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Population Ecology

Survival of White-Tailed Deer Fawns in the Grasslands of the Northern Great Plains

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ABSTRACT Environmental factors, such as forest characteristics, have been linked to fawn survival in eastern and southern white-tailed deer (*Odocoileus virginianus*) populations. In the Great Plains, less is known about how intrinsic and habitat factors influence fawn survival. During 2007–2009, we captured and radiocollared 81 fawns in north-central South Dakota and recorded 23 mortalities, of which 18 died before 1 September. Predation accounted for 52.2% of mortality; remaining mortality included human (hunting, vehicle, and farm accident; 26.1%) and hypothermia (21.7%). Coyotes (*Canis latrans*) accounted for 83.3% of predation on fawns. We used known-fate analysis in Program MARK to estimate summer (15 May–31 Aug) survival rates and investigated the influence of intrinsic and habitat variables on survival. We developed 2 a priori model sets, including intrinsic variables and a test of annual variation in survival (model set 1) and habitat variables (model set 2). Model set 1 indicated that summer survival varied among years (2007–2009); annual survival rates were 0.94 (SE = 0.06, $n = 22$), 0.78 (SE = 0.09, $n = 27$), and 0.54 (SE = 0.10, $n = 32$), respectively. Model set 2 indicated that survival was further influenced by patch density of cover habitats (Conservation Reserve Program [CRP]-grasslands, forested cover, and wetlands). Mean CRP-grassland and wetland patch density (no. patches/100 ha) were greater ($P < 0.001$) in home-range areas of surviving fawns ($\bar{x}_{\text{CRPPD}} = 1.81$, SE = 0.10, $n = 63$; $\bar{x}_{\text{WetPD}} = 1.75$, SE = 0.14, $n = 63$, respectively) than in home-range areas of fawns that died ($\bar{x}_{\text{CRPPD}} = 0.16$, SE = 0.04, $n = 18$; $\bar{x}_{\text{WetPD}} = 1.28$, SE = 0.10, $n = 18$, respectively). Mean forested cover patch density was less ($P < 0.001$) in home-range areas of surviving fawns ($\bar{x}_{\text{FCPD}} = 0.77$, SE = 0.10, $n = 63$) than in home-range areas of fawns that died ($\bar{x}_{\text{FCPD}} = 1.49$, SE = 0.21, $n = 18$). Our results indicate that management activities should focus on CRP-grassland and wetland habitats in order to maintain or improve fawn survival in the northern Great Plains, rather than forested cover composed primarily of tree plantings and shelterbelts. © 2012 The Wildlife Society.

KEY WORDS fawn, habitat, mortality, northern Great Plains, *Odocoileus virginianus*, survival, white-tailed deer.

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). Knowledge of fawn mortality is critical to understanding how pre-hunting-season survival rates affect deer harvest strategies (Porath 1980). However, fawns 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 (Grovenburg et al. 2011a). 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 fawn 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, Grovenburg et al. 2011a).

Macrohabitat variables influence neonate survival by affecting predator distribution, density, and hunting efficiency (Gese et al. 1996, Dijak and Thompson 2000, Rohm et al. 2007). Additionally, intrinsic variables such as age, sex, birth weight, and year have influenced fawn survival (Rohm et al. 2007, Grovenburg et al. 2011a). In Illinois, Rohm et al. (2007) documented that intrinsic (e.g., age and yr) and macrohabitat variables (e.g., forested cover patch size and shape, landscape patch size and shape, and landscape coefficient of variation) 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

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covariates. In eastern South Dakota and western Minnesota, Grovenburg et al. (2011a) evaluated 13 habitat covariates; intrinsic variables alone influenced survival.

Fawns are more vulnerable than adults to predation and death by natural causes; therefore, information on factors affecting survival is vital for population modeling and management (Porath 1980, Roseberry and Woolf 1991, Bowden et al. 2000, Rohm et al. 2007). Although Grovenburg et al. (2011a) evaluated fawn survival in the row-crop dominated region of eastern South Dakota and western Minnesota, limited survival information exists for fawn white-tailed deer in the grassland regions of the northern Great Plains. Our objectives were to 1) estimate summer survival and document cause-specific mortality of fawn white-tailed deer in north-central South Dakota, and 2) determine the influence of intrinsic and habitat characteristics on fawn survival in grassland habitats of the northern Great Plains. Permanent cover habitat is limited in the grasslands of the northern Great Plains (Smith et al. 2002); therefore, we hypothesized that greater available cover (i.e., Conservation Reserve Program [CRP]-grasslands, forested cover, and wetlands) would positively influence survival of fawns in this region.

STUDY AREA

During 2007–2009, we searched for neonatal white-tailed deer throughout Edmunds and Faulk counties (Fig. 1) in north-central South Dakota; the 2 counties comprised 5,558 km². Mean annual (30-yr) precipitation was 49.5 cm and mean summer (30-yr) temperature ranged from 18.2° C to 21.3° C (South Dakota Office of Climatology 2010). The area was located within the Northwestern Glaciated Plains and the Northern Glaciated Plains Level III Ecoregions; the landscape was flat to gently rolling terrain intermixed with pothole wetlands and mounds of glacial till (Bryce et al. 1998). Soils in the study area were dominated by Williams–Bowbells and Williams–Bowbells–Vida associations (Ensz 1977, Miller 1984). Land use in the 2 counties was dominated by agriculture, with cultivated land and pasture (including native grasslands) constituting 40.4% and 43.0%, respectively of total land use; average forested (mainly woodland plantings and shelterbelts) cover was about 2.3% and development was <0.5% (Smith et al. 2002). Pastures were continuously grazed from spring to fall and herbaceous cover available to neonates was inferior to that offered in CRP grasslands, forested cover, and wheat (Grovenburg et al. 2010a). Much of the native grasslands in the 2-county area were heavily grazed (Ensz 1977, Miller 1984), with all native grasslands in the fawn study area grazed from spring to fall. South Dakota had 631,704 ha enrolled in the 2006 Conservation Reserve Program with 14,975 ha in the 2-county area (2.7% total land cover; South Dakota Agriculture Statistics Service 2009). Minimum summer deer densities within the study area were estimated at 2.3–3.3 deer/km² (Grovenburg et al. 2009a).

Traditionally, white-tailed deer on the northern Great Plains select habitats consisting of draws, swales, and low-

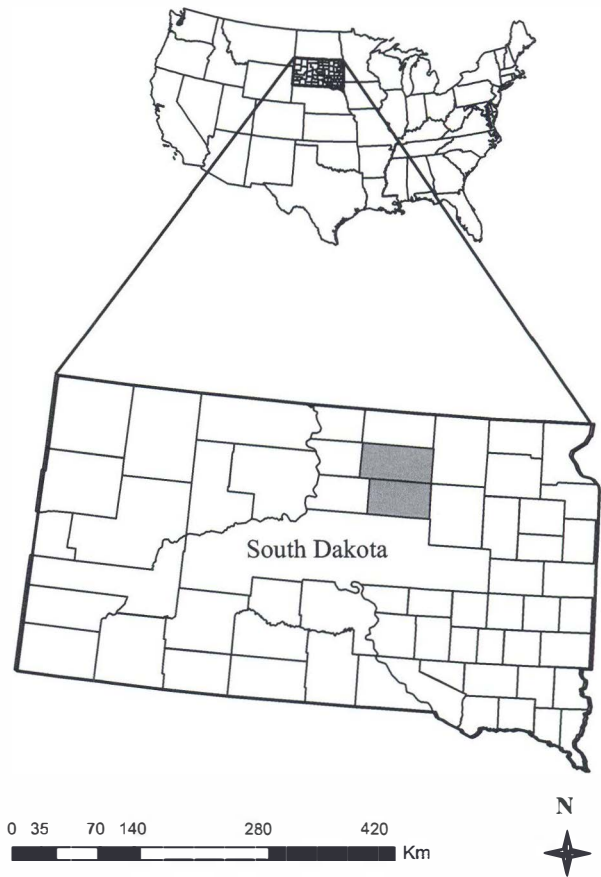


Figure 1. Two-county (Edmunds and Faulk) area for study of survival of fawn white-tailed deer (*Odocoileus virginianus*) in north-central South Dakota, USA, 2007–2009.

lands that received greater moisture than surrounding areas (Petersen 1984). Although marshes and sloughs occupy a relatively small portion of the northern Great Plains (11.1% land use in the 2-county area; Smith et al. 2002), they serve as cover and foraging areas for deer throughout the region (Petersen 1984). The Northern Mixed Grass Prairie extends in an arc below the boreal forests of Canada and into east-central South Dakota (Johnson and Larson 1999). Native vegetation in pastures was predominately western wheatgrass (*Elymus smithii*), big bluestem (*Andropogon gerardii*), porcupine grass (*Stipa spartea*), and little bluestem (*Schizachyrium scoparium*). Dominant tree species were green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), boxelder (*Acer negundo*), hackberry (*Celtis* spp.), and eastern cottonwood (*Populus deltoides*; Johnson and Larson 1999, Petersen 1984). Common wetland vegetation included prairie cordgrass (*Spartina pectinata*), reed canarygrass (*Phalaris arundinacea*), common reed (*Phragmites australis*), cattails (*Typha* spp.), rushes (*Juncus* spp.), and sedges (*Carex* spp.; Johnson and Larson 1999). Cultivated crops included corn (*Zea mays*), soybeans (*Glycine max*), wheat (*Triticum aestivum*), and alfalfa (*Medicago sativa*; South Dakota Agriculture Statistics Service 2009).

Conservation Reserve Program vegetation consisted primarily of CP1 (introduced grasses and legumes), CP2 (native

grasses and legumes), and CP10 (existing grasses and legumes; Jones-Farrand et al. 2007). The CP1 plantings were composed primarily of intermediate wheatgrass (*E. hispidus*), smooth brome (*Bromus inermis*), alfalfa, and sweet clover (*Melilotus* spp.) whereas CP2 plantings consisted of Indian grass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), big bluestem, and little bluestem (Best et al. 1997, Higgins 2000). Contracts for these CRP planting regimes were for 10 years (United States Department of Agriculture 2011a) and the average size of a patch of CRP-grassland in the fawn study area was 24.4 ha (SD = 23.3). Haying and grazing of CRP acreage may be authorized under certain conditions to improve quality and cover or to provide emergency relief to livestock producers (United States Department of Agriculture 2011a), but did not occur during our study.

Corn planting in north-central South Dakota began during the last week of April and concluded during the first week of June (United States Department of Agriculture 2011b). Although 96% of corn emerged by 31 May, average corn height was only 7.5 cm, offering minimal cover to neonates at time of peak parturition (United States Department of Agriculture 2011b, Grovenburg et al. In press). During our study, corn height averaged 58.4 cm on 1 July and 80–85 cm by mid-July (United States Department of Agriculture 2011b, Grovenburg et al. In press). Spring wheat was primarily sown in late March and early April with rapid growth occurring during parturition and early stages of neonate life. Harvest of wheat traditionally began in late-June to early-July, limiting use of wheat for cover during mid- to late-summer (Grovenburg et al. 2010a, United States Department of Agriculture 2011b, Grovenburg et al. In press). Planting of soybeans traditionally began during early May with 71% completed by 1 June; however, only about 25% of soybean fields had emerged, providing little cover to neonates (United States Department of Agriculture 2011b). Because agricultural crops provided cover to fawns temporally, often for only a few weeks (i.e., wheat), we included only permanent habitat types (e.g., CRP-grasslands [unmowed], forested cover, and wetlands) as cover habitat in our analyses.

METHODS

We captured fawns during 15 May–15 June 2007–2009 during nocturnal searches with vehicles and daytime ground searches using postpartum behavior of females as an indicator of parturition and presence of neonates (Downing and McGinnes 1969, White et al. 1972, Huegel et al. 1985b). Teams of 2–5 people intensively searched areas where we observed isolated females, females attempting to hide by lowering themselves to the ground, and females fleeing short distances as vehicles approached (Downing and McGinnes 1969, White et al. 1972, Huegel et al. 1985b). Once a neonate was visually located, we used a quick and loud approach to initiate a drop response (Nelson and Woolf 1987). Neonates that attempted to flee were pursued on foot and captured with a hand-held net (Ranger Salmon Net; Ranger Products, Inc., Detroit, MI).

We physically restrained neonates, recorded duration of chase, and determined sex (Grovenburg et al. In press). We determined age using hoof growth measurement and umbilicus condition (Haugen and Speake 1958, Brinkman et al. 2004b). We weighed individuals to the nearest gram using a 4.8-mm mesh bag suspended from a digital scale (Model FS 50, Berkley, Spirit Lake, IA) and recorded the habitat type in which we captured neonates. We calculated parturition date from fawn age at capture (Nelson and Woolf 1985, Rohm et al. 2007). We determined birth mass from age and weight at capture of each fawn using previous estimates of mean daily mass gain for fawns (0.25 kg; Robbins and Moen 1975, Nelson and Woolf 1985) multiplied by estimated age of fawn at capture and subtracted from mass of fawn at capture (Kunkel and Mech 1994, Rohm et al. 2007). We assumed capture mass of fawns <1 day old equaled birth mass. We used analysis of variance (ANOVA) to evaluate estimated birth mass by sex and capture year. We recorded capture locations (Universal Transverse Mercator [UTM]; Zone 14 NAD 83 coordinates) using a Magellan Triton 1500 Global Positioning System (GPS; Magellan Navigation, Inc., Santa Clara, CA), fitted captured neonates with model M4210 expandable breakaway radiocollars (Advanced Telemetry Systems, Isanti, MN), and recorded handling time. To minimize stress and reduce capture-related mortality, we minimized handling time (<4 min), processed fawns at capture sites, wore sterile latex gloves, stored radiocollars and other equipment for 6 weeks before capture in natural vegetation commonly found in the area, kept noise to a minimum, and rubbed fawns with native vegetation before release. We conducted statistical tests using SAS version 9.2 (SAS Institute 2000) with an experiment-wide error rate of 0.05. Animal handling methods used in this project followed guidelines approved by the American Society of Mammalogists (Sikes et al. 2011) and were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval number 04-A009).

We collected locations on each fawn from time of capture until 31 August each summer. We located deer 2 times/day using a truck-mounted null-peak antenna system with an electronic digital compass (C100 Compass Engine, KVH Industries, Inc., Middletown, RI; Lovallo et al. 1994, Brinkman et al. 2002) and hand-held 4-element Yagi antenna (Advanced Telemetry Systems). We visually located neonates and recorded UTM coordinates using a handheld GPS or estimated animal locations using LOCATE III (Nams 2006) with a minimum of 3 azimuths per location; 74.8% of locations were visual (Grovenburg et al. In press). We collected locations on a rotational schedule using 8-hour time intervals (i.e., 0600–1400, 1400–2200, and 2200–0600 hr) for each fawn and avoided obtaining locations during the same interval on successive location attempts. We monitored fawns 2–3 times/week for mortality during 1 September–1 December. When we detected a mortality signal, we immediately located the collar, conducted field necropsies, and recorded evidence at the mortality site to determine cause of death (White et al. 1987). We classified

mortality as human-induced, natural, or unknown (Rohm et al. 2007). Human-induced mortalities included mortality due to farming equipment (i.e., mowers, sprayers), vehicles, hunters, and fence entanglement. Natural mortalities included disease, starvation, hypothermia, and predation. If we could not determine cause of death in the field, we transported animals to the Animal Research Diagnostic Laboratory at South Dakota State University for further examination.

We used individual fawn home ranges to assess available land cover and to determine whether habitat characteristics influenced fawn survival. We used the fixed-kernel method in Home Range Tools (HRT) for ArcGIS 9.2 (Environmental Systems Research Institute, Inc., Redlands, CA; Rodgers et al. 2005) to calculate 95% home ranges. We calculated home ranges using an ad hoc smoothing parameter ($h_{ad\ hoc}$) by choosing the smallest increment of the reference bandwidth (h_{ref}) that resulted in a contiguous 95% kernel home range (i.e., $h_{ad\ hoc} = 0.9 \times h_{ref}$ – $0.8 \times h_{ref}$, etc.; Klaver et al. 2008, Jacques et al. 2009). We constructed fawn home ranges from capture date to 31 August each year using a minimum of 30 locations for each home range (Seaman et al. 1999, Grovenburg et al. In press). Because of mortality and censoring due to collar drop during the first 30 days post-capture, we were unable to calculate home ranges for 11 fawns. Therefore, we created buffered areas around capture locations based on age of fawn at time of mortality or censoring (Rohm et al. 2007). During 2007–2009, buffered areas were 48.2, 61.3, and 83.8 ha, respectively, corresponding to mean 30-day fawn home range each year (Grovenburg et al. In press).

We used ArcGIS 9.2 to analyze available land cover. We ground-verified individual habitats and annual land-use changes (i.e., grasslands placed into production, crop rotations) using GPS and digitized a unique map for each summer. We determined habitat characteristics for each fawn by overlaying individual home range or buffered area onto habitat maps. We classified habitat types as forested cover, CRP-grassland, pasture (including grazed native grasslands), wetland, corn, soybeans, wheat, and development (including roads), and calculated percent of each type available within each home range. We defined the fawn study area as southern Edmunds and northern Faulk counties where we captured 86.4% of fawns. To quantify available habitat within the area where fawns were captured, we used a buffered (1,000-m buffer equal to area of mean core home range of adult females; Grovenburg et al. 2009b) minimum convex polygon around all fawn locations and calculated percent of each habitat type available each year. We used FRAGSTATS Version 3.3 to calculate landscape and class-level metrics associated with each home range or buffered area (McGarigal et al. 2002).

We selected the initial set of landscape and class-level metrics potentially influential to fawn survival based on neonate ecology (Vreeland et al. 2004, Rohm et al. 2007, Grovenburg et al. 2011a). We grouped metrics into 6 categories: patch, edge, shape, proximity, diversity, and contagion (McGarigal et al. 2002). Because metrics within

each FRAGSTATS category often are correlated (Hargis et al. 1998), we selected 2 metrics within each category (Kie et al. 2002). To test for potentially confounding relationships, we evaluated collinearity between predictor variables using Pearson's correlation coefficient ($r > |0.50|$), which resulted in 23 uncorrelated variables that we used to determine the influence of habitat characteristics on fawn survival (Table 1). Class metrics included patch density (PD; number of patches/100 ha of the habitat category), mean area (MA; mean area of land cover patches [ha] of habitat category), and landscape shape index (SI; total length of edge [or perimeter] associated with the corresponding habitat, divided by the minimum length of habitat edge [or perimeter] possible for a maximally aggregated habitat). Landscape metrics included number of patches (NP; number of total patches in the area), landscape patch density (LPD; total number of patches in the area/100 ha), landscape shape index (LSI; total length of edge in the landscape, divided by the minimum total length of edge possible), and coefficient of variation (CV; a measure of patch area distribution; McGarigal et al. 2002).

We used known-fate models in Program MARK (White and Burnham 1999) with the logit-link function to estimate survival to the end of summer (31 Aug) and relate intrinsic and habitat variables to fawn survival. We constructed 2 sets of candidate models: model set 1 quantified the influence of intrinsic covariates on fawn survival and model set 2 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, Zablán et al. 2003, Rohm et al. 2007). Intrinsic variables included capture year, sex, birth mass, age at death, and parturition date relative to peak parturition. We parameterized age at death 2 ways: age at death (number of days neonate lived) and a 3-stage age-interval using dummy variable coding indicating age of death (0–2 weeks, 2–8 weeks, and >8 weeks of age; Nelson and Woolf 1987, Rohm et al. 2007). We used estimated birth mass instead of mass at capture because of positive correlation between age and weight (Rohm et al. 2007).

Model set 1 consisted of 11 a priori models constructed from various combinations of intrinsic variables. Model set 2 consisted of 14 a priori models constructed from various combinations of habitat variables. Our resulting sample size from capture activities was a function of low deer densities in the study area (Grovenburg et al. 2009a) and logistics; therefore, we set the maximum number of parameters in a model as ≤ 8 (Hosmer and Lemeshow 2000). We based a priori model construction on variables we considered biologically meaningful to fawn ecology and used Akaike's Information Criterion (AIC_c) corrected for small sample sizes to select models that best described the data. We considered models differing by $\leq 2 \Delta AIC_c$ from the selected model as model alternatives and used Akaike weights (w_i) as an indication of support for each model (Burnham and Anderson 2002). We evaluated covariates from competing models by estimating beta parameters and assessing whether

Table 1. Final variables (including mean, SD, and range) measured within fawn white-tailed deer home ranges used to estimate the influence of habitat characteristics on fawn survival in north-central South Dakota, USA, 2007–2009.

Variable	Mean (SD)	Range	Definition ^a
CRP-grassland	31.6 (26.8)	0.0–95.8	Total CRP-grassland cover (%)
Forested cover	3.4 (1.4)	0.0–5.9	Total forested cover (%)
Wheat cover	17.8 (16.2)	0.0–64.6	Total wheat cover (%)
Cropland cover	24.5 (16.9)	0.0–70.0	Total cropland cover (%)
Wetland cover	2.5 (2.5)	0.0–10.6	Total wetlands (%)
CRP-grassland patch density	1.6 (0.8)	0.0–2.6	Density (no./100 ha) of CRP-grassland patches
\bar{x} CRP-grassland patch area	24.4 (23.6)	0.0–112.4	Average patch size (ha) for all CRP-grassland patches
CRP-grassland shape index	1.5 (0.5)	0.0–2.6	Average departure of CRP-grassland patches from max. compaction
Forested patch density	0.8 (0.7)	0.0–2.6	Density (no./100 ha) of forested patches
\bar{x} forested patch area	0.3 (0.3)	0.0–1.3	Average patch size (ha) for all forest patches
Forest shape index	0.7 (0.6)	0.0–1.4	Average departure of forest patches from max. compaction
Wetland patch density	1.7 (1.1)	0.0–5.1	Density (no./100 ha) of wetland patches
\bar{x} wetland patch area	1.4 (0.8)	0.0–3.6	Average patch size (ha) for all wetland patches
Wetland shape index	1.4 (0.6)	0.0–2.3	Average departure of wetland patches from max. compaction
Cultivated patch density	2.2 (1.3)	0.0–6.4	Density (no./100 ha) of cultivated patches
\bar{x} cultivated patch area	14.2 (14.2)	0.0–64.0	Average patch size (ha) for all cultivated patches
Cultivated shape index	1.5 (0.6)	0.0–3.1	Average departure of cultivated patches from max. compaction
Wheat patch density	1.2 (1.2)	0.0–6.4	Density (no./100 ha) of wheat patches
\bar{x} wheat patch area	17.4 (21.0)	0.0–63.9	Average patch size (ha) of wheat patches
Wheat shape index	1.0 (0.7)	0.0–1.7	Average departure of wheat patches from max. compaction
Patch density	10.3 (3.5)	2.9–18.5	Total number of patches in the area/100 ha
Landscape shape index	5.2 (1.3)	2.5–7.4	Standardized measure of the amount of edge for all habitat patches
\bar{x} patch area	7.1 (5.6)	2.3–39.1	Average patch size (ha) for all habitat patches
Coefficient of variation	240.6 (64.7)	128.9–397.3	Mean coefficient of variation of patch size for all habitat patches

^a Variables are further defined in McGarigal et al. (2002).

95% confidence intervals included 0 (i.e., informative parameters; Neter et al. 1996, Barber-Meyer et al. 2008). We estimated summer survival rates and 95% confidence intervals using our top-ranked intrinsic survival model.

We evaluated sibling dependence and overdispersion in survival using the data-bootstrap option in Program MARK (Bishop et al. 2008). Bootstrap analysis consisted of 10,000 replicate datasets generated by resampling our data with replacement. We resampled litters rather than individual fawns and number of samples drawn in each replicate equaled number of litters (i.e., no. of adult females) in the original dataset (Bishop et al. 2008). We calculated mean and standard deviation of the 10,000 survival estimates and used the standard deviation of estimates to calculate overdispersion. We compared standard deviation of the replicate survival estimates with the theoretical standard errors obtained from our original analysis (Bishop et al. 2008). We estimated c as the ratio of the empirical (i.e., bootstrap) variance ($[SD(\hat{\theta})]^2$) to the theoretical variance ($[SE(\hat{\theta})]^2$) obtained from the maximum likelihood analyses of our original data set. We considered $1.0 < \hat{c} \leq 1.2$ as weak overdispersion, thereby reflecting the uncertainty in \hat{c} , and $\hat{c} < 1$ (i.e., underdispersion) as overestimated sample variance (Bishop et al. 2008).

Grovenburg et al. (2010a, In press) documented a shift in fawn bed sites from CRP-grasslands to wheat and a temporal shift in selection of wheat during early summer (i.e., selection for wheat progressed from avoided to selected) and hypothesized that reduced thermal characteristics of wheat would lead to decreased fawn survival. To determine differences in thermal insulation between CRP-grasslands and fields of wheat during the bed-site period (15 May–30 Jun;

Grovenburg et al. 2010a), we used Hobo 4-Channel External Data Loggers (Onset[®], Pocasset, MA) with Water/Soil Temperature Sensors (Onset[®]). We selected fields separated by ≤ 5 km in areas known to contain fawns and we installed 6 temperature stations in separate fields of CRP-grasslands ($n = 3$) and wheat ($n = 3$), using 2-m wooden posts. On each wooden post, we attached temperature sensors 1 m above the ground (hereafter ambient temperature) and 12.7 cm above the ground (hereafter bed site temperature) and sheltered each sensor from direct sunlight by installing a white, 0.21-m² plastic sunshade immediately above the sensor. To minimize heat flux between sensors and post, we attached sensor cables to posts using twine so that each temperature sensor was approximately 5.1–7.6 cm from the post. We housed the data logger in a watertight plastic container, and attached each data logger to the wooden post. We programmed each data logger to record temperature every 30 min (48 temperature readings daily per sensor) beginning at 1200 hrs on 15 May 2010 and ending at 2330 hrs on 30 June 2010. We selected this time period because it corresponded to fawn use of bed sites in the region (Grovenburg et al. 2010a), beginning of wheat harvest in the region (late Jun–early Jul; United States Department of Agriculture 2011b), and fawn avoidance of wheat fields during late summer (Grovenburg et al. In press). We divided the monitoring period into 2 equal intervals, early period (15 May–7 Jun) and late period (8–30 Jun), representing when fawns were inactive (< 14 days of age) and were becoming more mobile (> 14 days of age; observed following female) during our study. We used multivariate analysis of variance (MANOVA) to compare ambient and bed-site

temperatures within and between cover types (e.g., CRP grassland and wheat) and used each 30-min time interval as our class variable.

We used a Robel pole (Robel et al. 1970) to estimate vertical height of overstory (max. reading on Robel pole) and understory (min. reading on Robel pole) vegetation at each station site and at 4 locations 2 m from center along each of 2 perpendicular transects originating at the temperature station. We collected vegetation measurements 2 times/week for the duration of temperature monitoring. We used *t* tests to determine differences in vertical height of understory vegetation and density of understory vegetation between CRP-grasslands and wheat.

RESULTS

We captured and radiocollared 81 fawns (51 F, 30 M) during 15 May–15 June 2007 ($n = 22$, 14 F, 8 M), 2008 ($n = 27$, 17 F, 10 M), and 2009 ($n = 32$, 20 F, 12 M); including 20 (24.7%) siblings. Mean search-hours and person-hours per captured fawn were 5.1 hrs and 10.1 hrs, respectively. Median dates of parturition were 26 May 2007, 26 May 2008, and 29 May 2009. Estimated age at capture did not vary by sex ($F_{1,79} = 0.53$, $P = 0.47$) but varied by year ($F_{2,78} = 27.82$, $P < 0.001$); fawns were older at capture during 2007 ($\bar{x} = 6.0$ days, $SE = 0.6$, $n = 22$) than 2008 ($\bar{x} = 1.87$ days, $SE = 0.3$, $n = 27$) and 2009 ($\bar{x} = 1.84$ days, $SE = 0.3$, $n = 32$). Estimated birth mass ($\bar{x} = 2.65$ kg, $SE = 0.04$, $n = 81$) differed by sex ($F_{1,79} = 7.90$, $P = 0.01$) but not year ($F_{2,78} = 0.42$, $P = 0.66$). Males ($\bar{x} = 2.81$ kg, $SE = 0.05$, $n = 30$) weighed more than females ($\bar{x} = 2.56$ kg, $SE = 0.04$, $n = 51$).

We recorded 23 mortalities from date of capture to 1 December during the 3-year period: 2 in 2007, 6 in 2008, and 15 in 2009; 18 mortalities (1 in 2007, 5 in 2008, and 12 in 2009) occurred before 31 August and were used for summer

survival models. Predation was the leading source of mortality ($n = 12$, 52.2%) and increased temporally (0 in 2007, 3 in 2008, and 9 in 2009). Additional mortality included hypothermia ($n = 5$, 21.7%), farm vehicles ($n = 3$; 13.0%), hunting ($n = 2$; 8.7%), and vehicle collision ($n = 1$; 4.3%). Coyotes (*Canis latrans*) were the predominant predator, accounting for 83.3% ($n = 10$) of all mortalities attributed to predation. We could not classify 16.7% ($n = 2$) of predation deaths to specific predators with complete certainty. Hypothermia mortality occurred 1–6 June 2009; all 5 fawns dying from hypothermia were located alive 6–8 hrs prior to obtaining mortality signals and were found dead in fields of wheat. Necropsies revealed that fawns that died from hypothermia were in good body condition with no obvious signs of injury and had healthy lung tissue (i.e., pink coloration and lack of lesions), rumens >50% full, and had gained approximately 0.24 kg/day since capture.

The intrinsic survival model with the smallest AIC_c after excluding models where the confidence interval of at least 1 beta parameter estimate overlapped 0 was the year model. The year model indicated that survival varied among years; 95% confidence intervals of β estimates for the parameters ($\beta_1 = -2.30$, 95% CI = -4.34 to -0.26 ; $\beta_2 = -1.37$, 95% CI = -2.49 to -0.27) did not overlap 0. We initially considered 5 models containing parameters for year and sex ($w_i = 0.26$), year and date ($w_i = 0.26$), year only ($w_i = 0.22$), year and age interval ($w_i = 0.15$), and year and mass ($w_i = 0.08$) as supported by the data (Table 2). These models were ≤ 2.4 AIC_c units from the top model and remaining models were ≥ 5.9 AIC_c units from the top model. Our top-ranked model indicated that survival was best explained by year and sex of neonate. However, confidence intervals (95%) of β estimates for the parameter sex ($\beta = 0.82$, 95% CI = -0.30 – 1.94) overlapped 0; therefore, we removed this model from consideration. Our second-

Table 2. Top-ranked survival models of fawn white-tailed deer from birth to 31 August in north-central South Dakota, USA, 2007–2009 from model set 1 (intrinsic covariates).

Model ^a	AIC_c^b	ΔAIC_c^c	w_i^d	K^e	Deviance
$S_{\text{year} + \text{sex}}^f$	241.57	0.00	0.26	4	233.56
$S_{\text{year} + \text{date}}^f$	241.59	0.02	0.26	4	233.59
S_{year}	241.93	0.36	0.22	3	235.93
$S_{\text{year} + \text{age-interval}}^f$	242.68	1.11	0.15	5	232.67
$S_{\text{year} + \text{mass}}^f$	243.93	2.36	0.08	4	235.93
S_{sex}	247.54	5.97	0.01	2	243.54
S_{date}	247.70	6.13	0.01	2	243.70
$S_{\text{age} \times \text{interval}}$	247.91	6.34	0.01	3	241.90
S_{mass}	249.41	7.84	0.01	2	245.40
$S_{\text{age} + \text{mass}}$	509.89	268.32	0.00	8	493.86
$S_{\text{age} + \text{sex}}$	511.89	270.32	0.00	9	493.86
S_{full}	827.88	586.31	0.00	327	136.56
S_{age}	1,055.31	813.75	0.00	7	1,041.30
$S_{\text{age} + \text{date}}$	2,330.33	2,088.76	0.00	8	2,314.30

^a Date = Parturition date grouped into peak born and nonpeak born categories. Age-interval = 3-stage age-interval: 0–2 weeks, 2–8 weeks, 8+ weeks.

^b Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002).

^c Difference in AIC_c relative to minimum AIC_c .

^d Akaike weight (Burnham and Anderson 2002).

^e Number of parameters.

^f 95% CI for the β estimates of at least 1 parameter contained 0, so these models were not considered when selecting the model with the lowest AIC_c (Barber-Meyer et al. 2008).

ranked model indicated that survival was best explained by year and parturition date relative to peak parturition. Ninety-five percent confidence intervals of β estimates for the date parameter ($\beta = 0.62$, 95% CI = -1.43-0.48) overlapped 0; therefore, we excluded this model from consideration. Ninety-five percent confidence intervals of β estimates for 2 of 3 age-interval parameters ($\beta_1 = -2.05$, 95% CI = -3.71 to -0.39; $\beta_2 = -1.02$, 95% CI = -3.03-0.99, and $\beta_3 = -1.62$, 95% CI = -1.62-0.31) and for birth mass ($\beta = 0.02$, 95% CI = -2.20-2.25) also overlapped 0; therefore, we excluded these models from consideration. During 2007-2009, summer survival rates (including hypothermia deaths) were 0.94 (SE = 0.06, 95% CI = 0.67-0.99), 0.78 (SE = 0.09, 95% CI = 0.57-0.91), and 0.54 (SE = 0.10, 95% CI = 0.35-0.71), respectively. We removed the 5 hypothermia deaths to ensure that this single event did not dictate the results of our survival analysis; the year model remained the survival model with the smallest AIC_c.

For model set 2, the model containing parameters for patch density of 3 cover habitats (CRP, forested cover, and wetlands) was the best approximating model ($w_i = 0.99$; Table 3) of fawn survival. All other models were ≥ 8.7 AIC_c units from this model and 95% confidence intervals of β estimates for the parameters CRP patch density ($\beta = 5.24$, 95% CI = 3.18-7.31), forested cover patch density ($\beta = -1.55$, 95% CI = -2.36 to -0.73), and wetlands patch density ($\beta = 0.88$, 95% CI = 0.31-1.45) did not contain 0. Mean CRP-grassland and wetland patch density (no. patches/100 ha) were greater ($P < 0.001$) in home-range areas of surviving fawns ($\bar{x}_{CRPPD} = 1.81$, SE = 0.10, $n = 63$; $\bar{x}_{WetPD} = 1.75$, SE = 0.14, $n = 63$, respectively) than in home-range areas of fawns that died ($\bar{x}_{CRPPD} = 0.16$, SE = 0.04, $n = 18$; $\bar{x}_{WetPD} = 1.28$, SE = 0.10, $n = 18$, respectively). Mean forested cover patch

density was less ($P < 0.001$) in home-range areas of surviving fawns ($\bar{x}_{FCPD} = 0.77$, SE = 0.10, $n = 63$) than in home-range areas of fawns that died ($\bar{x}_{FCPD} = 1.49$, SE = 0.21, $n = 18$). Available CRP-grassland in the fawn study area (southern Edmunds and northern Faulk counties) decreased from 5.7% to 3.4% of available land cover from 2007 to 2009; a decrease of approximately 21% of available permanent cover habitat (e.g., CRP-grasslands, forested habitat, and wetlands).

We estimated c using our top-ranked intrinsic and habitat models. Our estimates for c for our top-ranked intrinsic model ranged from 1.15 to 1.26 and averaged 1.21. Our estimate of c for our top-ranked habitat model ranged from 1.11 to 1.22 and averaged 1.18, providing evidence of limited overdispersion (i.e., limited sibling dependence).

We recorded 26,784 temperature readings; 4,464 readings at each of 6 temperature stations over 45 days. During 15 May to 7 June (i.e., early period), ambient temperature among CRP grassland and wheat temperature stations did not differ ($F_{1,130} < 1.46$, $P > 0.23$) for any 30-min time interval. Bed-site temperature, however, differed from 0000 to 0530 and 1130 to 1730 hrs ($F_{1,130} > 4.03$, $P < 0.05$), being greater in CRP grasslands than in wheat. From 0000 to 0530 and 1130 to 1730 hrs, mean difference in bed site temperatures between CRP grasslands and wheat was 2.8° C (SE = 0.1, $n = 828$) and 2.2° C (SE = 0.1, $n = 897$), respectively. During 8-30 June (i.e., late period), ambient temperature among CRP grassland and wheat temperature stations did not differ ($F_{1,124} < 1.03$, $P > 0.31$) for any 30-min time interval. Bed-site temperature was 2.0° C (SE = 0.1, $n = 726$) greater in CRP-grasslands during 0100-0600 hrs ($F_{1,124} > 6.39$, $P < 0.02$) than in wheat. Mean vertical height of overstory vegetation was approximately 26.4% greater ($t_{70} = -6.68$, $P < 0.001$) in CRP-grasslands ($\bar{x} = 121.9$ cm, SE = 4.4, $n = 36$) than

Table 3. Top-ranked survival models of fawn white-tailed deer from birth to 31 August in north-central South Dakota, USA, 2007-2009 from model set 2 (habitat covariates).

Model ^a	AIC _c ^b	Δ AIC _c ^c	w_i ^d	K^e	Deviance
$S_{CRPPD} + FCPD + WetPD$	156.78	0.00	0.99	6	144.77
$S_{CRPMA} + FCMA + WetMA + CultMA + WheatMA$	165.50	8.72	0.01	8	149.48
$S_{CRPPD} + CRPMA + CRPSI$	169.26	12.48	0.00	6	157.24
$S_{CRPMA} + FCMA + WetMA$	172.90	16.12	0.00	6	160.89
$S_{CRP} + FC + Wet$	174.15	17.37	0.00	6	162.13
$S_{CRPSI} + FCSI + WetSI + CultSI + WheatSI$	195.64	38.86	0.00	8	179.61
$S_{CRPSI} + FCSI + WetSI$	200.94	44.16	0.00	6	188.93
$S_{WheatPD} + WheatMA + WheatSI$	201.26	44.48	0.00	6	189.25
$S_{FCPD} + FCMA + FCSI$	217.14	60.36	0.00	6	205.12
S_{LPD}	238.59	81.81	0.00	4	230.59
$S_{NP} + LPD + LSI + CV$	239.17	82.39	0.00	7	225.15
$S_{CultPD} + CultMA + CultSI$	240.90	84.12	0.00	6	228.88
$S_{WetPD} + WetMA + WetSI$	244.70	87.92	0.00	6	232.69

^a All models have the base structure of the top model from model set 1 $\{S_{year}\}$. Parameters ending in PD include patch density (no. patches/100 ha) of the cover type (CRP: Conservation Reserve Program grasslands, FC: forested cover, Wet: wetlands, Cult: cultivated). Parameters ending in MA include mean patch size (ha) for individual cover types. Parameters ending in SI include shape index (average departure of patch from max. compaction) for the specified cover type. LPD = landscape patch density of all cover types. LSI = landscape shape index. CV = coefficient of variation. NP = total number of patches in buffered area.

^b Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002).

^c Difference in AIC_c relative to minimum AIC.

^d Akaike weight (Burnham and Anderson 2002).

^e Number of parameters.

in wheat ($\bar{x} = 84.4$ cm, SE 3.5, $n = 36$). Mean height of understory vegetation did not differ ($t_{70} = -0.37$, $P = 0.36$) between CRP grasslands ($\bar{x} = 67.8$ cm, SE = 3.6, $n = 36$) and wheat ($\bar{x} = 65.9$ cm, SE = 3.6, $n = 36$).

DISCUSSION

Survival of fawns varied temporally in north-central South Dakota; survival decreased from 0.94 (SE = 0.06) in 2007 to 0.54 (SE = 0.10) in 2009. High survival rates similar to 2007 were documented in southwestern Lower Michigan (0.90–0.91) and were attributed to alternate food sources for coyotes, landscape composition, and dense ground cover (Pusateri-Burroughs et al. 2006). Additionally, Brinkman et al. (2004b) reported high fawn survival (0.84) in south-central Minnesota, which they attributed to low predator density, quality vegetation at bed sites, and high nutritional condition of dams. Similarly, Grovenburg et al. (2011a) observed high fawn survival (0.87) in eastern South Dakota and southwestern Minnesota. Survival rates during 2008 and 2009 were similar to those 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).

We realize that potential for bias exists in our results given that we captured fawns by hand, but we believe this potential was minimal (Rohm et al. 2007). Most fawns were captured soon after birth; 86.0% of fawns were ≤ 1 week of age at capture and 50.6% were newborns (< 2 days of age). Therefore, we unlikely captured smaller and slower fawns, as most fawns were small and slow given their age and the majority of fawns were captured at an age when their anti-predator strategy was to hide (Mech 1984); even the healthiest fawns were not capable of outrunning predators (Rohm et al. 2007). Furthermore, because we searched a variety of habitats and used several capture methods independent of habitat type, we do not believe our results were biased towards habitats that influenced mortality (Rohm et al. 2007).

We had evidence supporting variation in survival due to sex, date, birth mass, and age of fawn, but excluded these models from competition because 95% confidence intervals of β estimates for the parameters overlapped 0. Additionally, inclusion of these parameters to the year model resulted in only minimal changes (0–1.4%) in the deviance explained by each model. Grovenburg et al. (2011a) observed that age of fawn at death (3-stage age-interval) affected fawn survival and mortality decreased as fawns aged. However, we observed greater mortality > 8 weeks of age than during 2–8 weeks, possibly explaining differences in intrinsic models among studies. These models may have received stronger support had our sample sizes been larger. Model-selection results indicated that neonate survival was best explained by year of capture. In large herbivores, annual survival of young varies relative to survival of prime-age adults, environmental factors, and cause-specific mortality sources (Gaillard et al. 1998, 2000), and juvenile survival may be the predominant

influence in large herbivore population dynamics (Raithel et al. 2007). Recruitment parameters such as juvenile survival are relatively sensitive to environmental variation; changes in juvenile survival best reflect population response to environmental cues (Gaillard and Yoccoz 2003).

Similar to other studies that documented cause-specific mortality of fawns (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 was the major source of neonate mortality. Canid predation accounted for over 60% of white-tailed deer neonate mortalities in southern Illinois (69%, Nelson and Woolf 1987; 64%, Rohm et al. 2007), 77% in south-central Iowa (Huegel et al. 1985a), 67% in south-central Minnesota (Brinkman et al. 2004a), and 80% in eastern South Dakota and western Minnesota (Grovenburg et al. 2011a). Increases in predation influenced temporal variation in survival; canid predation during our study increased from 0 in 2007 to 9 in 2009. We suspect that loss of CRP-grassland cover habitat, resulting in 21% permanent cover loss during our study, may have made fawns easier for predators to locate and capture. Although the majority of predation occurred after fawns were older and shifted into corn, fawns continued using permanent cover (e.g., CRP-grasslands, forested cover, and wetlands) in proportion to availability throughout the summer (Grovenburg et al. In press). Furthermore, fawns in this region were more likely to escape predation when fleeing to grasslands and wetlands and were more likely to be captured when fleeing to agricultural fields. Additionally, increased probability of capture by predators was associated with increased distance to grassland and wetland habitats as well as decreased distance to wheat and row crops (e.g., corn and soybeans; T. W. Grovenburg, South Dakota State University, unpublished data). Rohm et al. (2007) attributed elevated predation during their study to increased coyote and bobcat (*Lynx rufus*) abundance. In our study area, coyote control effort (flight hr/coyote) during 2009 (0.08 hr/coyote) was similar to 2007 and 2008 (0.07 hr/coyote; South Dakota Department of Game, Fish and Parks, unpublished data), suggesting that coyote abundance did not change significantly during our study. However, accurate coyote density information was not available for the study area; therefore, any inference to temporal differences in fawn survival associated with coyote density are speculative at best.

Stochastic environmental conditions, in part, influenced the temporal variation we observed during our study; during 2009, cooler-than-normal temperatures combined with reduced availability of cover habitats likely contributed to mortality from hypothermia. Hypothermia is an influential cause of fawn mortality in the absence of predators (Andersen and Linnell 1998, Olson et al. 2005, Van Moorter et al. 2009). Hypothermia mortality in fawns has been documented in relation to stochastic weather events (Andersen and Linnell 1998). In Norway, roe deer (*Capreolus capreolus*) fawns died from hypothermic stress during a snowstorm in early May (Andersen and Linnell 1998). We suspect that the hypothermia documented during our study occurred because of a combination of stochastic weather conditions

during early June 2009 and reduced thermal insulation afforded by lower-quality habitat. Temperatures during early June 2009 were approximately 18% cooler than normal with above-average precipitation (>125% greater than normal) and winds (>19.7% greater than normal; South Dakota Office of Climatology 2010).

Use of thermal cover has been related to extreme temperatures (hot and cold), radiation, and wind speed (Bakken 1981, Peek et al. 1982, Mysterud and Ostbye 1999) and has been associated with space use or habitat selection by white-tailed deer (Verme 1965; Moen 1968*a, b*; Ozoga and Gysel 1972; Gates and Harmann 1980; Klaver et al. 2008). Summer mortality of fawns is strongly influenced by precipitation because it can influence thermal stability (Putman et al. 1996, Mysterud and Ostbye 1999). Rainfall may decrease body temperature and theoretically increase energy expenditure (Parker and Robbins 1985) and seeking cover to avoid wetting of pelage would thus be a strategy to conserve energy (Mysterud and Ostbye 1999). All hypothermia deaths occurred in fields of wheat. In our study, vertical height of understory vegetation in CRP-grassland habitat was greater and bed site temperatures were warmer than in wheat. Because neonates select for vertical structure, in part, for thermal insulation (Huegel et al. 1986, Grovenburg et al. 2010*a*) and cover to avoid precipitation, we speculate that the reduced insulation provided by wheat combined with cooler and wetter-than-normal environmental conditions predisposed fawns to death by hypothermia. Our sample size ($n = 6$) of sites for thermal analysis was limited by the number of data loggers available and we realize the small sample size may potentially bias our results. Nevertheless, weather conditions during 2007–2008 were not as severe as in 2009.

Though beyond the scope of our study, the more severe temperatures and precipitation in 2009 possibly caused fawns to become more vulnerable to predation. Bishop et al. (2005) documented that mule deer (*O. hemionus*) fawn mortality increased dramatically during severe winters and the majority of mortalities were proximately attributed to coyotes. Based on femur marrow fat measurements, coyotes seemed to kill fawns in poor body condition (Bishop et al. 2005). Colder-than-normal temperatures and above-average precipitation during early June 2009 may have forced fawns to commit additional resources to maintaining body temperature, resulting in fawns in poor body condition and more susceptible to predation.

Although fawns captured in 2007 were older than those captured in 2008–2009, the mean age of death for fawns killed by coyotes and unknown predators was 82 days and 14 days, respectively. The youngest fawn at time of mortality from predation was 12 days old, indicating capture of older fawns during 2007 likely did not influence predation mortality estimates. Additionally, although fawns dying from hypothermia were ≤ 6 days old, mean temperatures during early June in 2007 were approximately 5.5°C greater than during 2009 (South Dakota Office of Climatology 2010). Moreover, nocturnal low temperatures during fawn capture in early June 2007 were approximately 4.0°C greater

than during 2009 (South Dakota Office of Climatology 2010); indicating capture of older fawns during 2007 likely did not influence hypothermia mortality estimates.

Landscape characteristics affect deer distribution, abundance, and risk of mortality (Roseberry and Woolf 1998, Demarais et al. 2000, Rohm et al. 2007) and much previous research on fawn habitat selection focused on variables associated with bed sites (Huegel et al. 1986, Grovenburg et al. 2010*a*), and not the influence of habitat variables on survival. Our hypothesis that CRP-grasslands, forested cover, and wetland habitat would positively influence survival was only partially supported by our analyses, with greater fawn survival associated with greater patch density of CRP-grassland and wetland habitats, and with lower patch density of forested cover.

Proximity to escape cover influences survival for older fawns because of increased activity (Rohm et al. 2007). With >1 patch of CRP-grasslands in a 100-ha area, distance to nearest cover would be reduced; thus, decreasing amount of time spent moving between patches. Of equal influence, multiple patches of escape cover may allow dams to maintain smaller home range areas, resulting in increased time for maternal care and defense (Rohm et al. 2007, Grovenburg et al. 2009*a*). Although mean patch size of CRP-grasslands was not a significant variable in survival models, large average patch size (24.4 ha) of CRP-grasslands may have contributed to fawn survival. Rohm et al. (2007) hypothesized that a few large patches of forested cover and several small patches of other resources may represent optimal habitat for fawns when they are most susceptible to predation. In prairie landscapes, red fox (*Vulpes vulpes*) avoided interior areas of planted cover in landscapes with high grassland composition (Phillips et al. 2004). Grovenburg et al. (In press) observed that fawns selected for CRP-grasslands during the summer and increased home-range size and movements as a result of a 41% loss of CRP-grasslands in the fawn study area from 2007 to 2009 (approximately 21% loss in cover habitat [CRP-grasslands, forested cover, and wetlands]). However, land enrolled in the CRP peaked at 14.9 million ha in September 2007 and the United States Department of Agriculture predicted that CRP-enrolled land would reach a low of 12.2 million ha in 2013 (Fargione et al. 2009, United States Department of Agriculture 2009). As CRP-grasslands are returned to agricultural production, available cover habitat will continue to decrease.

A combination of visual obstruction from fawns hiding in tall, dense vegetation and diminished olfactory cues in wetland habitats were potentially responsible for increased fawn survival associated with wetland habitats; fawns fleeing to wetlands were more likely to escape predation (T. W. Grovenburg, unpublished data). We hypothesize that water may minimize ability of predators to locate prey species using olfactory cues (Hughes et al. 2010). Alternatively, water may serve as a physical barrier to predators, thereby minimizing mobility and capture success by predators. Although coyotes possess a keen olfactory sense, they also rely on visual cues in seeking prey (Wells 1978, Windberg 1996). Common wet-

land vegetation in temporary and seasonal wetlands in the northern Great Plains is dense and often grows to 2.4–3.0 m in height (Johnson and Larson 1999), which was 3.1–6.9 times taller than other habitat types in the study area (Grovenburg et al. 2010a). Other factors such as soils, plant communities, thermal environments, and disturbance regimes (including anthropogenic disturbance) related to CRP-grasslands and wetlands may have influenced fawn survival by influencing predator movements, adult female nutritional status, and movements to obtain water; however, these were beyond the scope of this study.

Fawn survival was negatively influenced by patch density of forested cover. Small, linear patches of trees in the northern Great Plains may function as ecological traps for fawns; tree plantings and shelterbelts provided little cover and concealment and were likely easy for predators to effectively search. In more forested areas, large patches of forested habitat provided neonates with cover and concealment, were more difficult for predators to search completely, and were searched less often (Andren and Angelstam 1988, Brown and Litvaitis 1995, Phillips et al. 2003, Rohm et al. 2007). Additionally, forested cover was the critical element determining deer distribution in Illinois; high deer densities were related to an increasing percentage of forested cover (Roseberry and Woolf 1998). However, in the grasslands of the northern Great Plains, deer did not select for forested cover and only selected for trees during extreme drought conditions (Grovenburg et al. 2010b, 2011b, In press). Limited and fragmented forested cover in our study area likely explained why forested habitat negatively influenced fawn survival in this region. In southern Illinois, Rohm et al. (2007) observed that neonates were associated with larger (by a factor of 11–22) mean forest patch size than those documented during our study (0.36 ha), which were mainly composed of tree plantings and shelterbelts.

Predator home-range distribution, number and arrangement of predator territories on the landscape, and juxtaposition of predator and prey home ranges can influence predation rates (Rogers et al. 1980, Vreeland et al. 2004). Furthermore, local and annual fluctuations in fawn survival have been attributed to variation in predator density (Beasom 1974, Stout 1982, Brinkman et al. 2004a). Because coyotes were the primary predator on our study area, habitat characteristics associated with areas of high fawn survival may represent landscapes where coyotes were less efficient at successfully locating and catching fawns (Rohm et al. 2007). Coyotes prefer more open habitats as opposed to forest habitats (Priest 1986, Cypher 1991, Person and Hirth 1991, Holzman et al. 1992, Rohm et al. 2007) and during summer were observed avoiding forested patches (Gehring and Swihart 2003) where they were less efficient at searching for prey (Gese et al. 1996, Richer et al. 2002). We suspect that large patches of CRP-grassland and dense vegetation associated with seasonal wetlands functioned similarly to large patches of forested cover in other regions and provided cover for fawns when they were most vulnerable. Coyote foraging may be explained by optimal

foraging theory (MacArthur and Pianka 1996, Stephens and Krebs 1986, Rohm et al. 2007); coyotes have a diverse diet and switch prey throughout the year depending on prey availability and handling time (Andelt et al. 1987, Windberg and Mitchell 1990, Rohm et al. 2007). Landscape characteristics associated with areas of greater fawn survival likely hindered the ability of coyotes to search and locate fawns; thereby diminishing the benefits of pursuing fawns (Rohm et al. 2007). However, in areas with no or limited CRP-grasslands and wetlands, coyotes were not as hindered by the landscape and may have maximized energy intake by preying on fawns.

MANAGEMENT IMPLICATIONS

We provided the first evaluation of the influence of intrinsic and habitat variables on fawn white-tailed deer survival in the grasslands of the northern Great Plains. Our study indicated that fawn survival was best explained by year and cover-habitat patch density. Knowing which cover types (i.e., CRP-grasslands and wetlands) are critical to fawn survival will aid wildlife managers in identifying habitats on which to focus management activities towards increasing neonate survival. However, continued loss of cover habitat such as CRP-grasslands in the northern Great Plains could lead to reduced fawn survival. White-tailed deer populations are not overabundant in the northern Great Plains as in other portions of North America. Here, the effect of CRP loss may be greater because of the inherent lack of hiding cover. However, we lacked control data to isolate the effect of CRP-grassland reductions on survival. Therefore, we suggest that additional research investigating the effect of declining enrollments in CRP-grasslands be undertaken to support our initial findings.

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