitat characteristics and neonatal white-tailed deer survival. *Journal of Wildlife Management* 83:1401–1414.

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