

## Assessing migration strategies and cause specific mortality of adult female White-tailed Deer (*Odocoileus virginianus*) in North Dakota, USA

BRIAN A. SCHAFFER<sup>1,2</sup>, JONATHAN A. JENKS<sup>1</sup>, WILLIAM F. JENSEN<sup>2</sup>, and ERIC S. MICHEL<sup>1,3,\*</sup>

<sup>1</sup>Department of Natural Resource Management, South Dakota State University, Brookings, South Dakota 57007 USA

<sup>2</sup>North Dakota Game and Fish Department, 3001 East Main, Bismarck, North Dakota 57501 USA

<sup>3</sup>Current address: Minnesota Department of Natural Resources, Division of Fish and Wildlife, Farmland Wildlife Populations and Research Group, 35365 800th Avenue, Madelia, Minnesota 56062 USA

\*Corresponding Author: eric.michel@state.mn.us

Schaffer, B.A., J.A. Jenks, W.F. Jensen, and E.S. Michel. 2021. Assessing migration strategies and cause specific mortality of adult female White-tailed Deer (*Odocoileus virginianus*) in North Dakota, USA. *Canadian Field-Naturalist* 135(4): 346–355. <https://doi.org/10.22621/cfn.v135i4.2104>

### Abstract

Life-history characteristics of White-tailed Deer (*Odocoileus virginianus*) have been documented in areas of the Northern Great Plains, but limited information is available in grassland dominated regions. We documented migration strategy, home range use, and survival of adult female White-tailed Deer in central North Dakota. We monitored 62 radio-collared adult (>1.5 year-old) female White-tailed Deer from February 2010 to December 2012. We documented 86 summer home ranges and classified deer as resident, migratory, or exhibiting a late season movement. Mean migration distance between non-overlapping summer and winter home ranges was 11.76 km (SE 0.86,  $n = 21$ ). Mean late season movements were 20.69 km (SE 2.94,  $n = 7$ ) and were likely the result of deer exhausting food resources throughout winter. We also developed five competing models that represented variation in survival among time periods (e.g., pre-hunt, hunt, and post-hunt in 2010 and 2011). Our top model indicated that survival (S) was similar between hunt 2010 and post-hunt 2011 periods but was lower (S = 0.82; SE 0.04, 95% CI 0.73–0.89) than the remaining time periods (S = 0.97; SE 0.01, 95% CI 0.93–0.99). Our results suggest that deer migration strategies and survival are likely influenced by a combination of winter severity and food availability. Mortalities attributed to hunter harvest were low during our study, which may indicate that increased recreational opportunities could be made available, even after severe winters.

Key words: Migration; mortality; Northern Great Plains; *Odocoileus virginianus*; survival; White-tailed Deer

### Introduction

White-tailed Deer (*Odocoileus virginianus*) were historically limited to bottomland hardwoods, riparian forests, and lacustrine woodlands that punctuated the landscape of North Dakota (Knue 1991). Deer radiated from these habitats with conversion of grasslands to agriculture (Dusek *et al.* 1989; Heffelfinger 2011), suppression of fire that allowed encroachment of trees in prairie environments (Oehler *et al.* 1995), predator management (VerCauteren and Hygstrom 2011), and regulations that closed hunting seasons to manage populations (Knue 1991). Presently, White-tailed Deer occur throughout the state; however, factors thought to limit the species include severe winter weather, predators (i.e., Coyotes [*Canis latrans*]; Grovenburg *et al.* 2011a), and human modification of suitable habitats. Previous studies in the Northern Great Plains documented movement patterns and

home range size (Sparrowe and Springer 1970; Brinkman *et al.* 2005; Smith *et al.* 2007; Grovenburg *et al.* 2009), and survival (Brinkman *et al.* 2004; Smith *et al.* 2007; Grovenburg *et al.* 2011a) of White-tailed Deer.

White-tailed Deer at northern latitudes are classified as residents (do not migrate but may shift habitat use within range in response to environmental conditions) or migrators; migrators can be either obligate (migrate a single time for the duration of the season and each season thereafter) or conditional (migrate some seasons but not others, or temporarily migrate for <1 month; Sabine *et al.* 2002; Fieberg *et al.* 2008; Grovenburg *et al.* 2011b). Seasonal movement patterns at northern latitudes include short distance, dispersal, and seasonal migration (Kernohan *et al.* 1994; Brinkman *et al.* 2005). Short distance movements typically occur under mild winter conditions when

food resources are sufficient (Marchinton and Hirth 1984; Grovenburg *et al.* 2009). Seasonal migration from winter to summer home ranges is the most commonly documented movement pattern of White-tailed Deer at the northern limits of their range (Ozoga and Gysel 1972; Nelson 1998; Van Deelen *et al.* 1998). In the Northern Great Plains, mean migration distance between seasonal ranges generally exceeds 10 km (Brinkman *et al.* 2005; Smith *et al.* 2007; Grovenburg *et al.* 2009).

Radio telemetry studies conducted throughout the Northern Great Plains suggest environmental and anthropogenic factors influence White-tailed Deer survival on a regional level (Brinkman *et al.* 2004; Grovenburg *et al.* 2011a; Robling 2011). Causes of adult deer mortality in northern climates include hunting, vehicle collisions, illegal harvest (Dusek *et al.* 1992; Brinkman *et al.* 2004; Grovenburg *et al.* 2011a), severe winter weather (DelGiudice *et al.* 2002), predation (Mech 1984; Van Deelen *et al.* 1997; Whitlaw *et al.* 1998), starvation (Lamoureux *et al.* 2001), and disease (Matschke *et al.* 1984). Most studies indicate hunter harvest as the primary cause of adult mortality, which emphasizes the need for accurate harvest mortality rates for proper management (DelGiudice *et al.* 2002).

Although White-tailed Deer ecology has been studied extensively in South Dakota (Sparrowe and Springer 1970; Kernohan *et al.* 1994; Burris 2005; Grovenburg *et al.* 2009; Robling 2011) and western Minnesota (Brinkman *et al.* 2005; Swanson 2005), limited information exists in North Dakota where latitudinal variation in climate and limited winter cover likely influence seasonal movements, home range size, and survival. Previous research addressing these factors in North Dakota focussed on wildlife management areas (WMA) where supplemental food plots were available throughout winter (Jensen 1999; Smith *et al.* 2007). Our objectives were to document seasonal movement patterns and home ranges while assessing how mortality varies during the recreational hunting season compared to other time periods for White-tailed Deer on the Missouri Coteau of central North Dakota, USA.

### Study Area

We monitored adult female White-tailed Deer in the Wing-Tuttle Study area (Burleigh, Kidder, and Sheridan counties; 47.1408°N, 100.2790°W) in central North Dakota from 2010 to 2012. These counties were located within the Northwestern Glaciated Plains Level III Ecoregion (Bryce *et al.* 1998) and comprised an area of 10 558 km<sup>2</sup>. Grasslands were the dominant habitat type and comprised 57.7% of the landscape. Croplands comprised 26.7%, wetlands

and water comprised 11.3%, developed land 4.1%, and other land uses comprised <1% of the total landscape (USDA 2011). There were 17 599 ha classified as wildlife management areas (WMAs), 13 293 ha as National Wildlife Refuges, and 12 821 ha as waterfowl production areas (WPAs; C. Penner pers. comm. 15 June 2021) within these three counties. Mean long-term (1981–2010) summer temperature was 19.4°C and mean long-term (1981–2010) annual precipitation was 44.9 cm (North Dakota Office of Climatology 2012).

Native vegetation included Western Wheatgrass (*Pascopyrum smithii* Barkworth & Dewey), Big Bluestem (*Andropogon gerardii* Wipff), Little Bluestem (*Schizachyrium scoparium* Nash), Needle-and-thread (*Hesperostipa comata* Trinius & Ruprecht), Green Needlegrass (*Nassella viridula* (Trinius) Barkworth), Prairie Cordgrass (*Spartina pectinata* Link), Northern Reedgrass (*Calamagrostis stricta* Timm), Plains Muhly (*Muhlenbergia cuspidata* Torey & Hooker), Prairie Junegrass (*Koeleria macrantha* Ledebour), Blue Grama (*Bouteloua gracilis* Kunth & Lagasca), and Inland Saltgrass (*Distichlis spicata* Torrey; Johnson and Larson 1999). Regional cultivated crops included wheat, sunflowers, corn, soybeans, canola, flaxseed, barley, peas, oats, dry beans, potatoes, sorghum, triticale, millet, rye, lentils, mustard, and safflower (USDA 2011).

### Methods

#### Data collection

We captured and radio-collared adult female deer (>1.5 years old) using helicopter net guns (February 2010; Jacques *et al.* 2009) and modified Clover traps (winter 2010–2011; Clover 1954). We restrained, blindfolded, processed, and released each deer at capture sites. We fitted very high frequency (VHF) radio-collars (model V5C 176; Sirtrack, North Liberty, Iowa, USA) to each captured deer; radio-collars were equipped with mortality sensors that switched to mortality mode after the transmitter remained stationary for ≥8 h.

We monitored adult radio-collared deer 2–3 times per week from 16 February 2010 to 30 December 2012 using a combination of aerial telemetry from a fixed-winged aircraft (American Champion 8-GCBC Scout, Burlington, Wisconsin, USA) and ground telemetry. We did not locate individuals on successive days or at similar times of day during the same week to ensure we accurately characterized home ranges while minimizing autocorrelation and temporal bias in location data. We used omnidirectional antennas and hand-held 4-element Yagi antennas (Advanced Telemetry Systems, Isanti, Minnesota, USA) to visually locate individuals and perform

ground triangulation. We recorded universal transverse mercator (UTM) coordinates using a geographical positioning system (GPS) unit (Garmin III Plus, Olathe, Kansas, USA) in the aircraft during aerial telemetry flights; there was no telemetry error associated with these visual sightings. We obtained a minimum of three directional bearings using a compass from prerecorded stations. We entered bearings and stations into LOCATE III (Nams 2006) to estimate locations and error polygons. We excluded locations that exhibited 95% error ellipses  $\geq 20$  ha from further analyses to maintain consistency with other regional studies (Brinkman *et al.* 2005; Burris 2005; Grovenburg *et al.* 2009). Due to lack of roads and substantial topography within the study area, we approached most collared animals on foot to obtain visual locations so we did not determine measurement error for ground triangulation.

We investigated all mortalities to establish cause of death; however, if we could not determine cause of death in the field and carcasses were not scavenged or in an advanced state of decay, we transported them to the North Dakota Game and Fish Wildlife Laboratory in Bismarck, North Dakota for further investigation. Adult mortalities that occurred within 26 days post-capture were not included in our analyses regardless of ultimate cause of death (Beringer *et al.* 1996).

Statewide hunting seasons for White-tailed Deer were open from 3 September to 2 January 2010–2011 and 2 September–8 January 2011–2012. Hunting seasons included youth firearm, firearm, muzzleloader, and archery. Given the firearm seasons (5–21 November 2010 and 4–20 November 2011) generally exhibit the greatest hunter participation and subsequent pressure on deer (Jensen *et al.* 2011, 2012), we avoided further disturbing deer and hunters to minimize our effects on movements of radio-collared animals during the firearm hunting season; thus, reducing any potential bias-related movements. We located radio-collared deer via aerial telemetry twice during each firearm season. Flights occurred the first Monday immediately following the firearm season opener and again during the second weekend of the season. After we obtained locations, we determined land ownership inhabited by radio-collared deer. We then contacted private landowners and obtained information on hunter access to their property. We classified the following land management types into two classes (open or closed to hunting): private land open to hunting, private land closed to hunting, public (WMAs, WPAs) lands (open to hunting), and National Wildlife Refuges (closed to hunting). We did not obtain the number of hunters accessing each property.

To assess potential relationships between winter severity and migration strategies, we calculated deer

winter severity indices (DWSI; Brinkman *et al.* 2005) for the Wing-Tuttle study area during the winters of 2009–2010, 2010–2011, and 2011–2012. We also calculated historical DWSI from 2001 to 2009 for comparative purposes. We obtained weather data from the North Dakota Office of Climatology (2012) and assigned one point for each day the mean temperature was  $\leq -7^{\circ}\text{C}$  and an additional point for each day snow depth was  $\geq 35.0$  cm from November through March (Brinkman *et al.* 2005). We then summed the daily point accumulation for each day to calculate an annual DWSI. We considered indices  $< 50$  as mild, 50 to 100 moderate, 101 to 200 as severe, and  $> 200$  very severe winters (W. Jensen unpubl. data).

#### *Home ranges and movements*

We used the fixed-kernel method in Home Range Tools (HRT) for ArcGIS 9.3 (ESRI, Redlands, California, USA; Rodgers *et al.* 2007) to calculate 95% and 50% (core) home ranges. We used least-squares cross-validation to estimate the smoothing parameter and constructed home ranges using a minimum of 28 locations, which is sufficient for home range analyses (Seaman *et al.* 1999). Due to inaccessibility during winter months, we collected an insufficient number of locations to generate winter home ranges of individuals. Therefore, after calculating summer home ranges we classified movement types on an annual basis to assess if movement strategies differed between years of varying winter severity by using a k-means cluster analyses on individual deer locations using Euclidean distance (coordinates of deer locations; Boulanger *et al.* 2006). This analysis identified deer with two significant, non-overlapping clusters and classified them as migrators (i.e., two separate seasonal home ranges with the initial movement to an individual's winter home range occurring before 1 January). We chose 1 January as the cutoff because of the requirements of the statistical analysis combined with most deer having moved to wintering areas by this time (Smith 2005). We did not classify deer as migrators if we detected any overlap between summer and winter home ranges (Brinkman *et al.* 2005). Furthermore, we lacked sufficient data to further classify migrators as obligate or conditional. We classified deer as residents if they failed to move between separate seasonal home ranges (i.e., single cluster). We classified deer as late season migrators if they failed to migrate during a documented migratory period (single cluster) but made late-winter movements (outside 95% home range contours) of short duration (1–2 weeks) after 1 January. We compared home range estimates between years at the population level using *t*-tests and among movement classifications using analysis of variance (ANOVA) in SAS (version 9.3; SAS Institute Inc. 2011). We compared migration distance

among years using a *t*-test and considered differences significant at  $\alpha = 0.05$ . Some animals were collared in both years but we had insufficient sample sizes to test for year effects, so we pooled data across years, even though it is understood that annual variation may exist (Schooley 1994).

#### Survival rates

We calculated annual and seasonal survival rates using known fate models adapted for staggered entry in program MARK (version 6.0; Pollock *et al.* 1989; White and Burnham 1999). We constructed five models incorporating variation of adult survival between and among three periods; post-hunt (January–May), pre-hunt (May–September), and hunt (September–January) and between years (Table 1). We used  $AIC_c$  to select models best describing the data (Burnham and Anderson 2002). We considered models within 2  $\Delta AIC_c$  from the top model as competing and used Akaike weights ( $w_i$ ) to indicate model support (Burnham and Anderson 2002).

#### Results

We captured and radio-collared 62 adult female (>1.5 year-old) deer using helicopter net guns ( $n = 48$ ) and Clover traps ( $n = 14$ ). Two capture related mortalities occurred during helicopter net-gunning operations in 2010. We collected 5603 locations from the radio-collared deer. Average annual DWSI in the Wing-Tuttle study area for the winters of 2009–2010, 2010–2011, and 2011–2012 was 166 (severe), 215 (very severe), and 93 (moderate), respectively (Figure 1).

We assigned 86 classifications to 62 captured deer (some individuals were radio-collared for both years). We determined 36 (84%) of the deer were residents (overlapping seasonal home ranges) and seven (16%) were migrators (non-overlapping seasonal home ranges) during 2010 with a mean migration distance of 11.6 km (SE 1.8). During 2011, 22 (51%) deer were residents and 14 (33%) were migrators with a mean migration distance of 11.9 km (SE 1.0). Mean migration distance did not differ between years ( $t_{19} = -0.16$ ,  $P = 0.874$ ); mean migration distance from

2010 to 2011 was 11.8 km (SE 0.9,  $n = 21$ ). Additionally, during winter 2011, seven (16%) radio-collared animals made late season movements; mean distance travelled was 20.7 km (SE 2.9). Number of locations during 2010 and 2011 ranged from 10 to 128 per individual collared deer. Based on visual evidence at the site, all seven late season movements resulted in radio-collared individuals leaving a habitat with no food or a depleted food source.

We calculated 86 individual summer home ranges using a mean of 49.4 locations (SE 1.0) from which we documented 58 home ranges of resident deer, 21 home ranges of migrating deer, and seven home ranges of deer that performed late season movements. Mean 50% and 95% home range size differed ( $t_{56} \leq -2.89$ ,  $P \leq 0.005$ ) by year for resident deer but not for migrating deer (mean 50%:  $t_{19} = 0.10$ ,  $P = 0.921$ ; mean 95%:  $t_{19} = -0.11$ ,  $P = 0.914$ ). Mean 50% and 95% home ranges were larger for resident deer in 2011 (2.0 km<sup>2</sup>, SE 0.4; 9.5 km<sup>2</sup>, SE 1.6) than 2010 (1.0 km<sup>2</sup>, SE 0.1; 5.2 km<sup>2</sup>, SE 0.6). Mean 50% ( $t_6 = -1.49$ ,  $P = 0.161$ ) and 95% ( $t_6 = -1.49$ ,  $P = 0.310$ ) summer home ranges for deer classified as late season movers did not differ between years.

We observed similar patterns of distribution of radio-collared deer on lands accessible to hunters in both years. During the 2010 firearms season, 80% of radio-collared deer were located on lands accessible to hunters and 20% were located on lands with no hunting allowed. During 2011, 84% of radio-collared deer were located on lands accessible to hunters and 16% were located on lands with no hunting allowed.

We recorded 20 adult mortalities; natural causes included starvation ( $n = 1$ , 4.8%), predation ( $n = 3$ , 14.4%), unknown winter-related ( $n = 6$ , 28.8%), and an unknown summer mortality ( $n = 1$ , 4.87%). Additional causes of mortality included harvest ( $n = 6$ , 28.6%) and vehicle collisions ( $n = 3$ , 14.3%). Only model {hunt2010=post2011, rest equal} where survival was similar between hunt 2010 and post-hunt 2011 and differed from remaining seasons that were similar was supported by our data ( $w_i = 1.00$ );

**TABLE 1.** Descriptions of candidate set of survival models for adult female White-tailed Deer (*Odocoileus virginianus*) captured in central North Dakota, USA, 2010–2011.

Model	Description
{hunt2010=post2011, rest equal}	Survival is similar between hunt 2010 and post-hunt 2011 and differs from remaining seasons which are similar
{pre-hunt=post-hunt=hunt}	Survival is similar among seasons
{pre-hunt=post-hunt=hunt, diff year}	Survival is similar among seasons but differs between years
{pre-hunt=post-hunt, hunt}	Survival is similar between pre-hunt and post-hunt seasons which differ from hunt season
{pre-hunt=post-hunt, hunt_diffyear}	Survival is similar between pre-hunt and post-hunt seasons which differ from hunt season which is different between years

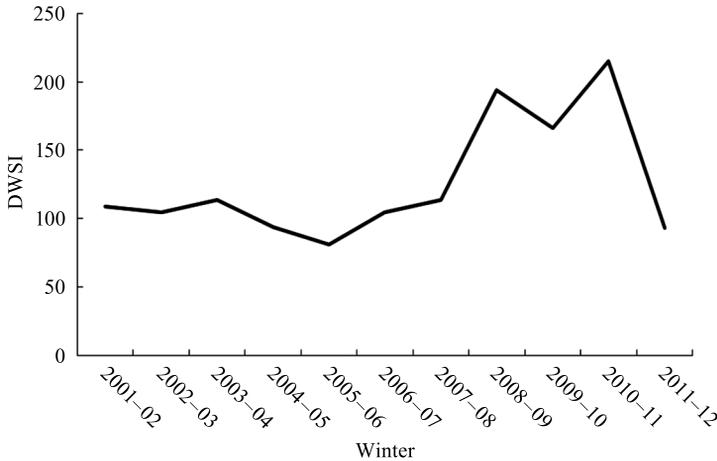


FIGURE 1. Deer winter severity indices (DWSI) for White-tailed Deer (*Odocoileus virginianus*) in central North Dakota, USA.

remaining models were  $\geq 14.86 \Delta AIC_c$  from the top-ranked model (Table 2). Model {hunt2010=post2011, rest equal} indicated that adult survival was similar between hunt 2010 and post-hunt 2011 periods but was lower than other periods. The survival rate for hunt 2010 and post-hunt 2011 was 0.82 (SE 0.04, 95% CI 0.73–0.89) whereas the survival rate for remaining seasons (post-hunt 2010, pre-hunt 2010, pre-hunt 2011, and hunt 2011) was 0.97 (SE 0.01, 95% CI 0.93–0.99).

## Discussion

During the very severe winter of 2010–2011 and moderate winter of 2011–2012 (severity based on our analysis), deer in central North Dakota exhibit a mixture of movement strategies consisting of residents, migrators, and late season movers. However, our results indicated that populations in this region were composed largely of residents. Percentage of resident deer (67%: 36 residents in 2010 + 22 residents

in 2011 / 86 total deer) documented during our study was substantially higher than previously reported in the Northern Great Plains (25–46%, Brinkman *et al.* 2005; 22.5%, Burris 2005; 33.3%, Smith 2005; 38%, Grovenburg *et al.* 2009; 50%, Robling 2011), although differences may be related to our methods of classifying deer movement strategies and/or loss of migrators in previous severe winters. Long *et al.* (2005) and Grovenburg *et al.* (2011b) reported deer that inhabited landscapes with limited tree cover were more likely to travel greater distances during migration periods to occupy landscapes with greater forest cover, which provided thermal cover, escape shelter, and food resources. However, microsite characteristics that minimize heat loss (i.e., forested habitat; Moen 1973) may not be critical to deer survival because deer may be able to maintain core temperature via consumption of high quality agricultural feedstuffs, such as waste or unharvested sunflower seeds and corn. Given White-tailed Deer in our study

TABLE 2. Survival model results for adult female White-tailed Deer (*Odocoileus virginianus*) captured in central North Dakota, USA, 2010–2011.

Model	AIC <sub>c</sub> *	$\Delta AIC_c$ †	$w_i$ ‡	K§	Deviance
{hunt2010=post2011, rest equal}	254.03	0.00	1.00	2	77.76
{pre-hunt=post-hunt=hunt}	268.89	14.86	0.00	1	94.62
{pre-hunt=post-hunt=hunt, diff year}	269.24	15.21	0.00	2	92.97
{pre-hunt=post-hunt, hunt}	269.25	15.22	0.00	2	92.97
{pre-hunt=post-hunt, hunt_diffyear}	269.65	15.62	0.00	3	91.37

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

†Difference in AIC<sub>c</sub> relative to minimum AIC.

‡Akaike weight (Burnham and Anderson 2002).

§Number of parameters.

area wintered in agricultural fields, there was likely no switch in browsing physiology from natural forage to agricultural crops. Regardless, White-tailed Deer in the grassland dominated landscapes of central North Dakota likely use unharvested crops instead of forested cover during severe winter weather (Smith *et al.* 2007; Grovenburg *et al.* 2010; Nagy-Reis *et al.* 2019).

We attribute the numerical decrease in resident animals (36 residents in 2010 and 22 residents in 2011) during winter 2011, in part, to the number of animals making late season movements. In our study area, DWSI during 2008–2009, 2009–2010, and 2010–2011 were among the most severe winters recorded for central North Dakota since 1949 and thus, these winters were more severe compared to conditions when other studies on deer movements were conducted in the Northern Great Plains. This variation in winter severity likely affected crop availability between the two winters. For example, by 20 December 2009, 68% of corn was harvested statewide (59% in our study area; USDA 2013). A major snowstorm in late December 2009 continued to delay corn harvest (71% statewide corn harvest by 4 January) and most producers waited until spring to harvest remaining corn (USDA 2013). However, during winter 2010–2011, availability of unharvested crops to deer was minimal; statewide corn harvest was 98% by 22 November 2010 (USDA 2013). All late season movements ( $n = 7$ ) were made by individuals leaving a food source or habitat (e.g., unharvested sunflowers/corn) with no available food remaining or with food that had become inaccessible because of drifting snow. These individuals were likely searching for food as they made late winter movements to a high-energy food source (unharvested corn, residential area). Additionally, 74% of the 86 radio-collared deer we monitored for two winters (43 each year) did not return to the same wintering area within their home ranges. This low degree of site fidelity in home range placement was likely related to forage availability (van Beest *et al.* 2013; Peignier *et al.* 2019) and use of prewinter reconnaissance within the matrix of stable cover habitats (i.e., shelter belts and wetlands).

Between 6 and 20 April 2010 we observed six radio-collared resident deer make non-traditional movements (relatively long-distance movements made during a short duration of time) ranging from 12 to 24 km before returning to their original starting location prior to parturition. These types of movements are referred to as “occasional sallies” (Burt 1943: 351) or exploratory movements (Pépin *et al.* 2008). They may have been movements to locate previously used or known resources that could be acquired during various seasons (e.g., parturition season, winter) for future use. These occasional sallies

might become more prevalent after severe winters such as those that occurred in North Dakota 2009–2011 (Jensen 2009) because of the potential need to travel to and use new food resources. Future research should focus on assessing whether these directed movements are used as a survival strategy during severe winters to better help our understanding of deer survival strategies in the Northern Great Plains.

Migration distances and 95% home ranges that we report were mostly comparable to other studies conducted in the Northern Great Plains (Brinkman *et al.* 2005; Burris 2005; Swanson 2005; Smith *et al.* 2007; Robling 2011). However, our mean migration distances and 95% home ranges were smaller than those reported by Grovenburg *et al.* (2009) in north-central South Dakota. Although many factors can contribute to the documented variation in the Northern Great Plains, we suggest that landscape level habitat characteristics are the most influential factors in spatial variation of migration distances and home ranges (i.e., unharvested agricultural crops; Jensen 1999; Grovenburg *et al.* 2009). Increased demand for bio-fuel production has caused increased conversion of grassland to cropland (Secchi and Babcock 2007; Searchinger *et al.* 2008; Fargione *et al.* 2009). This increased demand for corn production in the United States resulted in 4.9 million ha of land being converted from grasslands to cropland between 2005 and 2008. Widespread habitat change on this scale could directly affect wildlife populations (Fargione *et al.* 2009). We agree that the rapidly changing landscape (grassland conversion and wetland drainage) within the Northern Great Plains has affected home range size and movement strategies of White-tailed Deer occupying the region (Grovenburg *et al.* 2012). Furthermore, severe winter weather could require White-tailed Deer to engage in an energetically demanding strategy that involves seasonal migration, reconnaissance, and rapid response to resource abundance.

Although we located at least 80% of radio-collared adult female deer on hunter accessible lands, hunter harvest accounted for only ~29% of all mortalities with natural causes (predation, malnutrition, and unknown causes) representing ~52% of total mortalities of deer in our study. Our results support Moratz *et al.* (2018) who reported natural causes (52%) were the leading cause of mortality in the western portion of South Dakota and North Dakota while hunter harvest only accounted for about 19% of all mortalities. However, our results do not support other studies in the Northern Great Plains in which hunting was the primary cause of adult female White-tailed Deer mortality (e.g., 43%, Brinkman *et al.* 2005; 70%, Grovenburg *et al.* 2011a). Regardless, the presence of radio-collars does not seem to deter hunters from harvesting

specific deer (Buderman *et al.* 2014), although there are other reasons why hunter harvest may be limited in the western Dakotas. Limited antlerless tag allocations and short firearm seasons likely influenced hunter harvest in the region for adult females. If so, then the high mortality rate attributed to natural causes may be artificially inflated due to the inability of hunters to effectively harvest female deer in our study area.

### Conclusion

Although only associative, our results suggest that adult female White-tailed Deer migration strategies in central North Dakota are likely influenced by the interaction of winter severity and resource availability. We anecdotally observed an increased percentage of resident adults when agricultural crops were unharvested, which further suggests that White-tailed Deer display behavioural plasticity related to winter severity (Giroux *et al.* 2016; Courbin *et al.* 2017). Additionally, mortalities attributed to hunter harvest were low in our study. Harvest management can become conservative during severe winters in anticipation of high natural mortality. However, assuming recreational harvest of White-tailed Deer is compensatory and not additive (Mackie *et al.* 1998), then our results indicate that agencies could maintain or increase harvest opportunity after periods of severe winter weather. Ciuti *et al.* (2015) suggested Pacific decadal oscillations may be useful as predictors of subsequent winter conditions in western North Dakota. Therefore, continual monitoring of migration strategies and survival is needed as landscape level habitat changes continue in the Northern Great Plains (e.g., loss of Conservation Reserve Program, grassland conversion, wetland drainage) and could dramatically influence these life history traits of White-tailed Deer.

### Author Contributions

Writing – Original Draft: B.A.S.; Writing – Review & Editing: J.A.J., W.F.J., and E.S.M.; Conceptualization: J.A.J. and W.F.J.; Investigation: B.A.S., J.A.J., and W.F.J.; Methodology: J.A.J. and W.F.J.; Formal Analysis: B.A.S.; Funding Acquisition: W.J.F. and J.A.J.

### Acknowledgements

Our study was funded by Federal Aid in Wildlife Restoration (Project W-67-R STUDY NO. C-VIII), administered through North Dakota Game and Fish Department. We appreciate support provided by the Department of Natural Resource Management at South Dakota State University. We thank J. Smith, D. Grove, R. Gross, R. Parsons, and K. Manuell for field assistance during our study. We thank C. Penner and W. Jensen of the North Dakota Game and Fish

Department for providing additional information via personal communications and unpublished data. We thank C. Jacques, M. Obbard, and two anonymous reviewers for providing helpful comments on earlier drafts of our manuscript. The Institutional Animal Care and Use Committee at South Dakota State University approved our animal handling methods (Approval no. 10-006E) and we followed guidelines established by the American Society of Mammalogists for care and use of mammals (Sikes *et al.* 2016).

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Received 15 June 2018

Accepted 10 January 2022

Associate Editor: M. Obbard