MOVEMENT AND ASSOCIATION OF WHITE-TAILED DEER

IN SOUTHWEST MINNESOTA

BY

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MOVEMENT AND ASSOCIATION OF WHITE-TAILED DEER IN SOUTHWEST MINNESOTA

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

MOVEMENT AND ASSOCIATION OF WHITE-TAILED DEER IN SOUTHWEST MINNESOTA

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In highly fragmented landscapes typical of southwest Minnesota, assessing the effects of seasonal movements is fundamental to white-tailed deer (Odocoileus *virginianus*) population management. Understanding seasonal movement is critical to assessing the frequency of deer association and estimating risk for transmission of chronic wasting disease. Furthermore, knowledge of neonate survival and cause-specific mortality provides important information regarding reproduction, sex ratios, and how preseason mortality rates affect deer harvest strategies. However, biologists are usually forced to make educated guesses pertaining to these parameters because empirical data are difficult and costly to collect. Hence, data collected from this study will be used to improve farmland white-tailed deer population management and provide insight into the potential transmission of chronic wasting disease (CWD). Primary objectives of this study were to determine seasonal movements, patterns of association, and neonate survival and cause-specific mortality. Secondary objectives were to estimate seasonal home range and use and evaluate vaginal-implant transmitters as a tool for neonate capture. From September 2002 to May 2004, a total of 49 (47 adult, 2 fawn) female

radiocollared deer was monitored via radio telemetry at Redwood Falls and Walnut Grove study sites in southwest Minnesota. A total of 6,511 locations was collected with a mean 95% error ellipse of 4.6 ha. A total of 56 seasonal movements was calculated during four migratory periods; fall 2002 (n = 13), spring 2003 (n = 17), fall 2003 (n = 17), and spring 2004 (n = 9). Mean distance migrated between seasonal ranges was 14.6 km (SE = 1.1). During 3 seasonal range periods a total of 111 individual home ranges was estimated; winter 2002-03 (n = 41), summer 2003 (n = 39), and winter 2003-04 (n = 31). Mean 95% home range size during winter and summer was 3.31 (SE = 0.32) and 2.57 km (SE = 0.50), respectively. Cold temperatures and snow depth had the greatest influence on migration. To understand the role movement has on the potential spread of CWD, fuzzy cluster analysis was conducted to provide insight into the dynamics of subpopulation movements and interaction. Determining the frequency of association between subpopulations enabled the assessment of risk for CWD transmission. The mean number of clusters individual deer were associated with during winter 2002-03, summer 2003, and winter 2003-04 at Walnut Grove was 1.11 (SE = 0.11, n = 9), 1.22 (SE = 0.15, n = 9), and 1.17 (SE = 0.17, n = 6), respectively. Mean percentage of deer associated within their own subpopulation during winter 2002-03. summer 2003, and winter 2003-04 at Walnut Grove was 99% (SE = 0.02, n = 9), 89% (SE = 0.04, n = 9), and 97% (SE = 0.01, n = 6). Mean number of clusters each deer was associated with during winter 2002-03, summer 2003, and winter 2003-04 at Redwood Falls was 1.44 (SE = 0.01, n = 32), 1.21 (SE = 0.05, n = 31), and 1.42 (SE = 0.13, n = 26), respectively. Mean percentage of deer associated within their own

subpopulation during winter 2002-03, summer 2003, and winter 2003-04 at Redwood Falls was 79% (SE = 0.04, *n* = 32), 94% (SE = 0.02, *n* = 31), and 83% (SE = 0.04, n = 26), respectively. During this study, *Canid* predation accounted for 100% (n = 10) of neonate mortalities. Pooled neonate survival rate was 0.72 for the period June to August 2003-04. A total of 14 vaginal-implant transmitters were placed in adult females during winter 2003 capture. Seven implants were recovered at birth sites, leading to the capture of 2 sets of triplets, 3 sets of twins and 2 single neonates. Vaginal-implant transmitters enabled location of birth sites to radiocollar neonates independent of habitat characteristics. The required number of search-hours per neonate captured was approximately 2.3 times higher using vehicle and ground searches compared to vaginal-implant transmitters. Results from this study are applicable to highly fragmented regions characterized by intense agriculture, high road density, low grassland and forest cover, and large fluctuations in climate. Long-term collection of region-specific radio telemetry data is necessary to improve the predictive capabilities of deer harvest models and to increase understanding of deer population dynamics.

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CHAPTER 1

INTRODUCTION AND STUDY AREA

INTRODUCTION

Knowledge of white-tailed deer (*Odocoileus virginianus*) population dynamics is critical for population management. Deer populations have adapted to highly fragmented landscapes that occur in agricultural regions of the Midwest. Wildlife managers strive for balance between hunter demands, landowner tolerance, and representation of interested stakeholders. Managers must deal with a pluralistic society that requires they meet the needs of all people. Furthermore, management agencies cannot rely upon theory to adequately manage the resource (McCullough 1987). Sound biological evidence must be collected to justify the need for harvest and adaptive management. In Minnesota, the aesthetic, economic, and biological values that white-tailed deer provide are important and need to be maintained for future generations. Thus, studies that monitor deer population dynamics and improve the overall management of the species are vital to sustaining this valuable resource.

In the northern portion of their range, seasonal movement between winter and summer ranges of white-tailed deer is common (Severinghaus and Cheatum 1956, Ozoga and Gysel 1972, Nelson 1998, Van Deelen et al. 1998). Seasonal movements have evolved in response to adverse environmental conditions and to utilize differences in temporal and spatial variation within the landscape (French et al. 1989). Yet, seasonal migration and timing may differ among individual deer within a population (Sabine et al. 2002). In southwest Minnesota, migration is in response to extremely cold temperatures and increasing snow depths (DelGuidice 2000, Brinkman 2003, Brinkman et al. 2005 *in press*). Furthermore, dispersal of deer has been documented in northern deer populations

(Nelson and Mech 1992, Brinkman et al. 2005 *in press*). Determining the rate of dispersal provides information regarding the role emigration and immigration have on deer population dynamics (Rosenberry et al. 1999).

Currently, the Minnesota Department of Natural Resources (MNDNR) deer harvest model (Lenarz and McAninch 1994, DePerno et al. 1999) does not incorporate seasonal movements. The model estimates the number of antlerless deer permits needed for each permit area (PA) to maintain the deer population (DePerno et al. 1999). However, evidence from Brinkman (2003) indicated that movement of individual deer across permit area (PA) boundaries is common. Deer may have a summer range in one PA and winter range in a different PA. Therefore, deer management strategies need to reflect these movements. Long-term data regarding movements (i.e., migration, home range, dispersal) should be collected and evaluated to determine their impacts within specific PAs.

The onset of chronic wasting disease (CWD), a transmissible spongiform encephalopathy, has caused concern for researchers on the potential spread of this degenerative disease throughout North America's free-ranging deer populations. Wildlife managers have implemented programs aimed at reducing deer herds through culling or hunter harvesting of animals. However, Williams et al. (2002) suggested that areas not infected with CWD should develop surveillance programs that document current prevalence and geographic distribution, as well as implement guidelines for limiting the spread and eradicating CWD should an outbreak occur. Because transmission of CWD is horizontal (Miller et al. 1998, Williams and Young 1992, Sigurdson et al .1999, Williams et al. 2002), empirical data are needed regarding the level of association between individual white-tailed deer. Understanding how often deer associate is critical when determining the level at which deer densities need to be reduced to prevent the spread of CWD. Furthermore, region-specific data collected regarding deer movement and dispersal may be an intricate part of determining association. Fuzzy cluster analysis (Marsili-Libelli 1989, Odeh et al. 1992, Schafer and Wilson 2002) may be an important tool used to determine association. Furthermore, it provides information regarding trends among subpopulations of deer and may be valuable when managing deer densities at levels that would decrease the risk of transmission of CWD.

Documenting survival and cause-specific mortality is critical to understanding deer population dynamics (Nelson and Mech 1986). However, biologists are usually forced to make educated guesses pertaining to these parameters because empirical data is difficult and expensive to collect (Porath 1980). Knowledge of neonate mortality from birth to recruitment is essential for proper deer management (Huegal et al. 1985*a*). Furthermore, knowledge of neonate mortality rates is critical to understanding how preseason mortality rates will impact deer harvest strategies (Porath 1980). To avoid overexploitation of harvestable deer populations, adequate survival and cause-specific mortality data must be collected (Nelson and Mech 1986). Brinkman (2003) collected information regarding neonate survival in upland and farmland habitats of southwest Minnesota. However, information on neonate survival is lacking in riparian habitat in southwest Minnesota.

The main objective of the MNDNR is to maintain deer populations at the highest level the habitat can support, while accounting for landowner tolerance (DePerno et al. 2002*a*). Furthermore, consistent deer season frameworks allow for maximum recreational opportunities, while minimizing landowner/hunter conflicts (DePerno et al. 2002*a*). The collection of empirical data regarding seasonal movement, home range, dispersal, survival, and cause-specific mortality is necessary to satisfy the needs of hunters, landowners, and the general public (Nixon et al. 2001). Biological information collected through this study will improve the knowledge of wildlife managers and will be important for assessing farmland deer populations in Minnesota.

Primary objectives were to determine seasonal movements, association between white-tailed deer subpopulations, and cause-specific neonate mortality. Secondary objectives were to estimate seasonal home ranges, and to evaluate the use of vaginal-implant transmitters to aid in neonate capture. Furthermore, for female deer captured as adults (>1 year) and fawns (~8 months), objectives were to determine seasonal movements (i.e., migration, dispersal), home ranges, and evaluate subpopulation association using fuzzy cluster analysis (Odeh et al. 1992, Klaver et al. *in review*). For deer captured as neonates (<1 month), objectives were to determine monthly and summer survival rates during June to August and to determine cause-specific mortality. I predicted that cold temperatures and snow depth would have the greatest influence on seasonal movement. Additionally, I hypothesized that association between subpopulations would be highest during winter when deer congregate in areas providing available forage and cover and lowest in summer due to parturition activity. Finally, I predicted that neonate white-tailed deer would have low survival relative to Brinkman's (2003) neonate survival of 84% at Lake Benton, Minnesota. Survival may be lower near Redwood Falls than at Lake Benton due to high predator densities, habitat differences, and changes in vegetation density.

STUDY AREA

The study was conducted during September 2002 to August 2004 in southwest Minnesota (43° 29' N to 45° 16' N – 093° 38' W to 096° 27' W). Southwest Minnesota is characterized by flat to rolling topography with elevations ranging from 229 to 608 m above mean sea level (Albert 1995). However, topography is steeper along the Minnesota River and it tributaries (Voigtlander 1999). Twenty counties and 24 deer permit areas (Figures 1, 2) comprise the 34,627 km² study area. The region is composed of highly fragmented land dominated by intense row-crop agriculture. Active crop fields (corn [*Zea mays*], soybeans [*Glycine max*], wheat [*Triticum aestivum*], oats (*Avena sativa*) and alfalfa [*Medicago sativa*]) constitute 85.6% of total land use (Table 1). The remaining land use/cover types are grassland (6.5%), forest (3.0%), permanent bodies of water (1.6%), and wetlands (0.8%, Table 1; [Minnesota Department of Natural Resources 2000]).

Tall and mixed prairie grasses compose the majority of native vegetation in southwest Minnesota. Of these, big bluestem (*Andropogon geradii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), tall dropseed (*Sporobolus asper*), and sideoats grama (*Bouteloua curtipendula*) can be found on uplands (Johnson and Larson 1999, Voigtlander 1999). In low wet areas, prairie cordgrass (*Spartina pectinata*), reedgrass (*Calamagrostis arundinacea*), and sedges (Cyperaceae) are common (Voigtlander 1999). Forested areas are dominated by 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).

The majority of the study area lies within the Minnesota River Basin. The Minnesota River Basin covers roughly 24,140 km² and drains 20% of Minnesota as well as parts of South Dakota, Iowa, and North Dakota (Minnesota River Basin Data Center 2003). Specifically, four main watersheds (Cottonwood River, Hawk Creek-Yellow Medicine River, Middle Minnesota River, and Redwood River) occur within Redwood and Renville counties where the majority of this research was conducted. As a result of the Wisconsin Glaciation (10,000 to 100,000 years ago), lobes of glacial ice shaped the landscape in this region (Minnesota River Basin Data Center 2003). The oldest and deepest rocks in this region are Precambrian in age. The majority of these rocks are crystalline rocks of igneous (granites) and metamorphic origins. However, overlying the Precambrian rocks are sedimentary rocks (shale, siltstone and sandstone) from the Cretaceous age. Deposits of glacial drift, including: clay, silt, sand, and gravel cover the layers of Precambrian and Cretaceous age rocks (Minnesota Pollution Control Agency 2004).

Historically, this region was spotted with wetlands. Today, drain tiles and ditches have resulted in the draining of approximately 809,373 to 1,214,059 hectares of wetlands in the Minnesota River Basin (Minnesota Pollution Control Agency 1994). Furthermore,

40-60% of the original deciduous forests have been converted to agricultural lands (Minnesota River Basin Data Center 2003).

Climate in southwest Minnesota is continental with cold dry winters and warm wet summers. Temperatures in this region range from -40 to 43.3 °C. Average monthly temperatures (1971-2000) at Redwood Falls, Minnesota, (the main study site), were -10.6 °C in January and 23.1 °C in July and average precipitation and snowfall was 67.7 and 89.2 cm, respectively (Midwest Regional Climate Center 2005). Two thirds of this precipitation falls in the five months from May through September. Humidity is generally higher at night averaging 78% at dawn in Renville County (Voigtlander 1999). The prevailing winds are northwest.

In southwest Minnesota, majority of farming operations grow cash crops. However, some operations raise livestock. In Redwood and Renville counties alone, there are 1,198 and 1,164 farming operations (Minnesota Agriculture Statistics Service 2002), respectively. Similar to Brinkman (2003) cultivated land was defined as "areas under intensive cropping or rotation, including fallow field and fields seeded for forage or cover crops that exhibit linear or other patterns associated with current tillage (Minnesota Department of Natural Resources 2000)." Specifically, cultivated land in Redwood and Renville counties encompasses 93.6% and 94.6% of total land use, respectively. In southwest Minnesota, corn and soybeans are 96% of the total crop harvest (Minnesota Agriculture Statistics Service 2002). CHAPTER 2

MOVEMENT OF FEMALE WHITE-TAILED DEER IN SOUTHWEST MINNESOTA

INTRODUCTION

In the northern portion of its range, white-tailed deer migration is common between seasonal ranges (Severinghaus and Cheatum 1956, Ozoga and Gysel 1972, Nelson 1998, Van Deelen et al. 1998). Deer have evolved responses to spatial and temporal variation in the environment, which impact migration and seasonal movement(French et al. 1989). Many factors are thought to initiate deer migration between summer and winter ranges; snow depth along with cold temperatures are thought to have the greatest influence on fall migration (Ozoga and Gysel 1972, Drolet 1976, Nelson and Mech 1981, Nicholson et al. 1997, Brinkman 2003, Brinkman et al. 2005). Additionally, photoperiod, maturation of vegetation, and food availability have been suggested as secondary cues initiating fall migration (VerCauteren and Hygnstrom 1993, Nicholson et al. 1997, DePerno et al. 2002b). Likewise, rising temperatures and decreasing snow cover may initiate spring migration (Nelson and Mech 1981). While deer possess a strong homing instinct to return annually to winter range (Verme 1973), mild winters characterized by low snowfall can cause shifts within ranges rather than true migrations (Sparrowe and Springer 1970).

Although female white-tailed deer are philopatric, dispersal is a common occurrence in northern deer populations (Nelson and Mech 1992, Brinkman et al. 2005). Determining the amount of dispersal occurring in a deer population is critical to estimating the influence of emigration and immigration on population size and composition (Rosenberry et al. 1999). Dispersal is important because it involves the rate at which individuals occupy new or vacant habitats, which ultimately results in gene flow among populations and potential range extension (Nelson and Mech 1992). Knowledge of region specific dispersal may be important when making management decisions relating to deer population management.

Assessing the effects of seasonal movements, home ranges, and dispersal is fundamental to deer population management. Brinkman (2003) suggested that empirical data related to seasonal movements and amount of dispersal across permit area boundaries currently used by the MNDNR in southwest Minnesota were needed to improve the deer harvest model. Furthermore, lack of detailed and localized scientific data can lead to problems regarding proper deer management (DePerno et al. 1999). Thus, the objectives of my study were to determine seasonal movements (i.e., migration, dispersal) and home ranges of white-tailed deer in southwest Minnesota. I predicted that cold temperatures and snow depth would have the greatest effect on seasonal movements of deer.

METHODS

Adult (>1 year at capture) female and fawn (~8 months) white-tailed deer were captured near Redwood Falls (Figure 1) during January and February 2003 using helicopter net-guns (Barrett et al. 1982). Captured adult female deer were injected intramuscularly with 5 mg/kg Ketamine and 1 mg/kg Xylazine prior to transport to the processing site (Mech et al. 1985, Kreeger et al. 2002). At the processing site, physical condition was assessed and blood samples were obtained for disease evaluation. Rectal temperature was continuously monitored as an indicator of stress. Deer were radiocollared (Advanced Telemetry System, Isanti, Minnesota USA), aged, ear-tagged, measured (chest and neck circumference), and administered a broad-spectrum antibiotic. Tonsillar biopsies were collected from adult female deer as a pre-clinical antemortem test for CWD (Schuler et al. *in review*). Vaginal-implant transmitters (Advanced Telemetry System, Isanti, Minnesota USA) were placed in adult deer to aid in fawn capture (Bowman and Jacobson 1998). Anesthesia was reversed by intravenous or intramuscular injection of 0.125 mg/kg of Yohimbine (Mech et al. 1985). All field methods complied with animal care and use guidelines presented by the American Society of Mammalogists (1998) and the Institutional Animal Care and Use Committee (approval number: 02-A043) at South Dakota State University.

Radiocollared female white-tailed deer were monitored 2-3 times per week via ground triangulation using a null-peak antenna system (Brinkman et al. 2002) at Redwood Falls and Walnut Grove study sites in southwest Minnesota (Figure 1). An electronic digital compass (C100 Compass Engine, KVH Industries, Inc., Middletown, RI; Cox et al. 2002) was connected to the null-peak antenna system (Brinkman et al. 2002) and used to estimate azimuths and accuracy was $\pm 1^{\circ}$. A fixed-wing aircraft was used to locate deer that could not be located from the ground. I recorded visual observations of individual deer using Universal Transverse Mercator (UTM) coordinates. No less than 3 azimuths were used to estimate locations for deer from established telemetry stations. A minimum error estimate of < 20 hectares was required to retain a location for home range analysis. I estimated locations using the software program LOCATE II (Nams 2001) in UTM format and locations were plotted on USGS 3-meter Digital Orthophoto Quadrangles using ArcView (ESRI, Redlands, CA). Deer were monitored during four migration periods: fall 2002, spring 2003, fall 2003, and spring 2004. Individual white-tailed deer were monitored throughout the 21-month period unless unforeseen circumstances (e.g., mortality, malfunctioned transmitter) prevented monitoring of animals.

Home ranges were determined using the home range (Rodgers and Carr 1998) and spatial movement (Hooge and Eichenlaub 2000) analysis extensions in ArcView (ESRI, Redlands, CA). The fixed-kernel method was used to estimate home range using leastsquares cross-validation to determine the smoothing parameter (Seaman et al. 1999).

Migration to seasonal ranges was calculated as the straight-line distance between the center points of summer and winter home ranges (Sabine et al. 2002). A migration was considered as the temporary or permanent movement between non-overlapping seasonal ranges. Migration from summer to winter range was considered fall migration, and migration from winter to summer range was considered spring migration. Migration date was calculated using the median date between the last known observation and first date of observation at a new seasonal range (Sabine et al. 2002) and was classified as obligate, conditional, or resident (Brinkman et al. 2005). Deer were assigned a migration type if monitored for \geq 3 consecutive migration periods. Deer were considered obligate migrators if they migrated to a seasonal range and remained there until the subsequent season (Sabine et al. 2002). Deer were considered conditional migrators if they failed to migrate during any migration period or if they made several trips to a seasonal range for less than one month (Sabine et al. 2002, Nelson 1995). Deer were considered residents if seasonal home ranges overlapped or they failed to migrate for \geq 3 migration periods. Dispersal was defined as the permanent movement of individual deer from an established home area to a new, nonoverlapping home area (Marchinton and Hirth 1984). I used the methods of Brinkman (2003) to calculate deer winter severity index (DWSI) in southwest Minnesota; the index accumulates 1 point for each day mean ambient temperature was \leq -7 °C, and an additional point for each day snow depth was \geq 35 cm during the months of November-March (Climatology Working Group 2004). SYSTAT (SPSS 2000) was used to compare migration distance and home range size of deer between study sites and among years. A Bonferroni correction factor with alpha set at $P \leq 0.05$ was used to maintain experiment-wide error when multiple *t*-tests were performed (Neu et al. 1974).

RESULTS

During January and February 2003, average time spent handling deer was 19.1 minutes (SE = 2.0, range = 5 to 55; Table 2). Distance between capture location and processing site averaged 0.9 km (SE = 0.1, range = 0.21 to 2.68 km). Average adult and fawn rectal temperature was 39.5 °C (SE = 0.18) and 39.4 °C (SE = 0.25) and ranged from 38.6 °C to 41.3 °C. Neck circumference for adults and fawns averaged 44.3 (SE = 44.3) and 33.5 cm (SE = 0.5), respectively, and ranged from 33 to 54 cm. Mean chest circumference of adult and fawn deer was 103.5 (SE = 1.3) and 84 cm (SE = 4.0) and ranged from 80 to 111 cm (Table 2).

From September 2002 to May 2004, a total of 49 (47 adult, 2 fawn) female radiocollared deer was monitored at Redwood Falls and Walnut Grove study areas in southwest Minnesota (Figure 1). Thirty-two radiocollared deer (20, Redwood Falls, 12, Walnut Grove) remained from a previous study in southwest Minnesota conducted from January 2001 to August 2002 (Brinkman 2003). However, an additional 17 deer (15 adult, 2 fawn) were captured and radiocollared at Redwood Falls during January (n = 8) and February 2003 (n = 9; Table 2, Appendix A). The 17 deer were monitored in addition to the 32 deer previously radiocollared (Brinkman 2003). A total of 6,511 locations was collected with a mean 95% error ellipse of 4.6 ha. A total of 56 seasonal movements was calculated during four migratory periods; fall 2002 (n = 13), spring 2003 (n = 17), fall 2003 (n = 17), and spring 2004 (n = 9) (Appendix B, C, D). During 3 seasonal range periods, a total of 111 individual home ranges was estimated; winter 2002-03 (n = 41), summer 2003 (n = 39), and winter 2003-04 (n = 31) (Appendix B, C, D). Average deer winter severity index (DWSI) during winter 2002-03 (59; Figures 3, 4) was similar to that for winter 2003-04 (67; Figures 3, 5), and winter 2001-02 (51) as reported by Brinkman (2003).

Migration strategies

Thirty-seven radiocollared deer were monitored and relocated 5,035 times at Redwood Falls. Seasonal movements were documented for 28 of these deer. Fourteen deer (50%) did not migrate and thus, were categorized as residents. All resident deer had home ranges near the main wintering area where they were captured. Seven deer (25%) were obligate migrators (i.e., migrated every year regardless of environmental conditions) and seven deer (25%) were conditional migrators (i.e., migrated in response to environmental factors). Mean conditional migration distance (13.0 km; SE = 3.2) tended to be shorter but was similar (t = 0.959, df = 10, P = 0.360) to mean obligate migration distance (15.0 km, SE = 1.2).

Twelve radiocollared deer were monitored and relocated 1,476 times at Walnut Grove. Seasonal movements were documented for 8 of these deer. Two deer (25%) were non-migratory (i.e., residents). Both resident deer had home ranges near a main wintering area. Three deer (37.5%) were obligate migrators and 3 deer (37.5%) were conditional migrators. Mean conditional migration distance (9.7 km, SE = 2.4) was shorter (t = 3.963, df = 3, P = 0.029) than mean obligate migration distance (17.9 km, SE = 2.4). Mean migration distance for conditional (t = 1.613, df = 3, P = 0.205) and obligate (t = 0.490, df = 10, P = 0.634) migrators at Walnut Grove was similar to that of conditional and obligate migrators at Redwood Falls.

Fall movement 2002

During fall 2002, 13 deer (48.1%) migrated a mean distance of 14.3 km (range = 28.9 km, SE = 2.2 km; Table 3). Fourteen individuals (51.9%) were non-migratory and occupied at least a portion of their summer range as winter range. Mean date of departure from summer to winter range for 13 migratory deer was 24 November and ranged from 9 September to 2 February.

Fall 2002 migration distance at Redwood Falls and Walnut Grove study sites was 14.0 (SE = 2.2; n = 8) and 14.9 km (SE = 4.9; n = 5), respectively, and did not differ (t = 1.83, df = 11, P = 0.858) between study sites (Table 3). Walnut Grove had the higher percentage (50.0%) of migrating deer in fall 2002, followed by Redwood Falls (47.1%).

Spring movement 2003

Of the 43 deer monitored during spring 2003, 17 deer (38.6%) migrated a mean distance of 15.2 km (range = 29.5 km, SE = 2.1 km; Table 3). Eleven of the migratory deer in spring 2003 were monitored in fall 2002. Twenty-six deer (60.5%) were non-migratory in spring 2003, and of these deer, 13 remained non-migratory in fall 2002. Seventeen deer were captured (added to the sample) during winter 2002-03, and of these, 2 deer were migratory during spring 2003. Dispersal could not be determined for deer captured in winter 2002-03 because fall 2002 migration was unknown. Mean date of winter range departure was 22 April and varied from 13 March to 20 July.

Average spring 2003 migration distance at Redwood Falls and Walnut Grove were 15.1 (SE = 2.4; n = 12) and 15.4 km (SE = 4.4; n = 5; Table 3), respectively; distances did not differ (t = 0.078, df = 15, P = 0.939) between study sites, respectively. Walnut Grove had the higher percentage (55.6%) of migrating deer, followed by Redwood Falls (34.6%).

Fall movement 2003

During fall 2003, 17 deer (44.7%) migrated a mean distance of 14.6 km (range = 29.1 km, SE = 2.1; Table 3). Nearly all deer classified as migratory deer (90%) in fall 2002 remained migratory in fall 2003 (n = 10). Twenty deer (54.1%) were non-migratory during fall 2003, 18 deer remained non-migratory from spring 2003 and 2 deer migrated during the previous season. All individuals classified as residents in fall 2002 (n = 8) remained residents in fall 2003. Mean fall migration date was 26 November in fall 2003 and ranged from 10 October to 5 February.

Average fall 2003 migration distances at Redwood Falls and Walnut Grove study sites were 14.4 (SE = 2.1; n = 13), and 15.4 km (SE = 6.2; n = 4), respectively (Table 3). Difference in migration distances between study sites could not be determined due to an insufficient sample size at Walnut Grove. Walnut Grove had the higher percentage (50%) of migratory deer, followed by Redwood Falls (43.3%).

Spring movement 2004

During spring 2004, 32 deer were monitored, 9 of these deer migrated a mean distance of 13.6 km (range = 20.8 km, SE = 2.4 km; Table 3). Twenty-three individuals did not migrate during spring 2004; 18 of these deer were non-migratory during fall 2003 and 5 deer migrated during the previous season. Sixteen deer classified as residents in spring 2003 remained residents in spring 2004. Mean migration date was 6 April and ranged from 7 March to 30 May.

Mean migration distances during spring 2004 at Redwood Falls and Walnut Grove were 13.8 (SE = 3.0; n = 7) and 12.8 km (SE = 4.5; n = 2), respectively (Table 3). Difference in migration distances between study sites could not be determined due to an insufficient sample size at Walnut Grove. Walnut Grove had the higher percentage of migratory deer (33.3%) followed by Redwood Falls (25.9%).

Home range

Seasonal home ranges of individual deer were calculated using a minimum of 25 and a mean of 44 (SE = 0.9, n = 110) locations. Winter 2003 home ranges did not differ (t = 1.419, df = 61, P = 0.161) from those of winter 2004, and thus, were pooled in

analyses. During this study, summer 2003 was the only season in which summer home range information was collected.

Mean size of 95% and 50% winter home ranges were 3.3 (range = 14.0 km²; n = 72) and 0.65 km² (range = 3.1 km²; n = 72; Table 4), respectively. Mean size of 95% (t = 1.829, df = 70, P = 0.113) and 50% (t = 1.606, df = 70, P = 0.752) winter home ranges did not differ between study sites. Deer at Redwood Falls and Walnut Grove had a mean 95% winter home range use area mean of 3.0 km² (SE = 0.3; n = 57) and 4.4 km², respectively (SE = 0.91; n = 15; Table 4).

During summer 2003, mean 95% and 50% home range use area was 2.6 km² (range = 16.8 km²; n = 39) and 0.5 km² (range = 2.6 km²; n = 39). Mean 95% summer home range size differed (t = 2.055, df = 37, P = 0.047) between study sites. However, mean 50% summer home range size did not differ (t = 1.613, df = 37, P = 0.115) between study sites. Deer at Redwood Falls and Walnut Grove had mean 95% summer home range sizes of 2.0 (SE = 0.4; n = 39) and 4.38 km², respectively (SE = 1.7; n = 39; Table 4).

DISCUSSION

Seasonal movement

Multiple migration strategies may occur in the same population due to environmental fluctuations and individual variation in costs of migration (Fretwell 1972). For most white-tailed deer, seasonal movement is a learned experience and becomes established during early social development rather than based solely on demands of their physical environment (Nelson 1998). In southwest Minnesota, mean seasonal migration distance (14.6 km; Table 3) was comparable to other northern white-tailed deer populations (15.6 km, Carlsen and Farmes [1957]; 11.0 km, Simon [1986]; 17.1 km, Root et al. [1990]; 13.0 km, Nixon et al. [1991]; 15.7 km, Griffin et al. [1994]; 6-23.8 km, Kernohan et al. [1994]; 6.8-20.2 km, Sabine et al. [2002]; 10.1 km, Brinkman [2003]).

Deer in Redwood Falls and Walnut Grove exhibited a mixture of migration strategies. Both study sites were composed of migratory and nonmigratory deer. Of the 36 deer assigned migration strategies in southwest Minnesota, 10 (28%) were conditional migrators, 10 (28%) were obligate migrators, and 16 (44%) were permanent residents. Nicholsen et al. (1997) suggested that a mixed migration strategy in mule deer (*Odocoileus hemionus*) resulted from variability in climate, particularly snow depth and temperature; my results support this hypothesis for white-tailed deer in Minnesota. Variation in migration strategies was likely influenced by the severity of winter. Typically, during harsh winters more deer migrate to winter ranges in response to low temperatures and accumulating snow depths (Sabine et al. 2002). Likewise, during mild winters less deer were forced to migrate because of low snowfall and relatively warmer temperatures. Furthermore, during consecutive mild winters, there was a shift towards a localized increase in resident deer.

Use of winter range by deer is flexible and changes yearly according to variation in winter severity (Drolet 1976, Brown 1992). The winters of 2002-04 (Figures 3, 4, 5) were mild in comparison to the DWSI (138.7) of winter 2000-01, reported by Brinkman (2003) and Brinkman et al. (2005). Deer captured during the severe winter of 2000-01 on winter range were more likely to be migratory than animals captured during mild winters

because during severe winters an increase in conditional migration is common (Sabine et al. 2002). Hence, deer migrated to winter range during severe winters to use dense cover allowing them to conserve energy (Drolet 1976). Conversely, deer captured during the mild winter of 2002-03 were likely residents on the main wintering area. Thus, a higher number of resident females were likely radiocollared due to a lack of migratory individuals on winter range. I documented an 18.2% decline in conditional migration, 10.5% decline in obligate migration, and a 31.2% increase in resident deer during my study compared to results reported by Brinkman (2003) and Brinkman et al. (2005). There was less risk of delaying departure from summer range during mild winters, due to added benefits of increased food abundance and reduced competition (Sabine et al. 2002). Furthermore, the proportion of resident deer in my study may be higher because conditionally migrating deer may have remained on summer range (Van Deelen et al. 1998). Winter weather conditions can create a thermal energy sink for white-tailed deer resulting from a lack of food resources, and accumulating snow depths that deplete energy expenditures needed for movement (Moen 1976). Therefore, the need to expend energy is less during mild winters because food sources are more available and snow depths are less likely to limit daily movements.

Fall migration is stimulated by the onset of snowfall and increasing snow depths (Nelson and Mech 1981). In southwest Minnesota, cold temperature and snow depth had the greatest influence on fall migration. During fall 2002 (Figures 6, 7), 5 of 13 deer (38%) migrated from summer to winter range from 17 to 23 November. There was no snowfall during this period and temperatures ranged from -3° C to 7° C. On 16
November, temperatures reached their lowest point that fall at -6 °C. This is slightly above the effective lower critical temperature for white-tailed deer of -7° C (DelGuidice 2000). An influx of cold weather occurred from 24 to 29 December when mean ambient daily temperature reached -12 °C. As a result, 2 of 13 deer (15%) migrated to winter range. Nelson (1995) determined that migration to winter range was three times as likely when declining temperatures coincided with snowfall. An additional migration occurred when deer 591 migrated on 5 February in response to temperatures dropping to -17 °C and a 28 cm snowfall that occurred on 2 to 3 February (Figures 6, 7).

Spring migration in southwest Minnesota occurred in response to environmental cues. Similar to other deer populations (Nelson 1995, Sabine et al. 2002, Brinkman 2003, Brinkman et al. 2005), decreasing snow depths along with increasing temperatures were most influential in initiating spring migration. Snow depths decreased to zero by 15 March and temperatures increased to 13 °C on 24 March, which was the warmest to date in spring 2003 (Figures 8, 9). These factors initiated the migration of 80% of deer at Walnut Grove from 18 to 25 March. A second group (n = 3) of deer migrated from 1 to 4 May. Snow was non-existent and no significant fluctuations in temperatures occurred during this time.

Deer 163's spring migration may have been a result of the need to find unoccupied fawning grounds. Deer 163 was located on winter range on 18 May when it began exhibiting unusual movements. On 20 May, deer 163 was located 35 km northeast of its previous location. Deer 163 remained at this location until 23 May when it was located 31 km southwest of its previous location and near the original winter range. On

24 May, deer 163 was located on winter range where she gave birth to triplet neonates. Why deer 163 moved this distance before giving birth is unknown. However, Nixon et al. (1991) suggested that competition among female deer for suitable parturition sites is intense and females will readily defend fawning grounds. Matriarchal groupings are common in white-tailed deer (Hawkings and Klimstra 1970) and yearling females establish home ranges in the vicinity of their mothers (Severinghaus and Cheatum 1956, Mathews 1991). Conceivably, deer 163 may have been forced from winter range and thus, would have moved in search of fawning grounds. However, during deer 163's 35-km movement she may have failed to find unoccupied fawning grounds and had to reestablish her fawning grounds on her original winter range. Brinkman (2003) suggested that deer in southwest Minnesota might be forced to move long distances to establish fawning grounds in highly fragmented agricultural landscapes. Remaining deer (n = 10) migrations were staggered and ranged from 31 March to 20 July (Figures 8, 9). Furthermore, these results indicate that deer exhibit higher fidelity to summer than winter range, which supports results of other white-tailed deer populations (Tierson et al. 1985, Root et al. 1990, Van Deelen et al. 1998, Brown 1992).

An unusual migration occurred during fall 2003 where only one group of deer migrated in response to winter stimuli. Mean ambient daily temperatures from 5 to 9 November ranged from -5 °C to -11 °C. In response to the coldest temperatures recorded during fall 2003, 14 deer (21%) migrated to winter range (Figures 10, 11). No other groups of deer migrated together during fall 2003. Nelson (1998) suggested that migratory behavior is learned in the early social environment rather than being based on environmental stimuli. During fall 2003, deer may have migrated to find thermal cover allowing them to conserve energy and improve reproductive fitness. Also, photoperiod and phenology of vegetation (Nicholson et al. 1997) may have influenced the timing of migration of deer during fall 2003.

During spring 2004, migration of 3 of 9 deer (33%) occurred from 15 to 19 April in response to mean ambient daily temperatures reaching 21° C. Departure ranged from 7 March to 30 May (Figures 12, 13). Factors influencing migration during spring 2004 were less apparent. Six of nine deer (67%) migrated to summer range in response to warming temperatures. Increased photoperiod, low quality of vegetation on winter range (Nicholson et al. 1997), and pre-parturition behavior (Ozoga et al. 1982*a*) may have influenced migration to summer range.

Movements during the summer tended to be limited because deer had optimal cover (i.e., corn) with abundant forage. Movements of resident and migrant deer within the main wintering area were larger, and may have been in response to higher deer densities impacting the amount of available forage (Van Deelen et al. 1996). Migrations were generally oriented to the north of the main wintering area and usually followed creek drainages. Migration duration was brief and usually occurred in less than one week. In most cases deer moved with little or no meandering between seasonal ranges. I located deer moving through habitats suitable for seasonal range en route to "desired range." This would support the hypothesis that white-tailed deer migration is learned during early social development (Nelson 1998). However, high annual harvests typical in highly fragmented agricultural landscapes may preclude formation of social structure

preventing learning of traditional migration patterns (McNulty et al. 1997). In a study conducted in south central Wisconsin, differential hunter-caused mortality explained the prevalence of nonmigratory deer (Larson et al. 1978). Moreover, orphans of hunter-killed females may remain nonmigratory because they were unable to learn the migratory behavior of their mothers (Nelson 1995).

Spatial relations of female deer within localized populations have been attributed to kinship (Hawkins and Klimsta 1970, Ozoga et al. 1982*a*). However, Aycrigg and Porter (1997) suggested that in fragmented landscapes (e.g., southwest Minnesota) philopatry among deer is less likely to occur when preferred habitat for fawning is scarce. During 2001-2002, 17% of fawns and 5% of female adults dispersed in southwest Minnesota (Brinkman et al. 2005). Yet, during this study I documented no dispersal. Brinkman (2003) suggested that lower dispersal rates are more likely to occur with high rates of female deer harvest because of an increased abundance of orphaned young. Furthermore, Nelson and Mech (1992) described dispersal as a voluntary event. However, social pressures have been suggested as the primary factor initiating dispersal (Marchinton and Hirth 1984, Brinkman 2005). Potentially, an increased harvest on female deer may have occurred, creating an abundance of space left by hunter-killed deer, resulting in a decrease in intraspecific pressure to disperse.

Home range

Home ranges of white-tailed deer must include the required essentials for life and reproduction, while providing added survival advantages through familiarity of core area (Marchinton and Hirth 1984). Seasonal use of home range by female deer tends to remain unchanged from year to year (Tierson et al. 1985). In highly fragmented agricultural landscapes dominated by intensive row-crop agriculture as in southwest Minnesota, seasonal use of home ranges by white-tailed deer varied due to climatic factors (Brinkman 2003). Fluctuations in winter severity may cause deer to exhibit higher fidelity to summer range than winter range (Brown 1992). Deer fidelity to summer range may have been related to abundant high-quality forage (Leach and Edge 1994), reduced intraspecific competition, and abundant fawning habitat (DePerno et al. 2003). Furthermore, use of winter range by deer depended upon yearly differences in winter severity (Drolet 1976). Snow depth and cold temperatures had marked influence on use of winter home range (Rongstad and Tester 1969; Ozoga and Gysel 1972).

Nicholson et al. (1997) reported smaller home ranges of mule deer in California in summer compared to winter and Brinkman (2003) reported similar results for white-tailed deer in Minnesota. Deer in my study, had mean 95% summer home ranges of 2.6 km² and mean 95% winter home ranges of 3.3 km² (Table 4). Size of a home range is dependent upon habitat quality and population density (Sanderson 1966). Thus, differences in landscape and population densities will vary by region and caution should be used when comparing home range estimates. Brinkman (2003) documented that home ranges in southwest Minnesota were more than double in size in winter (5.2 km²) than in summer (2.3 km²). Sparrowe and Springer (1970) reported deer in eastern South Dakota had home ranges of 2.5 km². Rongstad and Tester (1969) noted home ranges of 1.61 to 4.80 km² in east-central Minnesota, and Kohn and Mooty (1971) documented home ranges in north-central Minnesota of 1.67 to 4.71 km².

Nicholson et al. (1997) and Kilpatrick et al. (2001) suggested that home range size decreases as high quality forage increases. In southwest Minnesota, deer have access to unlimited food and cover (i.e., corn) during summer from intense row-crop agriculture. Furthermore, summer home range size may have been reduced due to parturition activity and rearing of fawns (Hawkins and Klimstra 1970). Conversely, winter home ranges in southwest Minnesota were slightly larger than summer because deer need to maintain adequate nutrient intake and spend additional time foraging during winter (Nicholson et al.1997) to sustain metabolic processes (Moen 1976). Because southwest Minnesota is highly fragmented due to intense row-crop agriculture, patches of permanent cover (i.e., dense forest habitat) tend to be limited to riparian habitats and small vacant woodlots. Due to a fragmented landscape, available permanent cover was limiting, resulting in deer utilizing larger areas of winter range to meet their needs for survival.

Movements of deer outside of home ranges were usually influenced by human activities. Agricultural activities and firearm hunters caused deer to occasionally move outside of their home ranges. Corn was the most widely used row crop by deer during summer. Use of corn by deer began in early July and peaked during late summer (Brinkman 2003). Similar to VerCauteren and Hygnstrom (1998), most deer in my study shifted home ranges towards permanent cover after the removal of adjacent row-crops. Firearm hunters occasionally caused deer to make temporary movements out of their home ranges, but deer usually returned to their home range by the next morning. Nixon et al. (1991) suggested that deer may seek dense cover where they find refuge from increased hunting pressure. Dense cover dominated by abundant willow (*Salix* spp.) and cottonwood trees (*Populus deltoides*) may have contributed to reduced movements of deer during the firearms hunting.

CHAPTER 3

FUZZY CLASSIFICATION OF FEMALE WHITE-TAILED DEER IN AN INTENSIVELY FARMED REGION OF MINNESOTA

INTRODUCTION

Recently, researchers have become concerned with a naturally occurring transmissible spongiform encephalopathy impacting populations of white-tailed deer, mule deer (Odocoileus hemionus), and Rocky Mountain elk (Cervus elaphus) known as chronic wasting disease (CWD). Because evidence from captive animals suggests the transmission of CWD is horizontal (Miller et al. 1998, Williams and Young 1992, Sigurdson et al. 1999), spread of CWD through wild deer populations may have detrimental effects to the economic, aesthetic, and biological values these animals provide. White-tailed deer migration is common in the northern portion of their range (Severinghaus and Cheatum 1956, Ozoga and Gysel 1972, Nelson 1998, Van Deelen et al. 1998). To understand the role movement has on the potential spread of CWD, it is increasingly important to collect empirical data relating to movements of deer across the landscape and individual deer interactions. Therefore, fuzzy cluster analysis may provide insight into the dynamics of subpopulation movements and interactions. Moreover, assessing the effects of density (McNulty et al. 1997, Kilpatrick et al. 2001), climatic factors (Nelson and Mech 1981, Nicholson et al. 1997, Brinkman 2003, Brinkman et al. 2005), and matrilineal groupings (Hawkins and Klimstra 1970, Aycrigg and Porter 1997, Nelson and Mech 1999), may be important understand the spread of disease in or across subpopulations, which would ultimately aid in white-tailed deer management.

Knowledge of spatial and temporal dynamics of populations is critical to effective wildlife management (Bethke and Taylor 1996). Furthermore, all social and ecological variables must be carefully evaluated to understand the proximate causes for the spatial

distribution of individuals (Brown 1975). Schafer and Wilson (2002) suggest the biology of ecosystems is understood best through classification of similarly related objects. Because biological data are often vague (Schaefer and Wilson 2002) and have inherent uncertainty, traditional cluster analysis may yield unrealistic associations (Marsili-Libelli 1989). Additionally, traditional cluster analysis assigns objects or individuals to an absolute group membership (Odeh et al. 1992); either a value of 1 if the object is a member and 0 if not a member (Eqihua 1990). Determining if an object belongs exclusively in a class may not accurately represent the continuous nature of real world systems (Odeh et al. 1992). Moreover, Schaefer and Wilson (2002) suggest traditional methods of classification are inconsistent with modern synthesis (Mayr 1988) and fail to recognize variation and unique individuals.

The theory of fuzzy sets was developed to evaluate complex ecosystems that require scientifically justified decision-making (Zadeh 1973). Fuzzy sets categorize objects displaying continuous variation into classes without distinct boundaries (Schaefer and Wilson 2002). The object is assigned a membership value to a particular group, which provides information on probability of association to a certain structure (Marsili-Libelli 1989). Fuzzy membership variables may have any value between 0 and 1. Hence, the object has a degree of membership within a group. Degree of fuzziness represents the level at which objects are compact and separated (Odeh et al. 1992). The most efficient partition of classes is produced with an optimum level of fuzziness, which improves clustering flexibility (Marsili-Libelli 1989). Thus, fuzzy set theory can be used to define populations (Schaefer and Wilson 2002) though the display and analysis of spatial data (Marsili-Libelli 1989, Brown 1998, Klaver et. al *in review*).

Fuzzy classification has been used in several applications including: biological control of pests (Cheng et al. 1996), identifying wildlife habitat (Ayyub and McCuen 1987), climatic classification (McBratney and Moore 1985), soil-landform interrelationships (Odeh et al. 1992), population dynamics (Barros et al. 2000), population genetic structure (Schaefer and Wilson 2002), ecosystem classification (Bosserman and Ragade 1982), ordination (Marsili-Libelli 1989), mapping forest types (Brown 1998), community classification (Equihua 1990), and population substructure of white-tailed deer (Klaver et al. *in review*).

The purpose of this study was to determine the level of association between subpopulations of adult female white-tailed deer in southwest Minnesota. We hypothesized the level of interaction among subpopulations would be highest during winter when deer congregate in areas providing available forage and cover and lowest in summer due to parturition activity.

METHODS

Adult (>1 year at capture) female and fawn (~8 months) white-tailed deer (15 adult, 2 fawn) were captured near Redwood Falls (Figure 1) during January and February 2003 using helicopter net-guns (Barrett et al. 1982). Captured adult female deer were injected intramuscularly with 5 mg/kg Ketamine and 1 mg/kg Xylazine prior to transport to the processing site (Mech et al. 1985, Kreeger et al. 2002). Deer were radiocollared (Advanced Telemetry System, Isanti, Minnesota USA), aged, ear-tagged, measured (chest and neck circumference), and administered a broad-spectrum antibiotic. An intravenous injection of 0.125 mg/kg of Yohimbine (Mech et al. 1985) was used to reverse anesthesia. All field methods complied with animal care and use guidelines presented by the American Society of Mammalogists (1998) and the Institutional Animal Care and Use Committee (approval number: 02-A043) at South Dakota State University.

Ground triangulation using a null-peak antenna system (Brinkman et al. 2002) was used to monitor radiocollared female white-tailed deer (n = 49) 2-3 times per week at Redwood Falls and Walnut Grove study sites (Figure 1) in southwest Minnesota. An electronic digital compass (C100 Compass Engine, KVH Industries, Inc., Middletown, RI; Cox et al. 2002) was connected to the antenna system and used to determine azimuths. Individual deer were monitored throughout the study unless unforeseen circumstances (e.g., mortality, malfunctioned transmitter) prevented monitoring of animals.

Seasonal ranges were determined using the home range (Rodgers and Carr 1998) and spatial movement (Hooge and Eichenlaub 2000) analysis extensions in ArcView (ESRI, Redlands, CA). Locations collected during periods of migration (i.e., spring and fall migration) were excluded from the analysis. Migration was considered as the temporary or permanent movement between non-overlapping seasonal ranges. Migration from summer to winter range was considered fall migration, and migration from winter to summer range was considered spring migration.

The harmonic mean measure of an animal's center of activity was used to determine the geographic center of the seasonal range (Dixon and Chapman 1980). This

point of greatest activity was calculated using the harmonic means of UTM easting and northings (Klaver 2001). Harmonic means were used because they are insensitive to an animal's location and can indicate shifts in the center of activity within the seasonal range (Dixon and Chapman 1980). Harmonic centers were only calculated for an individual deer with \geq 22 locations.

The fuzzy k-means classification program FuzME version 3.5 (University of Sydney Australian Centre for Precision Agriculture,

http://www.usyd.edu.au/su/agric/acpa/fkme/FkME.html) was used to group the harmonic centers of activity into subpopulations (McBratney and Moore 1985). Because fuzzy analysis requires specific parameters to function, a diagonal distance measure, the range of classes to be created, and a fuzziness exponent (φ) were identified using results from the FuzMe program. Diagonal distance transformation was used to compensate for variances among the measured variables used in classification (Odeh et al. 1992). This transformation prohibited UTM northings from dominating UTM eastings. To determine an optimal number of classes, validity functions including the fuzziness performance index (F') and normalized classification entropy (H') were plotted against the number of classes. The interception of the minimum of F' and H' were then evaluated to determine the number of classes for a seasonal range (McBratney and Moore 1985). To accurately reflect the degree of fuzziness of the classes, a level of φ was chosen to best represent the data. To do this, the partial derivative of group sum of squares (\mathbf{J}_m) was multiplied by the square root of the number of classes (c) (i.e., $[(-\delta \mathbf{J}_m/\delta \phi)c^{\frac{1}{2}}]$, or slope) and plotted against φ (Odeh et al .1992). The curve with the least maximum of slope was evaluated to

represent the best level of φ for the data set (Odeh et al. 1992). Through expert knowledge of the data, subjective judgments were used to determine the appropriate number of classes and level of φ through biologically sound evidence (Bosserman and Ragade 1982, McBratney and Moore 1985, Odeh et al. 1992).

RESULTS

During this study, 49 (47 adult, 2 fawn) female radiocollared deer were monitored at Redwood Falls and Walnut Grove (Figure 1) in southwest Minnesota during 3 consecutive seasons; winter 2002-03 (n = 41), summer 2003 (n = 39), and winter 2003-04 (n = 31). A total of 6,511 locations was collected with a mean 95% error ellipse of 4.6 ha.

Winter 2002-03

I calculated the harmonic mean of activity for female deer (n = 9) with ≥ 27 locations at Walnut Grove. Results of fuzzy classification revealed 4 classes using $\varphi = 2.0$ (Figures 14, 15). The plot of $(-\delta \mathbf{J}_m / \delta \varphi) c^{\frac{1}{2}}$ against φ indicated an optimum level of φ at 2.0. Plots of fuzziness performance index (F') and normalized classification entropy (H') against the number of classes revealed a local minima at 9 classes (Figure 14). After careful scrutiny of the resulting plots, 4 classes (Figure 14) were selected because this provided a more biologically correct distribution of the membership values. Thus, 2.0 and 4 were the best combination of φ and *c*, which was suggestive of the structure and continuity of the classification.

The harmonic mean of the distribution was calculated for female deer with \geq 22 locations at Redwood Falls. Results of fuzzy classification revealed 7 classes using

 $\varphi = 1.9$ (Figures 16, 17). The plot of $(-\delta \mathbf{J}_m / \delta \varphi) c^{\frac{1}{2}}$ against φ indicated an optimum level of φ at 1.9. Furthermore, plots of fuzziness performance index (F') and normalized classification entropy (H') against the number of classes indicated a local minima at 7 classes (Figure 16). Thus, 1.9 and 7 were the best combination of φ and *c*, which was suggestive of the natural groupings in the data set.

Summer 2003

We calculated the harmonic mean of the center of activity for female deer (n = 9) with ≥ 51 locations at Walnut Grove. Results of fuzzy classification revealed 3 classes using $\varphi = 2.4$ (Figures 18, 19). The plot of $(-\delta J_m/\delta \varphi)c^{\frac{1}{2}}$ against φ indicated an optimum level of φ at 2.4. Moreover, plots of fuzziness performance index (F') and normalized classification entropy (H') against the number of classes indicated 9 classes of deer (Figure 18). I chose to use 3 classes (Figure 18) because the first minimum indicated by the plots of F' and H' best represented the membership values. Thus, 2.4 and 3 were the best combination of φ and *c*, which was suggestive of the structure and continuity of the classification.

The harmonic mean was calculated for female deer (n = 30) using ≥ 33 locations at Redwood Falls. Results of fuzzy classification revealed 7 classes using $\varphi = 2.2$ (Figures 20, 21). The plot of $(-\delta J_m/\delta \varphi)c^{\frac{1}{2}}$ against φ indicated an optimum level of φ at 2.2. Furthermore, plots of fuzziness performance index (F') and normalized classification entropy (H') indicated an intersection at a least maximum at 7 classes (Figure 20). Thus, 2.2 and 7 were the best combination of φ and c, which was suggestive of the natural groupings in the data set.

Winter 2003-04

I calculated the harmonic mean of the center of activity for female deer (n = 6) with ≥ 27 locations at Walnut Grove. Results of fuzzy classification revealed 4 classes using $\varphi = 2.0$ (Figure 22, 23). The plot of $-\delta J_m/\delta \varphi]c^{\frac{1}{2}}$ against φ indicated an optimum level of φ at 2.0. Plots of fuzziness performance index (F') and normalized classification entropy (H') against the number of classes revealed a local minima at 6 classes (Figure 22). After evaluating the membership values, $\varphi = 2.0$ and 4 classes were chosen because these best represented the natural groupings in the data set.

The harmonic mean of the center of activity was calculated for female deer (n = 25) with ≥ 36 locations at Redwood Falls. Results of fuzzy classification revealed 8 classes using $\varphi = 1.8$ (Figure 24, 25). The plot of $[-\delta J_m/\delta \varphi]c^{\frac{1}{2}}$ against φ indicated an optimum level of φ at 1.8. Furthermore, plots of fuzziness performance index (F') and normalized classification entropy (H') against the number of classes indicated a local minima at 8 classes (Figure 24). Thus, 1.8 and 8 were the best combination of φ and c, which was suggestive of the natural groupings in the data set.

Subpopulation Clusters

Mean number of clusters that individual deer were associated to during winter 2002-03, summer 2003, and winter 2003-04 at Walnut Grove was 1.11 (SE = 0.11, n = 9), 1.22 (SE = 0.15, n = 9), and 1.17 (SE = 0.17, n = 6), respectively. Mean percentage of deer associated within their own subpopulation during winter 2002-03, summer 2003, and winter 2003-04 at Walnut Grove was 0.99 (SE = 0.02, n = 9), 0.89 (SE = 0.04, n = 9), and 0.97 (SE = 0.01, n = 6), respectively.

The mean number of clusters each deer was associated to during winter 2002-03, summer 2003, and winter 2003-04 at Redwood Falls was 1.44 (SE = 0.01, n = 32), 1.21 (SE = 0.05, n = 31), and 1.42 (SE = 0.13, n = 26), respectively. The mean percentage of deer associated within their own subpopulation during winter 2002-03, summer 2003, and winter 2003-04 at Redwood Falls was 0.79 (SE = 0.04, n = 32), 0.94 (SE = 0.02, n = 31), and 0.83 (SE = 0.04, n = 26), respectively. Any association less than P = 0.1 was considered to have occurred by chance and was not included in the mean percentage of deer associated.

DISCUSSION

One of the most fundamental issues in spatial analysis is spatial classification (Leung 1983). Traditional cluster analysis places objects into mutually exclusive classes with rigidly defined boundaries (Odeh et al. 1992). However, fuzzy classification is a more flexible and realistic representation of the imprecise and continuous nature of living systems. Fuzzy set theory produces a graded membership, whereby objects displaying continuous variation are placed into classes without defined boundaries (Schaefer and Wilson 2002). Because of the discontinuous nature of populations, fuzzy set theory can more realistically describe the spatiotemporal connectedness needed to delineate populations (Schaefer and Wilson 2002). Fuzzy cluster analysis provides insight into the ambiguity and vagueness of population substructure.

Fuzzy sets, which were first introduced by Zadeh (1965), provide means for dealing with the imprecise nature of ecosystems characterized by large, loosely organized objects (Bosserman and Ragade 1982, Equihua 1990). The use of fuzzy classification is advantageous over traditional clustering because it produces a graded membership of data and has computational simplicity (Marsili-Libelli 1989). Fuzzy cluster analysis can more realistically represent biological populations though fractal membership in multiple clusters (Schaefer and Wilson 2002). Because ecological communities rarely have defined boundaries (Bosserman and Ragade 1982), fuzzy cluster analysis better represents ecosystems than those based on hard partitions (Equihua 1990).

The degree to which animals associate may be related to density (Chapman and Chapman 2000), social structure (Berger 1979), abundance and distribution of resources (Bekoff 1972, Wilson 1975), behavioral patterns (Bronikowski and Altmann 1996), and environmental variation (Barros et al. 2000). Furthermore, association may vary with species, sex, and age and should be evaluated using all ecosystem variables.

Fuzzy cluster analysis was conducted by analyzing spatial affiliations during a specific season. Subpopulations were delineated and female deer associations were weighted using membership values. This resulted in the classification of various levels of association on winter and summer range.

The index to association indicated that individual deer at Redwood Falls were more associated with subpopulations other than their own during winters 2002-03 and 2003-04 than at Walnut Grove during the same period. Female deer at Redwood Falls were concentrated on winter range and utilized forested areas of riparian habitats that offered adequate forage and cover. Telfer (1968) described forested areas as "shelter-providing" cover types which deer prefer when snow is present. In Redwood Falls, the land cover is dominated by cultivated row-crop agriculture (i.e., 81.1%). However, there is 7.26% forest cover at Redwood Falls, mainly in the Minnesota River valley riparian habitat (Minnesota Department of Natural Resources 2000). Female deer concentrated in woody riparian habitats to conserve energy and maintain a positive energy balance during winter (Ozoga and Gysel 1972). Moreover, dense expansive tracts of woody cover provide security for deer to inhabit areas with intense human activity (Vogel 1983, Herriges 1986). Due to a lack of other quality habitats in the Redwood Falls study area, deer were less associated within their own subpopulation. Rather, deer were more likely to be associated with other subpopulations because of the high density of deer utilizing riparian habitats on winter range. Therefore, permit areas within the farmland region of Minnesota containing riparian habitats and dense forest cover may be more susceptible to CWD transmission because subpopulations of deer congregate in forested habitats during winter. Furthermore, transmission of CWD in permit areas containing riparian habitats and high amounts of forest cover may be similar to those of Wisconsin due to similarities in their landscapes.

Female deer at Walnut Grove were highly associated to deer within their subpopulation. Land cover in Walnut Grove was composed of 93.4% cultivated row-crop agriculture and only 1.76% forest cover (Minnesota Department of Natural Resources 2000), therefore, available habitats are smaller and result in deer being randomly distributed rather than congregated into one specific area (e.g., Redwood Falls study area). Deer occupied small patches of habitat usually in the form of small tree groves or creek drainages. These areas were not capable of supporting high densities of deer during winter. Therefore, my results indicated that deer were more associated within their own subpopulation at Walnut Grove due to differences in land cover type. Therefore, transmission of CWD in PAs containing high cultivated row-crop agriculture and minimal forest cover would be less than in regions similar to the Redwood Falls study site.

Association of individual deer within subpopulations was high during summer 2003 at Walnut Grove and Redwood Falls study areas. Similar to other studies, female deer were isolated prior to parturition and during fawning (Hawkins and Klimstra 1970, Nixon et al. 1992, Klaver et al. *in review*). Association with other deer was rare during this period. Beginning in mid summer, individual deer associations were mostly represented by matrilineal groupings (Nelson and Mech 1999) and spatial associations were attributable to kinship. Deer exhibited high site fidelity to summer range and were more widely distributed than during winter.

Throughout North America, wildlife managers are concerned with the spread of CWD. Williams et al. (2002) suggested that agencies should evaluate trends in prevalence and geographic distribution to limit the spread of CWD. Fuzzy classification may be an important tool to determine trends among subpopulations of deer and enable state agencies to manage deer densities at levels that decrease the risk of transmission. Because CWD is a contagious and self-sustaining disease in free-ranging deer populations (Miller et al. 1998, 2000), it is critical to prevent the transmission of CWD before the occurrence and distribution becomes too widespread to contain and future outbreaks become inevitable (Williams et al. 2002).

Most wildlife management agencies associated with known CWD positive herds, monitor deer populations through collection and testing of hunter-harvested or culled animals. Miller et al. (2000) suggested this method of surveillance allows for the detection of new cases of CWD. However, once an area has tested positive for CWD, wildlife managers must be able to evaluate deer populations to determine the level of culling required to prevent the transmission of the disease. Fuzzy classification generates theoretical hypotheses through empirical data. The classification of deer populations into subpopulations with weighted membership values provides information on how often subpopulations occur and their level of interaction. Therefore, fuzzy classification will provide wildlife managers with scientifically based justifications for decreasing deer populations to prevent the spread of CWD. **CHAPTER 4**

SURVIVAL OF WHITE-TAILED DEER NEONATES

IN SOUTHWEST MINNESOTA

INTRODUCTION

Understanding deer population dynamics requires knowledge of survival and mortality (DelGiudice et al. 2002). However, biologists are usually forced to make educated guesses pertaining to these parameters because empirical data is difficult and costly to collect (Porath 1980). Specifically, neonates (<1 month of age) rely on cryptic coloration and inactivity making capture to evaluate survival challenging. However, female behavior (Downing and McGinnes 1969, Huegal et al. 1985*a*) and vaginal-implant transmitters (Bowman and Jacobsen 1998, Carstensen et al. 2003) provide means for successful capture of neonate white-tailed deer.

Research on neonates provides information regarding reproduction, sex ratios, mortality, movements, and behavior (Downing and McGinnes 1969). Furthermore, knowledge of neonate mortality rates is critical to understanding how preseason mortality rates will affect deer harvest strategies (Porath 1980). Neonate white-tailed deer survival may be influenced by predation (Wells and Lehner 1978, Hamlin et al. 1984, Blanton and Hill 1989), disease (Schulz 1982, Brinkman et al. 2004*a*), condition of the dam (Porath 1980, Kunkel and Mech 1994), vegetative conditions (Porath 1980, Huegal et al. 1985*a*, Nelson and Woolf 1987), and maternal age (Ozoga and Verme 1986, Kunkel and Mech 1994).

The objective of this study was to determine cause-specific mortality and survival rates of neonate white-tailed deer in southwest Minnesota. Brinkman et al. (2004*b*) suggested that low predator densities, quality vegetation at birth sites, and high nutritional

condition of dams contribute to high neonate survival in southwest Minnesota.

Furthermore, Brinkman (2003) noted that neonate survival may be related to coyote density. Hence, I hypothesized that neonate white-tailed deer would have low survival at Redwood Falls relative to Brinkman's (2003) neonate survival of 84% at Lake Benton, Minnesota. Therefore, survival may be lower near Redwood Falls than at Lake Benton due to high predator densities, habitat differences, and changes in vegetation density.

METHODS

Neonates were captured and radiocollared in May and June 2003-04 during diurnal and nocturnal searches in Redwood and Renville counties, Minnesota (Figure 1). Vehicle searches with the aid of spotlights were conducted during nocturnal time periods using 2-person teams. Neonates were located by observing behavioral changes exhibited by postpartum does (Downing and McGinnes 1969, Huegal et al. 1985*a*). When a visual of a neonate occurred or if the dam's behavior was suspect, a fast, noisy, approach was made attempting to invoke a "drop" signal (Downing and McGinnes 1969). Neonates able to run were pursued on foot and captured with long-handled landing nets (Frabill Inc., Jackson, Wisconsin, USA). Ground searches were conducted and areas were systematically searched if an observed adult female remained in the vicinity of the area after being flushed or when adult females used vocalizations (e.g., snorting) indicating the presence of a neonate (Lund 1975). Additionally, random diurnal ground searches were conducted in probable fawning habitats using multiple-person crews. Crews walked potential fawning areas in a linearly spaced format looking for hiding neonates or solitary dams.

During the winter of 2003, adult female white-tailed deer were captured using helicopter net-guns (Barrett et al. 1982) and fitted with vaginal-implant transmitters (Advanced Telemetry System, Isanti, Minnesota USA) to aid in the capture of neonates. Captured adult female deer were injected intramuscularly with 5 mg/kg Ketamine and 1 mg/kg Xylazine prior to transport to processing site (Mech et al. 1985, Kreeger et al. 2002). Deer were radiocollared (Advanced Telemetry System, Isanti, Minnesota USA), aged, ear-tagged, measured (chest and neck circumference), and administered a broad spectrum antibiotic. Anesthesia was reversed by intravenous injection of 0.125 mg/kg of Yohimbine (Mech et al. 1985). Vaginal-implant transmitters had unique frequencies and were equipped with a temperature activated censor that doubled in pulse rate when expelled from the dam at parturition (Bowman and Jacobson 1998).

In 2003, vaginal implant transmitters (Advanced Telemetry System, Isanti, Minnesota USA) were used to locate neonates at birth sites of dams. Signals from vaginal-implant transmitters were intensively monitored three times daily (every 8 hours) beginning in mid-May to ensure the location of birth sites and neonates. When the temperature activated switch was activated by the expelled implant, using hand-held telemetry located the transmitter and secured the neonates for processing. If the neonates were not immediately located on the birth site, a 300-m radius area surrounding the vaginal-implant transmitter (Carstensen et al. 2003).

Captured neonates were handled for an average of 4.7 minutes, recording sex, age, and weight. Neonates were aged based on hoof growth measurements (Haugen and Speake 1958, Brinkman et al. 2004c) and umbilicus condition. Neonates were weighed

using a digital hanging scale (Extech Instruments, Melrose, Massachusetts USA); neonates were placed in a drawstring sac that had been stored in natural vegetation to reduce scent contamination. All field methods complied with animal care and use guidelines presented by the American Society of Mammalogists (1998) and the Institutional Animal Care and Use Committee (approval number: 02-A043) at South Dakota State University.

Neonates were fitted with radiocollars (Advanced Telemetry Systems, Isanti, Minnesota USA and Telonics Inc., Mesa, Arizona USA) designed to expand and breakaway after 6 months post-capture. Mortality was detected by a change in the pulse rate, which doubled when the collar remained still for >4 hours in 2003 and >8 hours in 2004. To reduce scent contamination, radiocollars were stored in natural vegetation commonly found in the habitats searched. Vinyl gloves were worn by all crew members involved with capture to minimize human scent at the processing site. A Global Positioning System (GPS, [Garmin International Inc., Olathe, Kansas, USA]) was used to mark the capture location.

Radiocollared neonates were monitored 2 to 3 times daily for 9 weeks post-capture. Neonates were then monitored for survival 3 to 4 times weekly or until the radio signal was no longer audible. Cause-specific mortality was assessed via evidence collected at the death site and field necropsy. Mortality was classified as predation based on evidence collected at the kill site (e.g., feces, tracks, bone fragments, bite marks on radiocollar, buried heads, and drag marks [White et al. 1987]). If sign indicated death by predation, these deaths were attributed to *Canid* predation including coyote (*Canis latrans*) and domestic dogs (*Canis familiaris*).

The Kaplan-Meier method (Kaplan and Meier 1958) modified for a staggered entry design (Pollock et al. 1989) was used to calculate monthly survival rates from June through August 2003-04. Neonates were censored from this study due to collar failure or if collars broke-away off neonates. Multiple neonates captured at the same birth site via vaginal-implant transmitters were considered to be independent in the survival analysis because neonates were usually located more than 0.4 km apart. Survival estimates were compared between year, sex, and month using Program CONTRAST (Hines and Sauer 1989); alpha was set at $P \le 0.05$. A Bonferroni correction factor was used to maintain alpha when multiple chi-squared tests were performed.

RESULTS

A total of 37 neonates (21 in 2003, 16 in 2004) was captured and radiocollared in Redwood and Renville counties, Minnesota (Appendix E, F). Neonates (11 male, 26 female) were captured between 20 May and 8 June 2003 and 2004. Of 34 (91%) neonates that remained still when approached, 22 (65%) were completely passive during handling. Three neonates (8%) required a chase before capture and 46% of males (n = 5) and 39% of females (n = 10) struggled during capture. The mean age of captured neonates was 4 days (SE = 0.3, range = 1 - 13 days). Back-dating to estimate birth dates indicated the mean date of birth was 24 May (SE = 1.0, range = May 8 – June 3) during both years. During this study, no capture-related mortalities were documented. A total of 14 vaginal-implant transmitters were placed in adult females during winter 2003. Seven implants were recovered at birth sites, leading to the capture of 2 sets of triplets, 3 sets of twins and 2 single neonates. The remaining 7 vaginal-implant transmitters were expelled prematurely to parturition (range = 28 March to 14 May). Vaginal-implant transmitters prematurely expelled from adult deer captured in January and February 2003 averaged 97 (range = 73 - 111) and 36 (range = 34 - 38) days of activity, respectively. Implants recovered at birth sites of adult deer captured in January and February 2003 averaged 162 (range = 159 - 164 days) and 124 (range = 121 - 129) days of activity, respectively.

A total of 19 neonates was captured using vehicle searches (2 daylight, 17 night); 5 via daylight-ground searches and 14 via vaginal-implant transmitters. In 2003, 197 search-hours (116 vehicle and ground, 81 vaginal-implant transmitters) and 304 man-hours (239 vehicle and ground, 81 vaginal-implant transmitter) were required to capture 21 neonates. In 2004, 156 vehicle and ground search-hours and 396 vehicle and ground man-hours were required to capture 16 neonates. An average of 5.8 search-hours was needed per neonate captured using vaginal-implant transmitters in 2003. An average of 13.2 vehicle and ground search-hours (16.6 in 2003, 9.75 in 2004) and 23.5 vehicle and ground search man-hours (22.3 in 2003, 24.75 in 2004) were required per neonate captured.

It was not possible to reliably differentiate between coyote and domestic dog predation. Thus, predation included those mortalities with evidence from coyote or domestic dog. *Canid* predation accounted for 100% (n = 10; Appendix G) of neonate

mortalities. For eight of 10 neonate mortalities due to *Canids* mean weight tended to be lower (3.19 kg) than the mean weight of surviving neonates (4.02 kg) at capture. Yet, neonates killed by predators did not differ significantly (t = 1.503, df = 8, P = 0.171) in weight at the time of capture relative to survivors. Nelson and Woolf (1987) suggested that neonates can escape predation when they are <2 weeks of age through cryptic coloration and inactivity and at >8 weeks of age, neonates can out run predators. However, neonates are vulnerable to predation during the transition period occurring between 2 and 8 weeks of age due to increased activity when catchable by predators (Nelson and Woolf 1987). In fact, in this study, six of the 10 mortalities occurred during this transition period as neonates where becoming more active.

During 2003, neonate survival after 1-month post-capture was 0.76 (SE = 0.03, n = 21) and was 0.67 (SE = 0.05, n = 14) after 3 months of monitoring (Table 5). During 2004, 5 neonates were censored due to collar failure or if collars broke-away off neonates. In 2004, survival rate was 0.88 (SE = 0.04, n = 16) after 1-month post-capture and 0.81 (SE = 0.06, n = 11) after 3 months of monitoring (Table 5). Pooled survival rate was 0.72 for June to August 2003-04 (Table 5). Survival was similar ($\chi^2_1 = 1.371$, P = 0.2417) between females (0.77; SE = 0.04, n = 26) and males (0.64; SE = 0.11, n = 11, [Table 6]). However, survival rates differed between months ($\chi^2_5 = 17.36$, P = 0.004) with survival lower ($\chi^2_1 = 4.844$, P = 0.028) in June 2003 than in June 2004, lower ($\chi^2_1 = 4.582$, P = 0.0323) in July 2003 than July 2004

DISCUSSION

Successful deer management requires knowledge of neonate mortality from birth to recruitment. Neonate mortality rates from this study (28%) were comparable to other studies conducted in the Midwest. Mortality rates 90 days postpartum in Missouri were 29% and 36% (Porath 1980), 15% on a refuge in southeast Minnesota (Schulz 1983), 30% in southern Illinois (Nelson and Woolf 1987), 27% in southern Iowa (Huegal et al. 1985*b*), and 16% in southwest Minnesota (Brinkman et al. 2004*b*).

Neonates are vulnerable to mortality during the "critical period" representing the first two months of life (Cook et al. 1971, Nelson and Woolf 1987). Therefore, monitoring was intense during the "critical period" and during the transition period (i.e., between 2 and 8 weeks of age), six mortalities occurred. Most mortalities (70%) in this study occurred within 30 days postpartum, with all mortalities attributable to *Canid* predation. Additionally, the remaining 30% of mortalities occurred before neonates were 8 weeks old and also were caused by *Canid* predation.

Neonates avoided predation <2 weeks postpartum by relying upon cryptic hiding behavior and inactivity, while neonates >8 weeks postpartum were likely too quick to be caught by predators (Nelson and Woolf 1987). Neonates are more active and observable during the transition period making them susceptible to predation (Nelson and Woolf 1987). Active neonates are more likely to wander and/or bleat resulting in exposure to predation (Cook et al. 1971). In fact, Benzon (1998) noted that male neonate survival was lower than female survival because males are more likely to run when approached by predators. However, in this study, no significant differences were detected between male and female neonate survival.

During years with below average precipitation, other food sources are less abundant and coyotes may spend more time actively searching for neonate white-tailed deer (Porath 1980). However, during years when precipitation is abundant, coyotes spend more time feeding on alternative food sources (Porath 1980). Neonates select bedsites in denser habitat than their surrounding areas providing maximum concealment cover to escape predation (Huegal et al. 1986). Therefore, because coyotes rely upon visual cues to locate prey (Wells and Lehner 1978), years with increased vegetation densities may have reduced predation during the first 30 days of life when neonates are inactive (Huegal et al. 1985b). Higher neonate survival during June and July 2004, may have been higher than June and July 2003, because May and June 2004 precipitation totals were 14 and 6 cm higher than precipitation totals in May and June 2003 (Minnesota Climatology Working Group 2004, [Table 5]), respectively. Consequently, because vegetation was sparser due to less precipitation neonates may have been easier to locate by predators during 2003. Additionally, neonates may have been more susceptible to death from predation due to increased coyote densities compared to the findings of Brinkman (2003). Coyote densities seemed higher at Redwood Falls than at Lake Benton (Brinkman 2003), due to abundance of coyote feces found near Redwood Falls, as well as sightings of multiple covotes per night during neonate capture.

Because southwest Minnesota contains less than 20% permanent cover composed of small patches of grassland and tree groves (Brinkman 2003) predators could actively search these islands of suitable fawning habitat with maximum success during 2003. Furthermore, coyotes are opportunistic predators and may have focused their efforts on searching for neonates due to a lack of other food sources. Nelson and Woolf (1987) suggested that neonates are vulnerable to predation when they inhabit summer ranges that provide the least vegetative cover.

In the Midwest, coyote predation is a major source of fawn mortality (Huegal et al. 1985*b*). Neonates born in a weakened condition may not survive even under the best range conditions (Cook et al. 1971); early postpartum mortality may be related to the condition of the dam (Porath 1980). Neonates that are malnourished, or have infections, or injuries, may be vulnerable to coyotes and other predators due to their weakened condition (Cook et al. 1971, Porath 1980). During this study, neonates killed by *Canid* predation had a mean weight that was 21% (0.84 kg) lower than surviving neonates at time of capture. Thus, neonates may have been in poorer condition than their surviving counterparts making them more susceptible to predation. Kunkel and Mech (1994) stated that lighter and weaker neonates were most often selected by predators whereas, heavier neonates were more likely to escape predation. Neonates that survived may have been born to older does that typically produce healthier and heavier offspring (Kunkel and Mech 1994).

Additionally, reasons as to why predator-killed neonates were more vulnerable to predation also may be related to maternal care (Ozoga and Verme 1986) and experience (Kunkel and Mech 1994). Subordinate does may be delegated to unsuitable fawning habitats (Ozoga et al. 1982) increasing the risk of death to neonates. However, minimal

postnatal losses occur to prime aged does that forcefully defend their fawning grounds and closely attend their young (Ozoga et al. 1982).

Use of vaginal-implant transmitters proved to be a valuable tool for locating neonates with minimal effort. Vaginal-implant transmitters enabled location of birth sites to radiocollar neonates independent of habitat characteristics (Bowman and Jacobson 1998). The required number of search-hours per neonate captured was approximately 2.3 times higher using vehicle and ground searches compared to vaginal-implant transmitters. However, the success rate during this study (50%) of using vaginal-implant transmitters to locate neonates on birth sites was lower than that reported by Carstensen et al. (2003) (89%). During this study, a lower success rate was likely attributable to premature expulsion of the vaginal-implant transmitter. Nevertheless, 68% of neonates captured during 2003 were a direct result of locating birth sites using vaginal-implant transmitters. Because of the intense monitoring schedule of the vaginal-implant transmitters, expelled vaginal-implant transmitters near peak fawning always resulted in capture. Although 50% of vaginal-implant transmitters were prematurely expelled, no instance of "signal flux" described by Carstensen et al. (2003) was observed during this study. However, signal strength of vaginal-implant transmitters decreased when monitored at a distance of 1.62 km or greater. Female reproductive success and survival was not affected by the use of vaginal-implant transmitters during this study. Furthermore, overall disturbance to the female was less than the repeated efforts required using vehicle and ground searches. Use of the vaginal-implant transmitters has not been perfected but is an important tool for biologists with limited time, funding, and search crews.

CHAPTER 5

MANAGEMENT IMPLICATIONS

In highly fragmented landscapes typical of southwest Minnesota, assessing the effects of seasonal movements, home ranges, and dispersal is fundamental to deer population management. Hence, data collected from this study along with those of Brinkman (2003) will be used to determine long-term trends, which can be incorporated into the MNDNR farmland deer harvest model. Historically, the farmland MNDNR deer model has lacked empirical data to support the management recommendations made by biologists in southwest Minnesota. Therefore, the primary objective of these studies was to improve deer management in this region based on scientific data rather than educated guesses.

Seasonal migration and dispersal of deer is common in northern regions due to intense agricultural activity (i.e., row-crop agriculture). Currently, movements of deer are not incorporated into the MNDNR farmland deer model and emigration/immigration is assumed to be equal between PAs (DePerno et al. 1999). Empirical data collected on deer movements during this study and Brinkman (2003) are imperative for better deer management.

In southwest Minnesota, Brinkman (2003) suggested that social pressures were the main reason for deer dispersal. Nelson and Mech (1992) stated that at low deer densities, dispersal is less likely to occur due to abundant habitat vacancies and that hunger, fatigue, forage preferences, and cover requirements interact to affect rate of dispersal. If deer in this study had essential food, habitat, and the ability to effectively thermoregulate, females would have high overall fitness and no need to disperse. Also, subordinate females may receive less pressure from adult deer to disperse because of abundant vacant habitat needed for fawning grounds.

During consecutive mild winters (2001-2003), less deer migrated to winter range. Thus, deer radiocollared in 2003 were more likely resident deer because of a lack of migratory individuals using the main wintering area. All resident deer used the main wintering area and hunters may have been more likely to harvest a resident deer in the main wintering area. Additionally, during consecutive mild winters, more resident deer may occur on the landscape resulting in fewer deer migrating across PA boundaries, which may influence success rates between PAs. The farmland deer harvest model may need to incorporate a stochastic factor that increases with each consecutive mild winter allowing for an increase in antlerless deer tags with each year a severe winter event does not occur. Additionally, depredation permits may need to be increased during severe winters in main wintering areas.

White-tailed deer migration between seasonal ranges was related to change in mean ambient temperatures and snow depth. Results related to winter severity from this study are comparable to Brinkman (2003). The same relationship was noticed during both spring and fall migrations. In the spring, mean ambient temperatures increased and snow depths decreased, which initiated migration to summer range. Likewise, decreasing mean ambient temperatures and increasing snow depths initiated deer migration to winter range. However, compared to Brinkman (2003) a 28.7% decrease in migratory deer and a 31.2% increase in resident deer was documented in response to the mild winters of 2002 and 2003, respectively. Managers may notice differences in hunter success rates
from PAs with a high number of animals on summer range during mild winters to PAs containing main wintering grounds during years with severe winters. Because seasonal migration between PAs is common, it is recommended that managers take winter severity and the timing of hunting seasons into account. For example, if hunters are having problems harvesting deer during severe winters, managers may want to open firearm season in mid October to allow animals to be harvested on summer range before migration takes place. Additionally, landowner access to main wintering areas may impact harvest during severe winters if permission is denied. Continued monitoring of trends in harvest and population size within and across PAs in relation to winter severity may be important to achieve harvest goals. Future research may need to include studies on male white-tailed deer to determine movements and dispersal rates across PA boundaries. Also, effects of crop harvest may need to be evaluated when determining post-season survival. During years with late crop harvest, deer may escape being harvested by hunters due to abundant cover provided by standing corn. Thus, in years following late crop harvest, more antlerless tags may need to be issued to maintain manageable deer densities.

In southwest Minnesota, intense cultivation, limited permanent cover, high hunter density, high road density, low predator density, and variable winter severity had the most impact on movement and mortality of deer (Brinkman 2003). Results from this study and Brinkman (2003), indicate that in highly fragmented landscapes dominated by row-crop agriculture, deer seek the highest quality areas that provide adequate food and cover during winter and the highest quality habitats providing for fawn rearing and survival during summer.

Understanding deer movements and associations during winter and summer in relation to land cover in a specific PA provides insight into the rate of potential disease transmission of CWD in a given permit area. For instance, deer that occupy habitats in farmland Minnesota that contain forest cover similar to the Redwood Falls study area would be more likely to spread CWD than habitats similar to the Walnut Grove study area. The increase in association of multiple subpopulations during winter in riparian habitats could result in a widespread transmission of the disease across the landscape. However, PAs dominated by patchy remnants of prairie and by intensive row-crop agriculture would be less likely to spread CWD because female deer are more closely associated with their own subpopulation during winter. Manipulating deer densities in PAs in the farmland Minnesota containing high amounts of forest cover might help to decrease the rate of transmission of CWD.

Fuzzy cluster analysis was helpful in determining the probability of CWD being transmitted within various densities of deer in and across different habitat types. Understanding the level of association in farmland Minnesota at current deer densities will enable the MNDNR to adjust future deer densities to decrease the frequency of association, thereby decreasing the risk for the spread of CWD. Long term studies should be continued to monitor movements of deer in the farmland Minnesota to provide empirical data related to deer subpopulation association within specific cover types. To prevent new occurrence of CWD, management of deer populations has been through generalized population reduction (Williams et al. 2002). However, manipulating deer densities may not be a "cure-all" to controlling CWD. Future studies should evaluate the role that dispersal has on subpopulation association. Furthermore, the role of winter severity, food, and available cover may be important when assessing the potential for subpopulation associations.

Identifying survival and cause specific mortality of neonate deer will improve the knowledge of deer population dynamics. Brinkman et al. (2004*b*) determined that 67% of all neonate mortalities were from predation. However, during this study, I documented a 33% increase in predation related mortality compared to his results. Therefore, predators are the major cause of mortality to neonate white-tailed deer in southwest Minnesota, especially in the more forested areas near Redwood Falls. Future regional studies of radiocollared neonates may improve the predictive capabilities of the MNDNR deer model and allow deer managers to accurately project the number of antlerless tags needed in a given PA. Furthermore, it may be beneficial to use spring precipitation levels as an index of neonate survival as it relates to predation.

Vaginal-implant transmitters are an effective tool used to locate birth sites and capture neonates. The decision to use vaginal-implant transmitters may be advantageous in areas of high deer fecundity, densely vegetated landscapes, and poor road networks where capture of neonates is difficult using vehicle searches. Areas with high fecundity may offer opportunity for multiple neonate captures per vaginal-implant transmitter. However, until the premature expulsion rate can be decreased and signal strength

improved, deer managers may need to use vaginal-implant transmitters on a site-specific basis. Increasing battery strength and extending the length of the wings on the vaginal-implant transmitters may make them more effective. Additionally, increasing the monitoring schedule to 4 or 5 times daily may increase the chances of capturing multiple neonates.

To improve the knowledge of deer managers in southwest Minnesota, the goal of this study was to collect empirical data regarding deer movement, association, and neonate survival. Long-term data collection of seasonal movements is necessary and would provide more insight into the role winter severity, land cover, and crop harvest have on deer movement. Furthermore, understanding deer movement through long-term studies will allow managers to estimate their level of risk of transmission of CWD. Also, future studies that monitor radiocollared neonates in different PAs would increase knowledge regarding deer recruitment and how it impact on deer density. Finally, deer researchers must be willing to adapt to new methods of analysis to be able to justify their need to harvest and cull deer populations if a transmissible and contagious disease are discovered.

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Permit Area	Cultivated	Grassland/shrub	Forest	Water	Wetland
424	86.93	4.73	2.22	1.76	1.36
425	92.53	2.74	1.61	0.14	0.40
426	85.00	4.68	2.98	3.49	1.56
427	87.80	4.42	2.59	1.62	1.22
431	75.50	8.45	2.75	5.51	3.36
433	67.74	15.72	4.73	4.75	2.88
435 ^a	82.30	6.72	7.26	0.98	0.41
440	85.85	3.54	6.77	0.76	0.34
442	92.37	1.91	3.05	0.73	0.49
443	81.01	4.27	9.17	1.28	0.27
446	79.88	13.08	2.84	0.56	0.95
447	90.93	3.69	2.22	0.36	0.62
448	94.29	3.92	0.52	0.65	0.17
449	84.29	8.81	2.82	0.91	0.56
452	84.86	11.46	1.14	0.22	0.04
450 ^a	93.41	2.41	1.76	0.54	0.23
451	81.05	14.61	1.48	0.53	0.21
453	88.24	6.39	1.15	1.21	0.39
454	85.58	7.41	2.42	1.93	0.50
455	82.99	9.94	1.54	3.03	1.17
456	85.92	6.05	2.28	2.64	0.91
457	88.12	4.98	2.79	1.16	0.43
458	88.07	4.00	2.44	2.65	0.38
459	89.67	3.10	3.44	0.93	0.75
Average	85.60	6.54	3.00	1.60	0.82

Table 1. Percentages of major land use/cover types of deer permit areas in southwest Minnesota, 2002-2004 (Minnesota Department of Natural Resources 2000).

^a Permit area selected as white-tailed deer study site.

Age Adult (>1 year) Fawn (~8 months)	Adult	Fawn	All Deer
Number of deer captured	15	2	17
Mean (SE) handling	16.9	35	19.1
time (Minutes)	(2.0)	(20.0)	(2.9)
Mean (SE)	0.8	1.6	0.9
distance ^a (km)	(0.1)	(1.1)	(0.1)
Mean (SE) Rectal temperature (C°)	39.5	39.4	39.1
	(0.18)	(0.25)	(0.17)
Mean (SE) neck	44.3	33.5	43.1
circumference (cm)	(1.3)	(0.5)	(1.4)
Mean (SE) chest	103.5	84.0	101.2
circumference (cm)	(1.3)	(4.0)	(2.0)

Table 2. Capture data for female white-tailed deer in Redwood Falls, Minnesota, January and February 2003.

^a Distance (km) between capture site and processing site.

	Redwood Falls	Walnut Grove	All Deer
2002 Winter Migration ^a (km), (<i>n</i> , SE)	14.0 (8, 2.2)	14.9 (5, 4.9)	14.4 (13, 2.2)
2003 Spring Migration ^a (km), (<i>n</i> , SE)	15.1 (12, 2.4)	15.4 (5, 4.3)	15.2 (17, 2.1)
2003 Winter Migration ^a (km), (<i>n</i> , SE)	14.4 (13, 2.1)	15.4 (4, 6.2)	14.6 (17, 2.1)
2004 Spring Migration ^a (km), (<i>n</i> , SE)	13.8 (7, 3.0)	12.8 (2, 4.5)	13.6 (9, 2.4)
Pooled Migration ^a (km), (n, SE)	14.4 (40, 1.2)	14.9 (16, 2.4)	14.6 (56, 1.1)

Table 3. Mean seasonal migration distance by study site for radiocollared white-tailed deer in southwest Minnesota, 2002-2004.

^a Distance of deer movement between winter and summer home ranges.

	Redwood Falls	Walnut Grove	All Sites
Winter 50%	0.59	0.86	0.65
(km ²), (<i>n</i> , SE)	(57, 0.07)	(15, 0.19)	(72, 0.07)
Winter 95%	3.01	4.44	3.31
(km ²), (<i>n</i> , SE)	(57, 0.32)	(15, 0.91)	(72, 0.32)
Summer 50%	0.45	0.77	0.52
(km ²), (<i>n</i> , SE)	(30, 0.09)	(9, 0.21)	(39, 0.09)
Summer 95%	2.03	4.38	2.57
(km ²), (<i>n</i> , SE)	(30, 0.37)	(9, 1.73)	(39, 0.50)

Table 4. Seasonal home range size by study site for radiocollared white-tailed deer in southwest Minnesota, 2002-2004.

* 2002 summer home ranges are not reported above and were determined by Brinkman (2003).

	2003			2004			Pooled 2003-04		
Month	June	July	August	June	July	August	June	July	August
Number at-risk	21	16	14	16	14	11	37	28	23
Number of deaths	5	2	0	2	1	0	7	3	0
Number censored	0	0	0	2	2	1	2	2	1
Survival rate	0.7619	0.6667	0.6667	0.8750	0.8125	0.8125	0.8108	0.7239	0.7239
Confidence interval (95%)	±0.0129	±0.0182	±0.0208	±0.0118	±0.0172	±0.0221	±0.0066	±0.0102	±0.0123
Variance	0.0066	0.0093	0.0106	0.0060	0.0088	0.0113	0.0034	0.0052	0.0063

Table 5. Monthly survival rates by years and pooled by year for radiocollared white-tailed deer neonates in southwest Minnesota, 2003-2004.

Female			Male			
Month	June	July	August	June	July	August
Number at-risk	26	22	19	11	8	7
Number of	4	2	0	3	1	0
Number censored	2	2	1	0	0	0
Survival rate	0.8462	0.7692	0.7692	0.7233	0.6364	0.6364
Confidence interval (95%)	±0.0082	±0.0123	±0.0133	±0.0257	±0.0361	±0.0411
Variance	0.0042	0.0063	0.0068	0.0131	0.0184	0.0210

Table 6. Monthly survival rates pooled across years by sex of radiocollared white-tailed deer neonates in southwest Minnesota, 2003-2004.



Figure 1. Study areas for white-tailed deer capture and monitoring in southwest Minnesota, 2002-2004.



Figure 2. Minnesota Department of Natural Resources permit areas in southwest Minnesota, 2002-2004.



Figure 3. Annual deer winter severity index (DWSI) for individual study sites in southwest Minnesota, 2002-2004. (One point accumulated for each day with an ambient temperature \leq -7 °C, and an additional point accumulated for each day with snow depths \geq 35.0 cm; Climatology Working Group 2004).



Figure 4. Monthly deer winter severity index (DWSI) for individual study sites in southwest Minnesota, 2002-2003. (One point accumulated for each day with an ambient temperature \leq -7 °C, and an additional point accumulated for each day with snow depths \geq 35.0 cm; Climatology Working Group 2004).



Figure 5. Monthly deer winter severity index (DWSI) for individual study sites in southwest Minnesota, 2003-2004. (One point accumulated for each day with an ambient temperature \leq -7 °C, and an additional point accumulated for each day with snow depths \geq 35.0 cm; Climatology Working Group 2004).



Figure 6. Fall migration event at Redwood Falls study site for radiocollared female white-tailed deer in southwest Minnesota, 2002. The Y-axis is shared by all three variables (i.e., temperature [°C], snow depth [cm], migratory deer [%]). A migration event represents the cumulative percentage of migrating individuals at each study site with known departure dates from summer range.



Figure 7. Fall migration event at Walnut Grove study site for radiocollared female whitetailed deer in southwest Minnesota, 2002. The Y-axis is shared by all three variables (i.e., temperature [°C], snow depth [cm], migratory deer [%]). A migration event represents the cumulative percentage of migrating individuals at each study site with known departure dates from summer range.



Figure 8. Spring migration events at Redwood Falls study site for radiocollared female white-tailed deer in southwest Minnesota, 2003. The Y-axis is shared by all three variables (i.e., temperature [°C], snow depth [cm], migratory deer [%]). A migration event represents the cumulative percentage of migrating individuals at each study site with known departure dates from winter range.



Figure 9. Spring migration events at Walnut Grove study site for radiocollared female white-tailed deer in southwest Minnesota, 2003. The Y-axis is shared by all three variables (i.e., temperature [°C], snow depth [cm], migratory deer [%]). A migration event represents the cumulative percentage of migrating individuals at each study site with known departure dates from winter range.


Figure 10. Fall migration events at Redwood Falls study site for radiocollared female white-tailed deer in southwest Minnesota, 2003. The Y-axis is shared by all three variables (i.e., temperature [°C], snow depth [cm], migratory deer [%]). A migration event represents the cumulative percentage of migrating individuals at each study site with known departure dates from summer range.



Figure 11. Fall migration events at Walnut Grove study site for radiocollared female white-tailed deer in southwest Minnesota, 2003. The Y-axis is shared by all three variables (i.e., temperature [°C], snow depth [cm], migratory deer [%]). A migration event represents the cumulative percentage of migrating individuals at each study site with known departure dates from summer range.



Figure 12. Spring migration events at Redwood Falls study site for radiocollared female white-tailed deer in southwest Minnesota, 2004. The Y-axis is shared by all three variables (i.e., temperature [°C], snow depth [cm], migratory deer [%]). A migration event represents the cumulative percentage of migrating individuals at each study site with known departure dates from winter range.



Figure 13. Spring migration events at Walnut Grove study site for radiocollared female white-tailed deer in southwest Minnesota, 2004. The Y-axis is shared by all three variables (i.e., temperature [°C], snow depth [cm], migratory deer [%]). A migration event represents the cumulative percentage of migrating individuals at each study site with known departure dates from winter range.



Figure 14. Relationship between fuzziness performance index, (F'), and normalized classification entropy (H') with phi = 2.0 for winter range, Walnut Grove, Minnesota, 2002-2003.



Figure 15. Classification of female white-tailed deer on winter range, Walnut Grove, Minnesota, 2002-2003. Pie charts are located at harmonic centers of winter range radio-relocations and divisions of pie charts indicate degree of membership for the 4 classes.



Figure 16. Relationship between fuzziness performance index, (F'), and normalized classification entropy (H') with phi = 1.9 for winter range, Redwood Falls, Minnesota, 2002-2003.



Figure 17. Classification of female white-tailed deer on winter range, Redwood Falls, Minnesota, 2002-2003. Pie charts are located at harmonic centers of summer range radio-relocations and divisions of pie charts indicate degree of membership for the 7 classes



Figure 18. Relationship between fuzziness performance index, (F'), and normalized classification entropy (H') with phi = 2.4 for summer range, Walnut Grove, Minnesota, 2003.



Figure 19. Classification of female white-tailed deer on summer range, Walnut Grove, Minnesota, 2003. Pie charts are located at harmonic centers of summer range radio-relocations and divisions of pie charts indicate degree of membership for the 3 classes.



Figure 20. Relationship between fuzziness performance index, (F'), and normalized classification entropy (H') with phi = 2.2 for summer range, Redwood Falls, Minnesota, 2003.



Figure 21. Classification of female white-tailed deer on summer range, Redwood Falls, Minnesota, 2003. Pie charts are located at harmonic centers of summer range radio-relocations and divisions of pie charts indicate degree of membership for the 7 classes.



Figure 22. Relationship between fuzziness performance index, (F'), and normalized classification entropy (H') with phi = 2.0 for winter range, Walnut Grove, Minnesota, 2003-2004.



Figure 23. Classification of female white-tailed deer on winter range, Walnut Grove, Minnesota, 2003-2004. Pie charts are located at harmonic centers of winter range radio-relocations and divisions of pie charts indicate degree of membership for the 4 classes.



Figure 24. Relationship between fuzziness performance index, (F'), and normalized classification entropy (H') with phi = 1.8 for winter range, Redwood Falls, Minnesota, 2003-2004.



Figure 25. Classification of female white-tailed deer on winter range, Redwood Falls, Minnesota, 2003-2004. Pie charts are located at harmonic centers of winter range radio-relocations and divisions of pie charts indicate degree of membership for the 8 classes.

Capture Date	Study Site	Age at Capture (fawn, adult)	Collar Frequency	Processing Time	Rectal Temp. C°	Neck Girth (cm)	Chest Girth (cm)	Transport Distance (km)
1/24/03	RF	F	242	15	40.3	33	80	2.68
1/24/03	RF	А	303	15	40.0	40	103	0.82
1/24/03	RF	А	281	12	40.3	42	102	0.32
1/24/03	RF	F	222	55	39.8	34	88	0.51
1/24/03	RF	А	262	29	39.8	45	106	0.21
1/24/03	RF	А	202	15	39.0	44	100	1.28
1/24/03	RF	А	183	5	41.3	48	111	0.40
1/24/03	RF	А	023	10	39.8	43	100	1.24
2/23/03	RF	А	043	20	39.6	42	104	0.52
2/23/03	RF	А	063	20	39.9	44	98	0.75
2/23/03	RF	А	082	21	39.6	54	111	1.23
2/23/03	RF	А	103	21	38.7	44	93	1.19
2/23/03	RF	А	142	12	38.6	42	108	1.28
2/23/03	RF	А	123	12	38.6	39	104	0.94
2/23/03	RF	А	163	35	38.7	53	102	0.82
2/23/03	RF	А	233	18	39.1	36	101	0.84
2/23/03	RF	А	288	9	39.6	49	110	0.91

Appendix A. Capture data for radiocollared female white-tailed deer in southwest Minnesota, January and February 2003.

Deer ID	Study Site	Fall Migration (km)
054	Redwood Falls	0.0
111	Redwood Falls	14.8
149B	Redwood Falls	0.0
391B	Redwood Falls	18.3
410	Redwood Falls	4.1
512B	Redwood Falls	
531	Redwood Falls	0.0
591	Redwood Falls	7.7
662	Redwood Falls	0.0
680B	Redwood Falls	0.0
689	Redwood Falls	22.0
702B	Redwood Falls	21.0
722	Redwood Falls	0.0
750	Redwood Falls	0.0
770B	Redwood Falls	0.0
782	Redwood Falls	
811	Redwood Falls	0.0
841	Redwood Falls	12.4
862B	Redwood Falls	
871B	Redwood Falls	11.5
091	Walnut Grove	14.8
210	Walnut Grove	
271	Walnut Grove	31.5
331	Walnut Grove	0.0
390	Walnut Grove	0.0
449	Walnut Grove	
571	Walnut Grove	0.0
622	Walnut Grove	7.9
653	Walnut Grove	17.5
710	Walnut Grove	0.0
741	Walnut Grove	0.0
890	Walnut Grove	

Appendix B. Movement for individual radiocollared female white-tailed deer in southwest Minnesota, 2002.

Blank cell represents "no data".

Deer ID	Study Site	Winter 50% Home Range (ha)	Winter 95% Home Range (ha)	Summer 50% Home Range (ha)	Summer 95% Home Range (ha)	Spring Migration (km)	Fall Movement (km)
023	RF	66.0	369.0	14.1	78.7	0.0	0.0
043	RF	23.6	120.9	44.5	506.3	0.0	0.0
054	RF	43.0	161.6	33.4	151.8	0.0	0.0
063	RF	174.0	787.0			10.4	15.0
082	RF	99.3	412.4	39.9	188.3	0.0	0.0
103	RF	103.2	381.8	78.6	274.4	0.0	0.0
111	RF	20.3	80.3	69.3	308.9	15.2	19.6
123	RF	191.6	1073.1	32.1	157.2	19.7	19.6
142	RF	86.3	395.7	63.0	251.4	0.0	0.0
149B	RF	16.1	87.5	46.1	191.4	0.0	0.0
163	RF	48.2	414.3			32.8	32.4
183	RF			103.3	509.3	7.9	7.7
202	RF	91.3	456.8	27.4	150.0	0.0	0.0
222	RF	52.4	311.5	77.6	404.0	0.0	
233	RF	84.7	476.0	29.4	118.7	13.1	13.0
242	RF	104.6	528.2	273.4	1107.7	3.2	3.9
262	RF	42.9	215.3	28.2	121.5	0.0	0.0
281	RF	31.5	146.4	11.2	42.2	0.0	0.0
288	RF	31.7	188.7	20.3	111.9	0.0	0.0
303	RF	32.9	147.5	29.3	144.4	0.0	11.6
391B	RF	69.3	352.9	31.3	151.8	18.2	18.0
410	RF			21.1	83.6	4.0	4.4
531	RF	38.8	195.0	16.3	77.3	0.0	
591	RF	321.5	1434.8			0.0	0.0
662	RF	50.6	255.4	33.7	149.7	0.0	
680B	RF	35.0	254.5			0.0	0.0
689	RF	21.0	107.0	20.6	150.5	22.0	21.6
702B	RF	56.1	253.2	17.3	82.9	21.1	
722	RF	37.1	190.0	14.4	14.4	0.0	0.0
750	RF	98.0	470.2	75.5	287.9	0.0	0.0
770B	RF	104.3	468.3	55.7	258.3	0.0	0.0

Appendix C. Movement for individual radiocollared female white-tailed deer in southwest Minnesota, 2003.

Deer ID	Study Site	Winter 50% Home Range (ha)	Winter 95% Home Range (ha)	Summer 50% Home Range (ha)	Summer 95% Home Range (ha)	Spring Migration (km)	Fall Movement (km)
782	RF						
811	RF	35 5	175 1	13.0	873	0.0	0.0
841	RF	45.5	301.0	9.7	72.0	0.0	11.0
871B	RF	34.0	205.2	25.3	308.7	12.5	13.0
091	WG	107.1	453.6	103.2	378.2	11.8	0.0
271	WG	240.9	1133.1	183.3	1725.9	31.6	31.8
331	WG	140.5	738.5	124.0	480.4		0.0
390	WG	123.8	1053.9	144.8	637.1	8.7	0.0
571	WG	36.7	205.2	18.1	96.4		3.3
622	WG	33.7	155.2	48.9	319.1	7.7	8.8
653	WG	50.8	361.5	19.4	96.8	17.1	17.3
710	WG	36.4	199.0	18.0	76.4		
741	WG	25.4	104.2	36.3	132.8		0.0

Appendix C. Continued.

^arepresents a deer captured during January or February 2003. ^bhome range calculated using locations gathered during winter season 2002-03. Blank cell represents "no data".

Deer ID	Study Site	Winter 50% Home Range	Winter 95% Home Range	Spring Migration (km)
023	Redwood Falls	34.6	156.1	0.0
043	Redwood Falls	23.1	139.7	0.0
054	Redwood Falls	31.5	160.0	0.0
063	Redwood Falls	90.6	467.1	0.0
082	Redwood Falls	81.6	548.7	0.0
103	Redwood Falls	64.8	274.5	0.0
111	Redwood Falls	17.1	83.3	15.4
123	Redwood Falls	36.5	249.7	0.0
142	Redwood Falls	37.3	214.3	0.0
149B	Redwood Falls	12.5	71.4	0.0
163	Redwood Falls	26.8	155.7	0.0
202	Redwood Falls	77.4	322.7	13.1
233	Redwood Falls	80.4	311.2	0.0
242	Redwood Falls	151.7	674.8	0.0
262	Redwood Falls	25.3	111.0	0.0
281	Redwood Falls	10.6	55.8	0.0
288	Redwood Falls	7.3	31.3	0.0
303	Redwood Falls	29.6	185.5	0.0
391B	Redwood Falls	47.5	266.8	18.4
410	Redwood Falls			4.1
591	Redwood Falls			
680B	Redwood Falls	37.8	268.4	0.0
689	Redwood Falls	31.6	168.9	22.8
722	Redwood Falls	45.9	194.0	0.0
750	Redwood Falls	49.5	276.8	2.1
811	Redwood Falls	38.3	277.5	0.0
841	Redwood Falls	39.9	206.0	0.0
091	Walnut Grove	83.8	342.9	0.0
331	Walnut Grove	236.2	888.7	0.0
390	Walnut Grove	31.8	225.0	0.0
622	Walnut Grove	103.3	591.0	8.3
653	Walnut Grove	15.7	95.2	17.3
741	Walnut Grove	29.0	122.3	0.0

Appendix D. Movement for individual radiocollared female white-tailed deer in southwest Minnesota, 2004.

^bhome range calculated using locations gathered during winter season 2003-04. Blank cell represents "no data".

Radiocollar Frequency	Date of Capture	Sex	Handling	Estimated Age
			Time (min.)	$(\pm 3 \text{ days})$
503	5/20/03	М	6	2
344	5/20/03	F	10	7
424	5/22/03	М	9	1
404	5/24/03	М	4	1
385	5/24/03	F	3	1
524	5/24/03	F	3	1
444	5/25/03	М	6	6
545	5/25/03	F	4	3
563	5/26/03	М	7	5
463	5/27/03	F	4	1
364	5/27/03	F	3	1
323	5/29/03	М	4	1
603	5/29/03	М	4	1
583	5/29/03	М	2	1
486	5/29/03	М	3	10
770	5/30/03	F	3	11
070	5/31/03	F	5	1
090	6/1/03	М	3	1
050	6/1/03	F	2	1
503B	6/3/03	F	3	1
020	6/3/03	F	4	1

Appendix E. Capture data for white-tailed deer neonates in southwest Minnesota, spring 2003.

Radiocollar Frequency	Date of Capture	Sex	Handling Time (min.)	Estimated Age (± 3 days)
634	5/21/04	М	6	13
334	5/26/04	F	6	35
455	5/28/04	F	3	11
516	5/28/04	F	4	4
594	5/28/04	F	7	6
573	5/29/04	F	3	5
494	5/30/04	F	6	9
435	5/30/04	F	6	2
375	5/31/04	F	5	8
414	5/31/04	F	7	10
395	6/1//04	F	4	8
534	6/1/04	F	4	8
553	6/3/04	F	5	5
920	6/3/04	F	3	1
634B	6/3/04	F	5	1
553B	6/8/04	F	6	6

Appendix F. Capture data for white-tailed deer neonates in southwest Minnesota, spring 2004.

Sex	Year	Capture Date	Cause of Mortality	Mortality date
Male	2003	5/20/03	Canid Predation	5/30/03
Female	2003	6/3/03	Canid Predation	6/6/03
Male	2003	5/22/03	Canid Predation	6/11/03
Female	2003	5/24/03	Canid Predation	6/18/03
Female	2003	6/1/03	Canid Predation	6/21/03
Female	2003	5/27/03	Canid Predation	7/18/03
Male	2003	5/29/03	Canid Predation	7/18/03
Male	2004	5/21/04	Canid Predation	5/28/04
Female	2004	6/3/04	Canid Predation	6/8/04
Female	2004	6/8/04	Canid Predation	7/30/04

Appendix G. Mortality of radiocollared white-tailed deer neonates in southwest Minnesota, summer 2003-04.