Research Article

Survival of White-Tailed Deer Neonates in Minnesota and South Dakota

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ABSTRACT Understanding the influence of intrinsic (e.g., age, birth mass, and sex) and habitat factors on survival of neonate white-tailed deer improves understanding of population ecology. During 2002–2004, we captured and radiocollared 78 neonates in eastern South Dakota and southwestern Minnesota, of which 16 died before 1 September. Predation accounted for 80% of mortality; the remaining 20% was attributed to starvation. Canids (coyotes [*Canis latrans*], domestic dogs) accounted for 100% of predation on neonates. We used known fate analysis in Program MARK to estimate survival rates and investigate the influence of intrinsic and habitat variables on survival. We developed 2 a priori model sets, including intrinsic variables (model set 1) and habitat variables (model set 2; forested cover, wetlands, grasslands, and croplands). For model set 1, model $\{S_{\text{age-interval}}\}$ had the lowest AIC$_c$ (Akaike's information criterion for small sample size) value, indicating that age at mortality (3-stage age-interval: 0–2 weeks, 2–8 weeks, and >8 weeks) best explained survival. Model set 2 indicated that habitat variables did not further influence survival in the study area; β-estimates and 95% confidence intervals for habitat variables in competing models encompassed zero; thus, we excluded these models from consideration. Overall survival rate using model $\{S_{\text{age-interval}}\}$ was 0.87 (95% CI = 0.83–0.91); 61% of mortalities occurred at 0–2 weeks of age, 26% at 2–8 weeks of age, and 13% at >8 weeks of age. Our results indicate that variables influencing survival may be area specific. Region-specific data are needed to determine influences of intrinsic and habitat variables on neonate survival before wildlife managers can determine which habitat management activities influence neonate populations. © 2011 The Wildlife Society.

KEY WORDS habitat, landscape, Minnesota, mortality, neonate, *Odocoileus virginianus*, predation, South Dakota, survival.

Understanding white-tailed deer (*Odocoileus virginianus*) population dynamics requires knowledge of survival rates and cause-specific mortality (Nelson and Mech 1986, Dusek et al. 1992, DePerno et al. 2000, DelGiudice et al. 2002). Research on neonates (<1 month of age) provides information regarding reproduction, sex ratios, mortality, movements, and behavior (Downing and McGinnes 1969). Furthermore, knowledge of neonate mortality is critical to understanding how prehunting season survival rates affect deer harvest strategies (Porath 1980). However, neonates rely on cryptic coloration and inactivity making capture difficult and survival information costly to collect (Porath 1980). Therefore, biologists often make educated guesses pertaining to neonate survival. Nevertheless, knowledge of female behavior (Downing and McGinnes 1969, Huegel et al. 1985a) and recent technology (e.g., vaginal-implant transmitters [VITs]; Bowman and Jacobson 1998, Carstensen et al. 2003, Swanson et al. 2008) improve capture success of neonate white-tailed deer.

Previous research indicates survival rates and cause-specific mortality of deer differ regionally and seasonally with respect to sex, age-class, and density of deer (Gavin et al. 1984, Dusek et al. 1992, Whitlaw et al. 1998, DelGiudice et al. 2002). Sources of mortality include starvation (Carroll and Brown 1977), disease (Cook et al. 1971, Schulz et al. 1983, Brinkman et al. 2004a), and predation (Huegel et al. 1985a, Nelson and Woolf 1987, Kunkel and Mech 1994, Rohm et al. 2007).

Macrohabitat variables affect survival of other wildlife species (Brown and Litvaitis 1995, Stuart-Smith et al. 1997, Kunkel and Pletscher 2000, Thogmartin and Schaeffer 2000) and clearly influence neonate survival by affecting predator distribution, density, and hunting efficiency (Gese et al. 1996, Dijak and Thompson 2000, Rohm et al. 2007). In Illinois, Rohm et al. (2007) documented that intrinsic and macrohabitat variables influenced survival, whereas in Pennsylvania, Vreeland et al. (2004) provided contradictory results relative to these variables. However, Vreeland et al. (2004) only evaluated 4 variables (i.e., habitat edge density, habitat diversity, proportion of herbaceous habitat, and road density), whereas Rohm et al. (2007) considered >10 covariates.

Limited survival information exists for neonate white-tailed deer in the Prairie Coteau of eastern South Dakota

and the Minnesota River Valley of southwest Minnesota. Brinkman et al. (2004a) documented survival and cause-specific mortality for neonates in Lincoln and Pipestone counties in southwestern Minnesota but did not investigate the influence of intrinsic and macrohabitat variables on survival. Our objectives were to 1) estimate survival and document cause-specific mortality of neonate white-tailed deer in eastern South Dakota and southwest Minnesota and 2) determine the influence of intrinsic and habitat characteristics on neonate survival in an intensively farmed landscape.

STUDY AREA

We conducted our study in eastern South Dakota and southwest Minnesota (Fig. 1). The region was fragmented and dominated by intense row-crop agriculture. Study sites we selected for neonate captures included Brookings County, South Dakota and Lincoln, Pipestone, Redwood, and Renville counties, Minnesota (Fig. 1). Brookings, Pipestone, and Lincoln counties occurred within the Prairie Coteau physiographic region, whereas, Redwood and Renville counties occurred within the Minnesota River Valley. As a result of Wisconsin Glaciation (10,000–100,000 yr ago), lobes of glacial ice shaped the landscape in this region (Minnesota River Basin Data Center 2003), creating steep topography along the Prairie Coteau and Minnesota River and its tributaries (Voigtlander 1999) compared to upland prairie habitats. The Minnesota River Valley was a linear corridor heavily forested with small interspersed grassland remnants and adjacent lands comprised primarily of cultivated crops. The Coteau was a large, dead-ice moraine that historically contained numerous wetlands (Johnson and Larson 1999). In eastern South Dakota, approximately 35% of natural wetlands were drained through anthropogenic modifications (e.g., agriculture; Dahl 1990, Johnson and Higgins 1997).
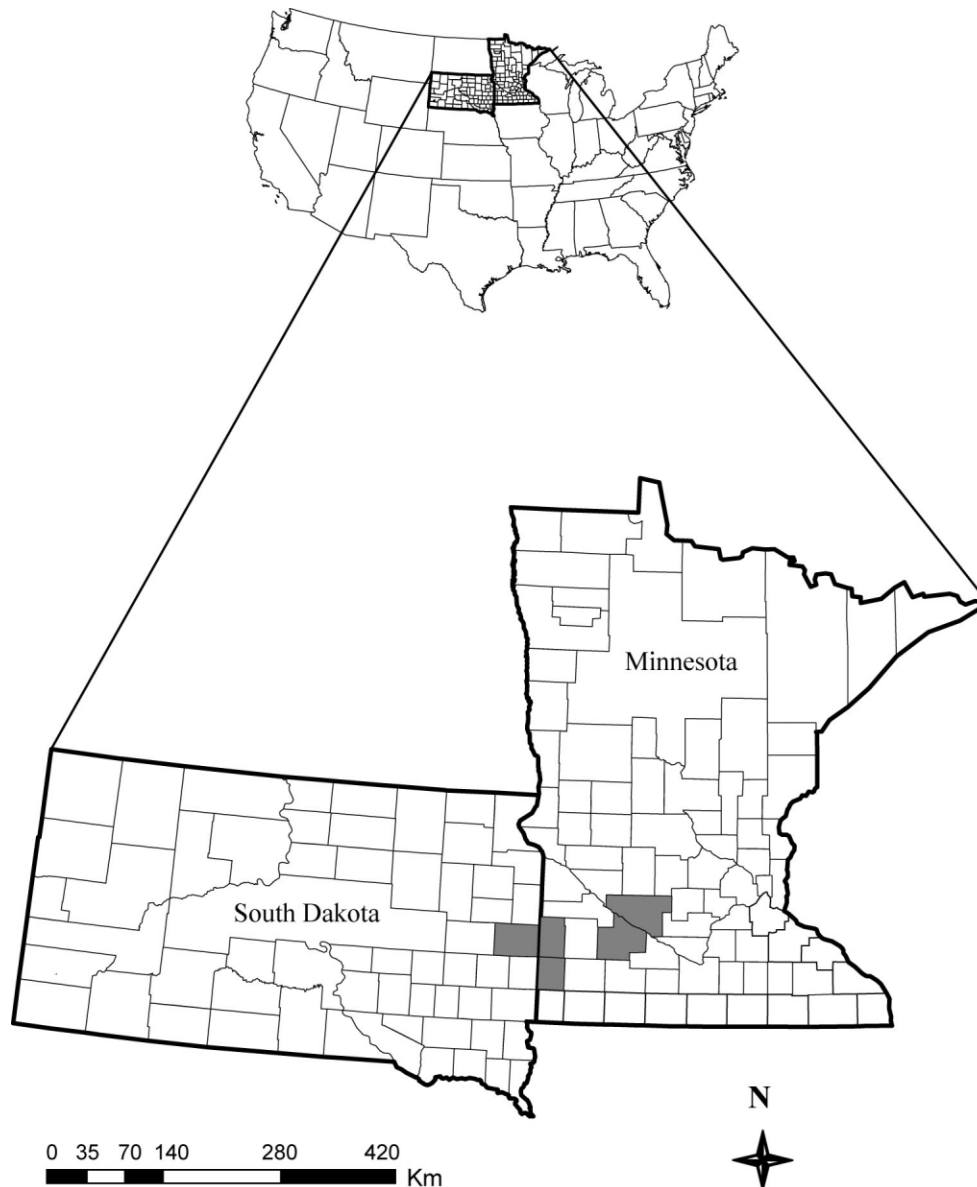
Figure 1. Neonate white-tailed deer (*Odocoileus virginianus*) study area (shaded) in eastern South Dakota and southwestern Minnesota, USA, 2001–2004.

Land-cover types in this region were primarily agricultural, with cultivated land and pasture–grassland dominating the landscape. Land cover of the study sites on the Prairie Coteau was 58.9% cultivated, 31.4% pasture–grassland, 4.2% wetland, and 2.3% forest (Smith et al. 2002). The Minnesota River Valley study sites were composed of 85.8% cultivated, 7.0% pasture–grassland, 3.0% forest, and 2.4% wetland (Vogelmann et al. 2001, Smith et al. 2002). Harvested crops included soybeans, corn, wheat, oats, and alfalfa. Grasslands in this region were dominated by tall and mixed-prairie grasses, including Indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), smooth bromegrass (*Bromus inermis*), tall dropseed (*Sporobolus asper*), prairie dropseed (*S. heterolepis*), sideoats grama (*Bouteloua curtipendula*), porcupine grass (*Stipa spartea*), and western wheatgrass (*Elymus smithii*; Johnson and Larson 1999). In low, wet areas, prairie cordgrass (*Spartina pectinata*), reedgrass (*Calamagrostis arundinacea*), reed canarygrass (*Phalaris arundinacea*), common reed (*Phragmites australis*), cattails (*Typha* spp.), rushes (*Juncus* spp.), and sedges (Cyperaceae) were common species on the landscape (Johnson and Larson 1999, Voigtlander 1999). Woodlands were dominated by American elm (*Ulmus americana*), bur oak (*Quercus macrocarpa*), basswood (*Tilia americana*), green ash (*Fraxinus pennsylvanica*), and eastern cottonwood (*Populus deltoides*; Minnesota Association of Soil and Water Conservation Districts Forestry Committee 1986, Johnson and Larson 1999).

METHODS

We captured neonatal deer 15 May–15 June from 2002 through 2004 (for model analysis, we included fawns captured and monitored 2001–2002; Brinkman et al. 2004*a*) using postpartum behavior of reproductive females (Downing and McGinnes 1969, White et al. 1972, Huegel et al. 1985*b*). Additionally, we captured neonates during 2003 with the aid of VITs (Advanced Telemetry Systems, Isanti, MN) fitted to adults as part of a companion study (Swanson et al. 2008). We fitted captured neonates with expandable breakaway radiocollars (Advanced Telemetry Systems and Telonics Inc., Mesa, AZ). We recorded sex and weight of neonates and determined age (in days) using hoof growth measurement and umbilicus condition (Brinkman et al. 2004*b*). We calculated parturition date from fawn age at capture and calculated birth mass from age and weight at capture (Nelson and Woolf 1985, Rohm et al. 2007). We located deer daily for the first 8 weeks of life and then 3–4 times/week through 31 August using a truck-mounted null-peak antenna system (Brinkman et al. 2002) and hand-held 4-element Yagi antenna (Advanced Telemetry Systems). When we detected a mortality signal, we immediately (<1 hr) located the collar, conducted field necropsies, and recorded evidence at the site of the mortality to determine cause of death. If we could not determine cause of death in the field, we transported animals to the Animal Disease Research Diagnostic Laboratory (ADRDL) at South Dakota State University for further examination.

Animal handling methods followed guidelines of the American Society of Mammalogists (Gannon et al. 2007) and were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval No. 00–A038, 02-A037, and 02-A043).

To determine if habitat characteristics influenced neonate survival, we created 500-m circular buffers around capture locations (Kie et al. 2002, Rohm et al. 2007). Corresponding buffer areas (0.78 km^2) comprised a land area equivalent to the largest mean 50% summer home range documented for adult females in each of the study areas (Brinkman et al. 2005, Burris 2005, Swanson 2005). To determine habitat characteristics associated with each neonate, we overlaid buffered areas with the 2001 National Land Cover Data set (Homer et al. 2007) and calculated habitat composition (% composition of each buffer) using ArcGIS 9.2 (Esri, Inc., Redlands, CA). We re-classified land cover data into 6 categories, including open water, forested cover, grassland-herbaceous, pasture-hay, cropland, and wetlands. We used FRAGSTATS Version 3.3 to calculate landscape and class-level metrics associated with each buffered area (McGarigal et al. 2002).

We selected the initial set (19 variables) of landscape and class-level metrics important to neonates based upon neonate ecology and metrics significant to survival in previous studies (Vreeland et al. 2004, Rohm et al. 2007). We defined metrics as a) patch density (number of patches/100 ha of the cover type), b) shape index (i.e., average departure of patches from max. compaction), and c) landscape shape index (i.e., standardized measure of the edge for all cover type patches; McGarigal et al. 2002). We tested for colinearity of independent habitat variables using variance inflation (Allison 1999), which resulted in 13 uncorrelated variables that we used to determine the impact of habitat characteristics on neonate survival (Table 1).

To estimate survival to the end of the field season each summer (31 Aug) and determine factors influencing fawn survival, we used known fate models in Program MARK (White and Burnham 1999). We constructed 2 sets of candidate models: 1) model set 1 generated survival estimates and quantified the influence of intrinsic covariates on fawn survival and 2) model set 2 generated survival estimates and quantified the influence of habitat covariates on fawn survival (Rohm et al. 2007). We used the best approximating model from model set 1 as the underlying (constant) structure for all models in model set 2 to account for maximum variation in the data (Burnham and Anderson 2002, Hill et al. 2003, Zablan et al. 2003, Rohm et al. 2007). Intrinsic variables included capture year, sex, site, birth mass, age at death (days), 3-stage age-interval at death (0–2 weeks, 2–8 weeks, and >8 weeks of age; Nelson and Woolf 1987, Rohm et al. 2007), and parturition date relative to peak parturition.

Model set 1 consisted of 13 a priori models (Table 2) constructed from various combinations of intrinsic variables. Model set 2 consisted of 14 a priori models (Table 3; plus best approximating model from model set 1 as the constant survival model) constructed from various combinations of habitat variables. We based a priori model construction on

Table 1. Final variables we measured within neonate capture areas used to model the influence of habitat characteristics on neonate white-tailed deer survival in eastern South Dakota and southwestern Minnesota, USA, 2001–2004.

Variable name	No.	Definition
Forested cover	1	Total forested cover (%)
Grassland cover	2	Total grassland cover (%)
Cropland cover	3	Total cropland cover (%)
Wetland cover	4	Total wetland cover (%)
Mean forest patch area	5	Average patch size (ha) for all forest patches
Forest shape index	6	Average departure of forest patches from max. compaction (i.e., square shape)
Mean grassland patch area	7	Average patch size (ha) for all grassland patches
Grassland patch density	8	Density (no./100 ha) of grassland patches
Grassland shape index	9	Average departure of grassland patches from max. compaction (i.e., square shape)
Mean wetland patch area	10	Average patch size (ha) for all wetland patches
Landscape shape index	11	Standardized measure of the amt of edge adjusted for size of the buffered area
Mean patch area	12	Average patch size (ha) for all habitat patches
CV	13	Mean CV of patch size for all habitat patches

Table 2. A priori models constructed for model set 1 to determine the influence of intrinsic variables on white-tailed deer neonate survival in eastern South Dakota and southwestern Minnesota, USA, 2001–2004.

Model	K^a	Description
$S_{constant}$	1	Survival was constant
S_{age}	16	Survival varied by age (days) of neonate
$S_{age-interval}$[b]	4	Survival varied by age of neonate in 3 stages
S_{year}	4	Survival varied among the 4 yr
S_{sex}	2	Survival varied between gender of neonates
S_{site}	4	Survival varied between the study sites
S_{date}[c]	2	Survival varied between date of birth
S_{mass}	2	Survival varied by birth mass
$S_{age + mass}$	17	Survival varied by age and birth mass
$S_{age + date}$[c]	17	Survival varied by age and parturition date groups
$S_{age + sex}$	17	Survival varied by age and sex
$S_{age + site}$	19	Survival varied by age and study site
$S_{sex + year}$	19	Survival varied by sex and year

[a] Number of parameters.
[b] 3-Stage age-interval: 0–2 weeks, 2–8 weeks, and >8 weeks.
[c] We grouped neonates into peak born and nonpeak born categories.

Table 3. A priori models constructed for model set 2 to determine the influence of habitat variables on white-tailed deer neonate survival in eastern South Dakota and southwestern Minnesota, USA, 2001–2004.

Model[a]	Variables[b]	Description
S_{fc}	1	% forest cover influences survival
$S_{landscape + fc}$	1, 11–13	Landscape metrics and % forest cover
$S_{landscape + grassland}$	2, 11–13	Landscape metrics and % grassland
$S_{grassland}$	2	% grassland influences survival
$S_{landscape + forest metrics}$	5, 6, 11–13	Landscape metrics and forest metrics
$S_{landscape}$	11–13	Landscape metrics
$S_{landscape + grassland metrics}$	7–9, 11–13	Landscape metrics and grassland metrics
S_{size}	5, 7, 10, 12	Variables pertaining to size influence survival
$S_{landscape + cropland}$	3, 11–13	Landscape metrics and % cropland
$S_{age-interval}$	0	Survival is constant
$S_{wetland}$	4	% wetland influences survival
$S_{cropland}$	3	% cropland influences survival

[a] All models have the top model from model set 1 {$S_{age-interval}$} as the basic structure to which we added habitat covariates.
[b] Variables included in model numbered in Table 1.

variables we considered biologically meaningful to neonate ecology and used Akaike's Information Criterion corrected for small sample size (AIC_c) to select models that best described the data. We compared AIC_c values to select the most parsimonious model and considered models differing by ≤ 2 ΔAIC_c from the selected model as potential alternatives (Burnham and Anderson 2002). We used Akaike weights (w_i) as an indication of support for each model and used multi-model inference to average parameters across potential models. Models ≤ 2 ΔAIC_c from the best model were examined to ascertain if they differed by 1 parameter from the best model and had essentially the same maximized log-likelihood. In this case, models with additional parameters were unsupported and noncompetitive and considered

Table 4. Top-ranked survival models of neonate white-tailed deer from birth to 31 August in eastern South Dakota and southwestern Minnesota, USA, 2001–2004 from model set 1 (intrinsic covariates) when $\hat{c}$ (a model term representing overdispersion) was 1.0 (i.e., assumed no dispersion).

Model[a]	AIC$_c$[b]	ΔAIC$_c$[c]	w_i[d]	K[e]	Deviance
$\{S_{\text{age-interval}}\}$	211.70	0.00	0.76	4	203.70
$\{S_{\text{age}}\}$	214.82	3.11	0.16	8	198.80
$\{S_{\text{age + mass}}\}$	216.56	4.86	0.07	9	198.54
$\{S_{\text{age + year}}\}$	220.65	8.95	0.01	11	198.62

[a] Compositon and description of models are listed in Table 1.
[b] Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002).
[c] Difference in AIC$_c$ relative to min. AIC.
[d] Akaike wt (Burnham and Anderson 2002).
[e] Number of parameters.

potential models only because they contributed an additional parameter (Burnham and Anderson 2002). We evaluated competing models with covariates in which β estimates did not have 95% confidence intervals that included zero (Neter et al. 1996, Barber-Meyer et al. 2008). Because there is no goodness-of-fit test statistic available for known-fate models, we investigated model robustness by artificially inflating $\hat{c}$ (i.e., a model term representing overdispersion) from 1.0 to 3.0 (i.e., no dispersion to extreme dispersion) to simulate various levels of dispersion reflected in Quasi-AIC$_c$ (QAIC$_c$; Devries et al. 2003, Barber-Meyer et al. 2008).

RESULTS

During 2002–2004, we captured and radiocollared 78 neonates (6 in 2002, 56 in 2003, 16 in 2004; 41 F, 37 M). Peak parturition occurred on 29 May 2002, 24 May 2003, and 24 May 2004. Age at capture ranged from <1 to 13 days, and 78% of fawns were ≤1 week of age at capture; mean age and weight at capture was 4.3 days (SE = 0.1) and 4.1 kg (SE = 0.4), respectively. Average estimated birth mass was 3.0 kg (SE = 0.1, n = 78). Of the 78 neonates, we documented 16 mortalities from time of capture until 31 August: 0 in 2002, 12 in 2003, and 4 in 2004. One neonate died <24 hr postcapture; thus, we censored it from survival analyses. Mean age at death was 24.3 days (SE = 6.8, n = 15). Predation was the leading cause of mortality; canid predation accounted for 12 (80.0%) neonate mortalities. We were unable to determine cause of death in the field for the remaining 3 (20.0%) mortalities; however, necropsies conducted at the ADRDL revealed starvation as the likely cause of death.

From model set 1, we considered model $\{S_{\text{age-interval}}\}$ as the only model that fit the data (AIC$_c$ wt = 0.76); remaining models were ≥3.1 ΔAIC$_c$ units from this model (Table 4). Weight of evidence supporting this model was 4.7 times greater than the next model and >10.9 times greater than remaining models (Table 4). Model $\{S_{\text{age-interval}}\}$ had the lowest QAIC$_c$ when $\hat{c}$ = 2.0 (moderate dispersion; QAIC$_c$ wt = 0.92) and through $\hat{c}$ = 3.0 (extreme dispersion; QAIC$_c$ wt = 0.94). The β estimates and 95% confidence intervals for the intercept (9.01, 95% CI = 7.05–10.97), 0–2 weeks (−6.73, SE = 1.04, 95% CI = −8.77 to −4.69), 2–8 weeks (−5.12, SE = 1.08, 95% CI = −7.24 to −3.00), and >8 weeks of age at death (−4.74, SE = 1.16, 95% CI = −7.01 to −2.48) indicated $\beta \neq 0$ for all intervals; survival was best explained by 3-stage age-intervals. Survival estimates for 0–2 weeks, 2–8 weeks, and >8 weeks were 0.91 (95% CI = 0.90–0.92), 0.98 (95% CI = 0.97–0.98), and 0.99 (95% CI = 0.98–0.99), respectively; overall survival was 0.87 (95% CI = 0.83–0.91). Of 23 mortalities (including those from Brinkman et al. [2004b]) used in covariate models, 14 (60.9%) occurred during the first 2 weeks of life and 6 (26.1%) during 2–8 weeks of life; remaining (13.0%, n = 3) mortalities occurred >8 weeks of age.

Using habitat variables, we considered 6 competing models as supporting the data; models were ≤2.0 ΔAIC$_c$ apart (Table 5). The constant model $\{S_{\text{age-interval}}\}$ had the lowest AIC$_c$ and weight of evidence supporting this model was ≥2.3 times greater than competing models and ≥17.1 times that for noncompeting models. Model $\{S_{\text{age-interval}}\}$ had the lowest QAIC$_c$ when $\hat{c}$ = 2.0 (moderate dispersion; QAIC$_c$ wt = 0.32) and through $\hat{c}$ = 3.0 (extreme dispersion;

Table 5. Top-ranked survival models of neonate white-tailed deer from birth to 31 August in eastern South Dakota and southwestern Minnesota, USA, 2001–2004 from model set 2 (habitat covariates) when $\hat{c}$ (a model term representing overdispersion) was 1.0 (i.e., assumed no dispersion).

Model[a]	AIC$_c$[b]	ΔAIC$_c$[c]	w_i[d]	K[e]	Deviance
$\{S_{\text{age-interval}}\}$	211.70	0.00	0.32	4	203.70
$\{S_{\text{wetland}}\}$	213.40	1.69	0.14	5	203.39
$\{S_{\text{water}}\}$	213.66	1.96	0.12	5	203.65
$\{S_{\text{cropland}}\}$	213.67	1.96	0.12	5	203.66
$\{S_{\text{grassland}}\}$	213.68	1.97	0.12	5	203.67
$\{S_{\text{forested cover}}\}$	213.71	2.00	0.12	5	203.70

[a] Compositon and description of models are listed in Table 2; all models have the base structure of the top model from model set 1 $\{S_{\text{age-interval}}\}$.
[b] Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002).
[c] Difference in AIC$_c$ relative to min. AIC.
[d] Akaike wt (Burnham and Anderson 2002).
[e] Number of parameters.

QAIC$_c$ wt = 0.33). Although competing models {S_wetland}, {S_water}, {S_cropland}, {$S_\text{grassland}$}, and {$S_\text{forested cover}$} were within ≤2.0 ΔAIC$_c$, β estimates and 95% confidence intervals for these habitat parameters encompassed zero. Furthermore, these models differed from {$S_\text{age-interval}$} by the addition of only 1 parameter and had approximately the same maximized log-likelihood; thus, we excluded these models from consideration.

DISCUSSION

The neonate survival rate we documented (0.87) was greater than previously reported in southern Illinois (0.70: Nelson and Woolf 1987, 0.59: Rohm et al. 2007), Minnesota (0.49: Kunkel and Mech 1994), Maine (0.40: Long et al. 1998), New Brunswick (0.47: Ballard et al. 1999), and Pennsylvania (0.46: Vreeland et al. 2004). Rohm et al. (2007) attributed elevated predation during their study to increased coyote and bobcat (*Lynx rufus*) abundance. However, in southwestern Lower Michigan, Pusateri-Burroughs et al. (2006) documented similar high survival rates (0.90–0.91), which those authors attributed to alternate food sources for coyotes, landscape composition, and dense ground cover. Although actual coyote density estimates were unknown, we believe the high neonate survival we observed was likely the result of low coyote density in the region based on observations during trapping in southwestern Minnesota (Brinkman 2003).

Similar to other studies documenting cause-specific mortality (Huegel et al. 1985a, Kunkel and Mech 1994, Long et al. 1998, Ballard et al. 1999, Rohm et al. 2007), we determined that canid predation (wolves [*Canis lupus*] were believed absent from South Dakota and southwestern Minnesota) was the major source of neonate mortality. In the Midwest, coyote predation was the main cause of fawn mortality (Huegel et al. 1985a, Benzon 1998), significantly reducing survival (Messier et al. 1986). Canid predation accounted for 50–53% of white-tailed deer neonate mortalities in southern Texas (Cook et al. 1971, Carroll and Brown 1977), 69% in southern Illinois (Nelson and Woolf 1987), 77% in south-central Iowa (Huegel et al. 1985a), 67% in southwest Minnesota (Brinkman et al. 2004a), and 64% in southern Illinois (Rohm et al. 2007). Our results are consistent with previous investigations; coyote predation was the main cause of fawn mortality.

Maternal abandonment because of handling was the proximate cause of starvation-related mortality <3 days postcapture in Pennsylvania (Vreeland et al. 2004). However, starvation or malnutrition as the likely cause of mortality has been documented for fawns up to 37 days postcapture; abandonment even after fawns begin to ruminate might cause starvation or malnutrition related mortality not attributed to handling (Vreeland et al. 2004). Although fawn mortality attributed to starvation occurred 4–7 days postcapture during our study, we have no direct evidence of abandonment due to handling or death of females.

Model selection results with intrinsic covariates indicated that neonate survival was best explained by 3-stage age-interval. Nelson and Woolf (1987), in an area of high forest cover, described the 3-stage age-interval and observed that neonate mortality was greatest when neonates were becoming more active but were not capable of evading predators (i.e., during the second interval). Neonates can avoid predation when they are <2 weeks of age through cryptic coloration and inactivity, and at >8 weeks of age neonates can escape predators (Nelson and Woolf 1987). However, during our study, survival was lowest during the first 2 weeks of life and highest after neonates reached >8 weeks of age. Our observations support previous hypotheses suggesting the greatest period of vulnerability occurred during the first 2 weeks of life (Rohm et al. 2007).

Model set 2 indicated that variation in neonate survival was not explained by habitat covariates. In southern Illinois, large patches of forested habitat adjacent to several smaller non-forest patches likely provided neonates with cover and concealment (Rohm et al. 2007). However, limited and fragmented forested cover in our study area may have explained why forested habitat did not influence survival in this region. Average forest patch size (0.93 ha) available to neonates was smaller than in southern Illinois, where neonates had larger (by a factor of 4–8 than those in our study) mean forest patch sizes (Rohm et al. 2007).

In southern Illinois, neonate survival was higher in areas with more edge habitat (Rohm et al. 2007). Increased survival in areas with greater edge density may have been an indicator of higher quality habitat; edge habitat likely provided better forage for dams, thereby increasing their condition and neonate survival (Vreeland et al. 2004, Rohm et al. 2007). However, we documented no influence of landscape shape index on neonate survival. During our study, landscape shape indices for neonate survival (3.5) and mortality (3.7) were larger (approx. double) than those documented for survival (2.0) and mortality (1.8) in southern Illinois (Rohm et al. 2007). Furthermore, Rohm et al. (2007) documented that survival areas contained more irregular forest patches than mortality areas in southern Illinois. Irregular boundaries of forested patches may have affected the ability of predators to locate and capture neonates with nonlinear edges being more difficult to search than linear edges (Rohm et al. 2007). However, we documented no influence of irregular forest patches on survival; forest shape indices during our study were similar to those documented in southern Illinois (Rohm et al. 2007).

MANAGEMENT IMPLICATIONS

We provided the first evaluation of the influence of intrinsic and understudied habitat variables on neonate white-tailed deer survival in the Northern Great Plains. Our study indicated that neonate survival was best explained by neonate age. Variables influencing survival may be area specific; for instance, outside our study area, survival may be dependent on available land cover and juxtaposition of habitats. Knowing when critical periods of fawn survival occur and causes of mortality will aid wildlife managers in identifying the time periods necessary to focus management activities aimed towards increasing neonate survival.

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