INVESTIGATION OF MOVEMENT DYNAMICS OF WILD DEER IN SOUTHEASTERN MINNESOTA TO UNDERSTAND POTENTIAL SPREAD OF CHRONIC WASTING DISEASE

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SUMMARY OF FINDINGS

In November 2016, the Minnesota Department of Natural Resources (MNDNR) discovered chronic wasting disease (CWD) in wild white-tailed deer (*Odocoileus virginianus*) in southeastern Minnesota. To date, 17 positive cases have been detected in 2 spatial clusters approximately 5 miles apart. The apparently early detection of CWD in wild deer motivated research to 1) understand potential pathways of CWD spread on the landscape by movement of deer, and 2) increase our likelihood of managing the outbreak in this and other areas of Minnesota. We received $449,557 through the Environment and Natural Resource Trust Fund (ENRTF)-Emerging Issues account (M.L. 2015, Chp. 76, Sec. 2, Subd. 10) - to initiate this investiagtion. In March 2018, we captured and collared 109 white-tailed deer (34 juvenile females, one adult female, 25 adult males, and 49 juvenile males) in southeastern Minnesota to initiate the study and better understand activity ranges and dispersal patterns of juvenile deer in and around our CWD Management Zone, called Deer Permit Area (DPA) 603. As of Aug 5 2018, 12 deer have slipped free of their collars and 10 have died, leaving 87 deer available for satellite tracking, which includes 30 juvenile females, one adult female, 19 adult males, and 37 juvenile males. Prior to the dispersal period between April and July 2018, we estimated the average winter home range size as 1.60 km^2 for juvenile females, 2.96 km^2 for adult males, and 2.28 km^2 for juvenile males. Preliminary assessment of dispersal suggests that dispersal probability of juvenile females (40%, n=20) was slightly greater than juvenile males (28%, n=28) in spring 2018, although this difference was not statistically significant (p = 0.41). The average apparent dispersal distance travelled was 30.4 km (n=8) and 14.6 km (n=8) for juvenile females and juvenile males, respectively. Although sample sizes for apparent dispersing animals was small (n=16), more formal analyses of spring dispersal is pending. These valuable data will be informative for understanding potential CWD spread in wild deer in southeastern Minnesota and enable MNDNR to adjust surveillance and management activities more effectively to counter CWD in southeast Minnesota.

INTRODUCTION

Chronic wasting disease (CWD) is a fatal infectious disease first characterized in the late 1960s in Colorado that affects elk *(Cervus canadensis)*, mule deer *(O. hemionus)*, white-tailed deer, reindeer (*Rangifer tarandus*) and moose *(Alces alces)*. It has been detected in wild and captive cervids in 25 states and 2 Canadian provinces in North America, as well as Finland, Norway, and South Korea. Recent work has demonstrated that CWD can cause population declines in deer in the western US, particularly at high prevalence levels in a population (Edmunds et al .2016). In the upper Midwestern US, an ongoing study of CWD in white-tailed deer in Wisconsin has shown that CWD-infected deer die at 3x the rate of uninfected deer (Wisconsin Public Radio, 2018). In the same CWD system, research has shown that deer regularly die from CWD in the wild, although they typically go undetected by people (Samuel and Storm

2016).

During the regular hunting season in 2016, MNDNR detected 3 wild white-tailed deer with CWD in Fillmore County, Minnesota, and established a disease management zone (forming deer permit area 603) approximately 10 miles in radius around the positive detections. Further sampling of wild deer through March 2017 resulted in a total of 11 positives found in two spatial clusters approximately 5 miles apart (Figure 1). Additional sampling during the 2017 regular and special hunting seasons resulted in an additional 6 CWD cases detected in DPA 603 with a new apparent cluster in ForestvilleMystery Cave State Park (Figure 1). It is not clear how CWD was introduced into the area, but potential routes of introduction include movement of infectious deer from neighboring states (e.g., Wisconsin, Iowa, or Illinois), contact between wild deer and prior CWD-positive captive cervid facilities (e.g., Pine Island, MN), or contamination of the environment with infectious cervid carcass material facilitated by out-of-state hunters disposing of butchering remains on their property. In June 2017, the MNDNR was made aware of available funding in the emerging issues account of the Environment and Natural Resources Trust Fund (ENRTF) managed by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). We applied for and received funding (M.L. 2015, Chp. 76, Sec. 2, Subd. 10) which allowed us to execute a research project to 1) understand potential pathways of CWD spread on the Minnesota landscape mediated by movements of wild deer, 2) increase the likelihood of success of managing the CWD outbreak in this and other areas of the state, and 3) quantify sources of mortality for deer in southeast Minnesota and incorporate survivorship estimates into population models. This study aims to better understand deer movement ecology as it relates to potential prion transmission in southeastern Minnesota in and around the newly established CWD management zone, DPA 603. The apparent sample prevalence of CWD in DPA 603 through fall 2017 sampling was 0.4%, which suggests we have discovered the disease in the early stage of the outbreak. This timing offers the best chance of mitigating disease spread and optimizing surveillance and management actions. A growing body of research suggests that in the long-term, CWD causes deer population decline (Monello et al. 2014, Edmunds et al. 2016) and has the potential to cross species barriers (Waddell et al. 2018).

As infected and non-infected deer interact and move across the landscape, they transmit infectious prions through direct contact with other deer or indirectly through environmental deposition (Almberg et al. 2011). Limited information exists about deer contact rates and their relationship to transmission rates, especially in areas recently infected. The presumed main driver of spatial spread among wild deer are natural movements. Currently, there is no research that demonstrates the extent to which potentially infected deer move across the landscape and interact with each other in southeastern Minnesota.

Deer behavior and movements vary by biological and environmental conditions, along with deer population demographics and social structure. Two types of movement likely facilitate disease spread across the landscape, recurrent seasonal movements and one-time dispersal or foray events. The most substantial long-distance movements involve dispersal from birth to adult ranges, most likely to occur in 1-year-old deer. Because deer densities and movement behavior can be altered by management actions, a better understanding of both deer density and movement tendencies related to density will enhance our ability to effectively manage disease risk in the Minnesota deer population. The importance of this research is underscored by the increased risk of disease spread from Wisconsin and Iowa, and our findings will help the MNDNR understand those risk factors as well.

METHODS

Study Area

The study area, approximately 7,250 km^2, is centered on DPA 603, also referred to as the CWD management zone, in Fillmore County, Minnesota (Figure 2). The study area limits are flexible and have been established as approximately a 20 mile buffer outside and including DPA 603. We need extensive area around DPA 603 to capture and release GPS-collared deer, so that our collared sample is representative of the deer population inside and surrounding the CWD management zone in southeastern Minnesota. Since some deer were collared inside and may move through DPA 603, we expect some study animals to be exposed to higher harvest pressure during hunting seasons. This tradeoff is necessary, however, to gain understanding of how deer move through the DPA 603 landscape and for estimating survivorship in areas with liberal hunting regulations.

The study area is composed of a matrix of agricultural lands interspersed with deciduous forest upon a landscape of rolling hills and in some cases very steep ridges and valleys. There is considerable heterogeneity in landscape topography and land use, particularly as one moves from east to west. The eastern part of the study area is composed of forested blufflands and steep ridges and moving west and south, the landscape transitions to be flat and dominated by agriculture. More than 90% of the landscape is held in private ownership, and there is significant heterogeneity in deer density due to both habitat heterogeneity and localized refugia.

Since most of the region is in private ownership, our initial efforts focused on securing permission to access private property in the study for our deer capture and collaring efforts. We secured permissions to use 105,473 acres of property, consisting of private (67,924 ac) and public (37,549 ac) lands, for search and capture of white-tailed deer in southeastern Minnesota (Figure 3). We could not have achieved our sampling goals without the enormous outpouring of support from private landowners in the study area (>200). Public properties included state wildlife management areas, state forests, and state natural areas. We do not have a limit on acquiring available properties for future deer capture, and hope to add to our land permission list with time. We focused on properties that are forested (where deer may be flushed) with adjacent open fields (where deer may be captured and a helicopter may safely land).

Sampling Design and Data Collection

Given the breadth of the study area, we divided it into 10 quadrants (Figure 3) from which we established a baseline target goal of capturing 6 juvenile males (≈ 7-9 months old), 3 juvenile females (≈ 7-9 months old), and 2-3 adult males (> 2.5 years old) per quadrant. In total, our intent was to capture and collar 115 deer in the first year of this study; 60 juvenile males, 30 juvenile females, and 25 adult males. For years 2 and 3, we plan to capture and collar an additional approximately 60 juvenile male deer (6 per quadrant). We did not collect biopsy tissue for CWD sampling at the time of capture, but plan to collect retropharyngeal lymph nodes for CWD testing at the time of death for all recovered carcasses.

We contracted with Hells Canyon Helicopter Company (Clarkston, WA) to capture deer by net-gunning from a R44 Raven 2 helicopter. Deer handling consisted of collar placement, collection of auxiliary measurements (body temperature, age class, sex, and body condition), blood sampling for serological screening of diseases, and an ear punch for genetic analysis. Average handling time was approximately the same across all sex and age groups at 13.1 minutes.

Deployed GPS collars (Irridium TL330, Lotek Wireless Inc, Newmarket, Canada) were programmed to collect location coordinates primarily during spring dispersal, fall dispersal, and rut periods. The rate of GPS location fixes was approximately once per hour for the following age-sex cohorts and time periods: all juvenile deer between April 1 and July 15 and September 1 through November 30; and adult males between September 1 and December 31. During all other time periods, collars were scheduled to collect positional data every 2 hours or 12 locations per day. We chose these periods in part based on seasonal movements recorded from yearling males in Wisconsin. To ensure that location data were collected across the entire

24-hour day distribution instead of fixed times per day, we programmed collar GPS fixes on a staggered data collection schedule which changes every day.

All GPS collars housed identical hardware for communication with satellites, carried at the bottom of the collar, underneath the deer's neck. The only difference between collar types consisted of the type of expansion mechanism which allowed the necks of individuals to change in size over time. Specifically, juvenile female collars did not have an expansion mechanism and consisted of a complete loop of inelastic leather as female neck size does not vary appreciably after maturity. On the other hand, the necks of juvenile males expand because of growth associated with aging and seasonal reproductive changes. During the reproductive period (i.e., rut), the necks of male deer expand substantially, and following this period they contract again. Similar dynamics occur in adult male deer. To accommodate the expansion and contraction of neck size depending on season, we fitted our juvenile male deer with a collar that contained an elastic band permitting expansion and contraction. For adult males, we used a magnetic expansion mechanism on collars to accommodate seasonal neck growth and contraction dynamics.

Data Analysis

Objective 1: Document dispersal patterns and estimate movements of juvenile (1-year-old) males and females, and adult males (>2 year old)

Generally, we will follow methods from Kenward et al. (2001), Long et al. (2005), Lutz et al. (2015, 2016), and Peterson et al. (2017). For juveniles, we define dispersal as having occurred if an individual displayed a permanent, 1-way movement from a natal range to a distinct adult range (Kenward et al. 2001, 2002), such that pre-dispersal locations do not overlap post-dispersal locations (Long et al. 2005, Lutz et al. 2015). We will estimate natal and adult home ranges using minimum convex polygons (MCP). We will assume that we captured juveniles on their natal range and model the probability of dispersal from natal to adult range using time-to-event models (Walsh et al. 2015). We will designate the date of dispersal as the first date a location was recorded outside the natal range. These methods accommodate uncertainty in dispersal specification (Walsh et al. 2018). For deer in which we have insufficient location data suggesting dispersal based on Kenward et al. (2001) methods, we will assign a probability that a dispersal event occurred on a case-by-case basis. We will calculate dispersal distance as the straight-line distance between the median *x* and *y* natal range coordinates and the median *x* and *y* adult coordinates (Kenward et al. 2002). We will designate a dispersal location as the first dispersal location when all subsequent locations do not occur within an MCP containing all previous locations. Similarly, the last location of a dispersal path will be determined by when it was the last location not contained within a natal MCP. We will map dispersal path movements by beginning at the edge of the natal range nearest the first dispersal location and ending at the edge of the adult range nearest the last dispersal location (Karns et al. 2011). We will perform all spatial data analysis using R software and ArcMap 10.2.2 (Environmental Systems Research Institute, Redlands, CA, USA).

We will calculate the direction of dispersal as the azimuth measurement from true north between the median *x* and *y* natal range coordinates and the median *x* and *y* adult range coordinates. We will use Rao's spacing test (Batschelet 1981) to test for a directional trend in dispersal direction and correlate trends with the orientation of topographical features (e.g., ridges, valleys). We will use Greenwood and Durand's *V* test to determine if there is a relationship between dispersal directions and mean axial orientation of topographic landscape features. We will estimate dispersal path distance as the sum of distances between the nearest edge of the natal MCP to the first location of the dispersal event, subsequent points of the dispersal event, and the nearest edge of the adult MCP to the last point of the dispersal event.

However, we will consider only sequential movements >250 m (i.e., we retained only the first location of closely spaced sequential locations) to minimize the influence of high location frequencies (Long et al. 2010). We will classify a movement as a foray (or excursion event) if it was a movement >1.5 km from the edge of the natal MCP with a subsequent return to the natal MCP and designate the foray date as the first date a foray location is recorded outside the natal range. We will estimate the distance of a foray as the straight-line distance between the farthest foray location out of the natal range and the nearest edge of the natal range. Likewise, we will estimate foray path distance as the sum of distances between the nearest edge of the natal MCP to the first location of the foray, subsequent locations of the foray event, and the nearest edge of the natal MCP to the last location of the foray before the animal returned to the natal MCP. We will examine seasonal differences in the direction and distance of foray and dispersal movements with linear mixed models assigning direction and distance as continuous response variables; season, sex, natal range deer density, and mean percent forest cover along the linear dispersal path (from National Land Cover Database) as fixed effects; and each deer as a random effect.

For adult males, we will assume animals are already within their adult range and use minimum convex polygons (MCP) to estimate this range. Foray events will be calculated as described for juveniles and we will examine seasonal differences in the direction and distance of foray movements with linear mixed models assigning direction and distance as continuous response variables, season as a fixed effect, and each deer as a random effect.

Following Long et al. (2010), we will consider potential barriers to dispersal to be highways (e.g., interstate highways, U.S. routes, state routes), dense residential or developed areas (as delineated on U.S. Geological Survey 7.5-minute Quadrangle topography maps and confirmed via aerial photographs), and large rivers.

Objective 2: CWD spatial pathways mapping to inform future surveillance and management

Using results from analysis of objective 1, we will map MCPs from collared animals onto GIS layers containing the landcover types and major topographical features (e.g., ridge lines, interstates, large cities, etc.). We will identify movement corridors by examining trends in dispersal path directions and distance by sex. Using Greenwood and Durand's *V* test to determine if there is a relationship between mean dispersal directions and mean axial orientation of topographic landscape features, we will also characterize the distribution of dispersal distances and directions by sex. This initial effort will entail qualitative spatial pathway risk mapping based on inferences from objective 1. Future work to further characterize spatial pathways of likely CWD spread will entail application and extension of methodology presented in Hefley et al. (2017), which uses a spatio-temporal partial differential equation.

Objective 3: Determination of cause-specific mortality

Each GPS collared deer is designed to transmit a mortality text and email message signaled by a 12-hour window of inactivity. To adhere to the current harvest-based deer population model used by MNDNR, we will attempt to verify cause of death as hunting or non-hunting within 48 hours of deer mortalities by searching for a carcass at the collar location. Although current models used by MNDNR only require these broad categories, we will record additional details about cause-of-death (e.g., deer-vehicle collision, poaching, depredation, and starvation). Collared deer will not be protected from legal harvest during hunting seasons, and we will request via press release that hunters select animals for harvest based on their personal preference regardless of whether the hunter notices a collar on the deer. We will ask hunters that harvested a collared deer to contact DNR and return the collar, as there is valuable GPS location and activity data stored on-board devices. While we receive GPS locations via a web service, there is potentially additional location data stored in memory, which is invaluable for our movement analyses. In addition, the activity data consists of a numeric index indicating the relative level of movement the collar experienced every 5 minutes, and this can be used as a proxy for relative levels of deer activity. For estimation of cause-specific mortality, we will use the Bayesian hierarchical modeling approach outlined in Walsh et al. (2018). We will estimate the instantaneous hazard h(t) using a conditional survival function (Kalbfleisch and Prentice 2002) using time to death (T_i), time of entry (e_i), time the subject was last known alive (r_i), and the time the subject was first encountered dead (s_i) for each deer classified according to sex and age. We will then assign a probability the fate was associated with a specific cause based on field investigations (Walsh et al. 2015). We will evaluate the best fitting model using deviance information criterion (DIC), and consider model averaging for estimating age, sex, and mortality source survival probabilities.

RESULTS AND DISCUSSION

From March 18-23, 2018, we captured 111 white-tailed deer in our study area (Figure 4). Of these 111 - one juvenile male was able to kick off its collar twice and escaped without being re-collared, and 1 adult male accidentally broke its neck upon being captured. Of the 109 deer captured with successfully deployed collars, 3 animals (2 juvenile males and 1 adult male) were able to kick their collars off within the first week, reducing our sample size to 106. Of these 106 remaining collared deer, 10 additional deer had died by August 10, 2018. Nine of these mortalities occurred before April 10, 2018 and appear to be related to some extent to capture based on necropsy results (such as capture myopathy, n=5), although coyote predation (n=2), suspected vehicle collision (n=1), and suspected disease (n=1) also played a role. Due to structural failures of the expansion mechanism, we have lost 9 additional juvenile male collars leaving 87 GPS-collared deer available including 30 juvenile females, 1 adult female, 19 adult males, and 37 juvenile males. We have established databases for capturing updated movement and mortalities, and are monitoring all GPS-collared animals daily.

As of August 10, 2018, we have amassed over 120,000 records of deer location data. Prior to the dispersal period between April and July 2018, we estimated the average winter home range size as 1.60 km^2 for juvenile females, 2.96 km^2 for adult males, and 2.28 km^2 for juvenile males (Table 1). These winter home range estimates align with our expectations of deer activity at this time of year. Contrary to our expectations, juvenile female deer had higher apparent dispersal probability (40%, n=20) than juvenile males (28%, n=28) in spring 2018, although this difference was not statistically significant (p = 0.41). The average apparent dispersal distance travelled was 30.4 km (n=8) and 14.6 km (n=8) for juvenile females and juvenile males, respectively (Table 1). Although sample sizes for apparent dispersing animals was small (n=16), more formal analyses of spring dispersal is pending. The data also suggests that only 17% of our adult male sample underwent appreciable foray movements (n=2).

We found that as many as 7 deer have traveled to and from Iowa, and it's not clear yet if they have established an adult range in that state. Of these 7 deer, they include 3 juvenile males, 1 juvenile female, and 3 adult males. We do not yet have sufficient mortality data to estimate cause-specific mortality, and we expect that upcoming hunting season mortalities will be able to inform this analysis.

While juvenile male dispersal is typically regarded as the primary force driving potential disease spread (CWD) on the landscape (Grear et al 2006, Oyer et al. 2007), evidence suggests that females orphaned at a young age (Etter et al. 1995) or high underlying deer density (Lutz et al. 2015) can drive juvenile females to disperse. Given the relatively high rate and extent of juvenile female dispersal and high deer densities in the farmland-forest transition zone of our study area (Norton and Giudice 2017), we hypothesize that this phenomenon is playing out in southeastern Minnesota. This highly productive landscape favors high deer survival and fecundity, given extensive food resources, winter cover, and relatively mild winters. Future capture and GPS collaring efforts in the study area should include representative cohorts of juvenile female and male deer to monitor the rate and extent of dispersal movements, as it relates to potential spread of CWD prions on the Minnesota landscape.

We made considerable efforts to provide outreach materials both for landowners that have provided us with permission to use their properties for deer capture and for the general public. We have established a structure to contact participating landowners quarterly with map updates on all of the collared deer in the study, and provide big picture messages about periodic study findings and expectations for future work. Similarly, we have created a website dedicated to this research project at https://www.dnr.state.mn.us/cwd/deer-movement-study.html. This site provides information about the purposes of the study, periodic updated findings, and information about how readers can assist and contribute to our efforts. We encourage the public to provide us with trail camera photos of collared deer they may encounter, and with their permission, we make these pictures available on our website. There have also been over a dozen popular press articles covering this study in various media outlets. We seek to continually improve how we communicate science to the public, and provide transparency in all of the work that we conduct.

Future Capture and GPS-Collaring Efforts

Between January and February 2019, we plan to capture and GPS-collar approximately 60 juvenile white-tailed deer in the study area to maintain a sample size of about 100 deer for location monitoring at any given time. The exact distribution of juvenile male and female deer for capture has not been decided upon yet, but we expect to conduct capture and collaring operations for at least an additional 2 years in the study area.

ACKNOWLEDGMENTS

We extend warm thanks to all of the participating landowners in southeastern Minnesota that gave us permission to access and conduct capture operations on their properties. We thank all the MNDNR Wildlife and Enforcement staff, who assisted in contacting landowners and fielding questions about the study to the public including Don Ramsden, Mike Tenney, and Mitch Boyum. Special thanks to Jason Jensen for flying our spotter aircraft during capture operations; John Giudice for flying in the spotter aircraft as an observer; Julie Hines and Bob Wright for their great work assisting us with our GIS mapping needs; Mike Kallok, Chris Scharenbroich, and Pete Takash for their efforts with setting up a webpage dedicated to this project on the DNR website; Larissa Minicucci for being available for darting efforts had we needed them; Rushford Municipal Airport (Airport Manager Mike Thurn) and Fillmore County Airport (Airport Manager Isaac Deters) in Preston, Minnesota for use of their facilities; Jamie Gangaware, Louise Spiczka, Dan Stark, John Wollenberg, Scott Noland, and Marshall Deters for their willingness to assist as aircraft observers. We appreciate the continued support and assistance of the USDA-Wildlife Services disease biologist Tim White. Without the support of these and many more people behind the scenes, this project would not be possible. We also thank LCCMR – the Environment and Natural Resource Trust Fund (ENRTF) - Emerging Issues account (M.L. 2015, Chp. 76, Sec. 2, Subd. 10) that we received grant funding from providing the needed funds to get this project off the ground. Additional funding was provided in part by the Wildlife Restoration (Pittman-Robertson) Program.

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Table 1. Preliminary mean estimate (and 95% confidence interval) of winter home range (HR - km^2), apparent spring dispersal probability (Pr. Dispersal), and apparent spring dispersal distance (Distance – km) of white-tailed in southeastern Minnesota collared in March 2018. The distance estimates do not account for non-linear pathways traveled, forward and backwards movements along pathways, and only describe straight-line distances. Please note the differences in sample sizes used in the analysis of winter home range (n-HR) and apparent dispersal (n-Dispersal).

Cohort	n-HR	HR (95% C.I.)	n-Dispersal	Pr. Dispersal (95% C.I.)	Distance (95% C.I.)
Juvenile Female	31	1.60 (1.19, 2.00)	20	0.40 (0.20, 0.64)	30.42 (1.35, 52.40)
Juvenile Male	39	2.28 (1.65, 2.91)	29	0.28 (0.13, 0.47)	14.65 (7.64, 19.60)
Adult Male	18	2.96 (2.12, 3.79)	12	0.17 (0.03, 0.49)	18.90 (8.80, 29.00)
TOTAL	88		61		

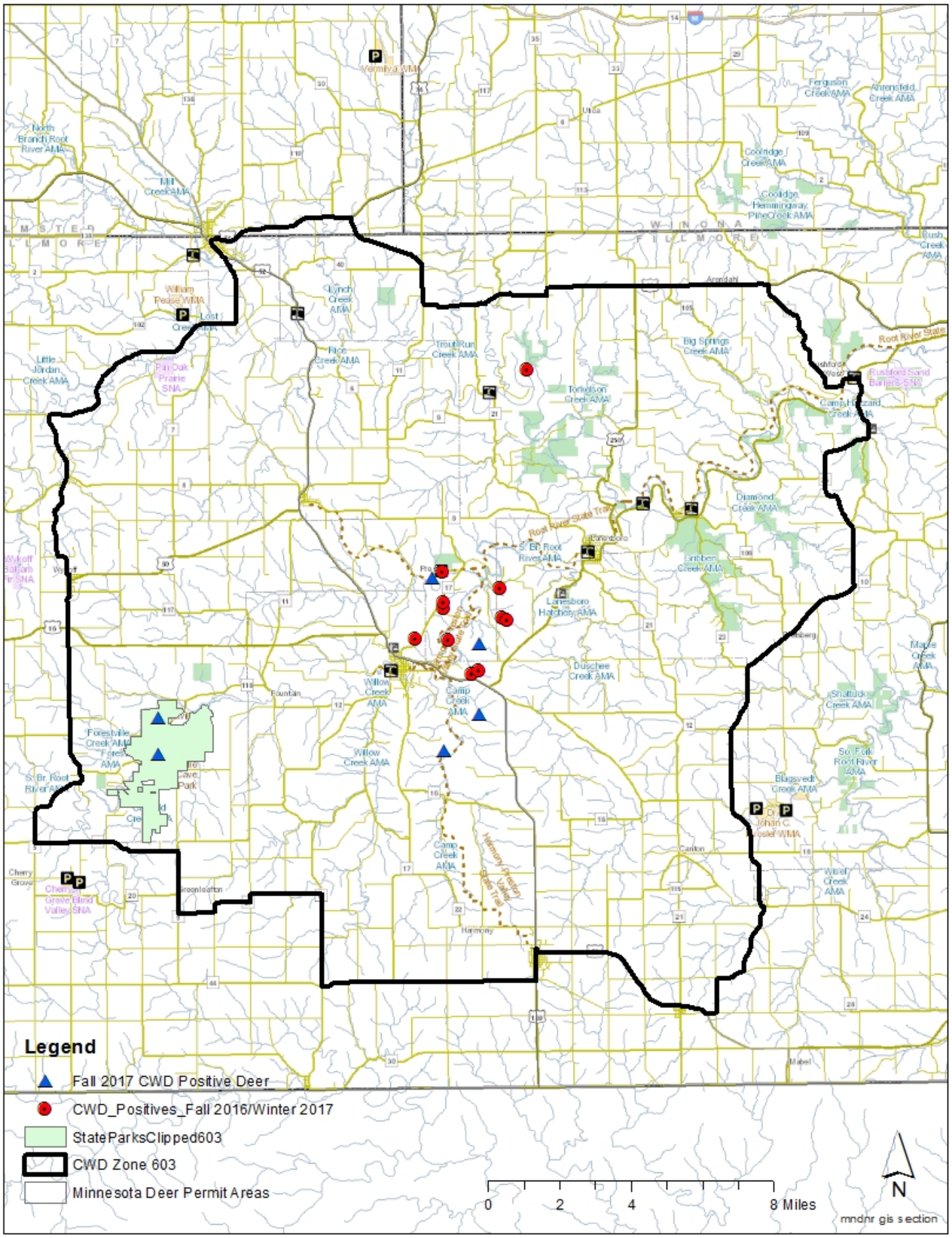

Figure 1. Spatial distribution of wild white-tailed deer confirmed with CWD infection in DPA 603 in Minnesota as of 08/10/18. In the 2016-17 season, there were 11 confirmed detections, and in 2017-18 there were an additional 6 confirmed detections.

Study Area

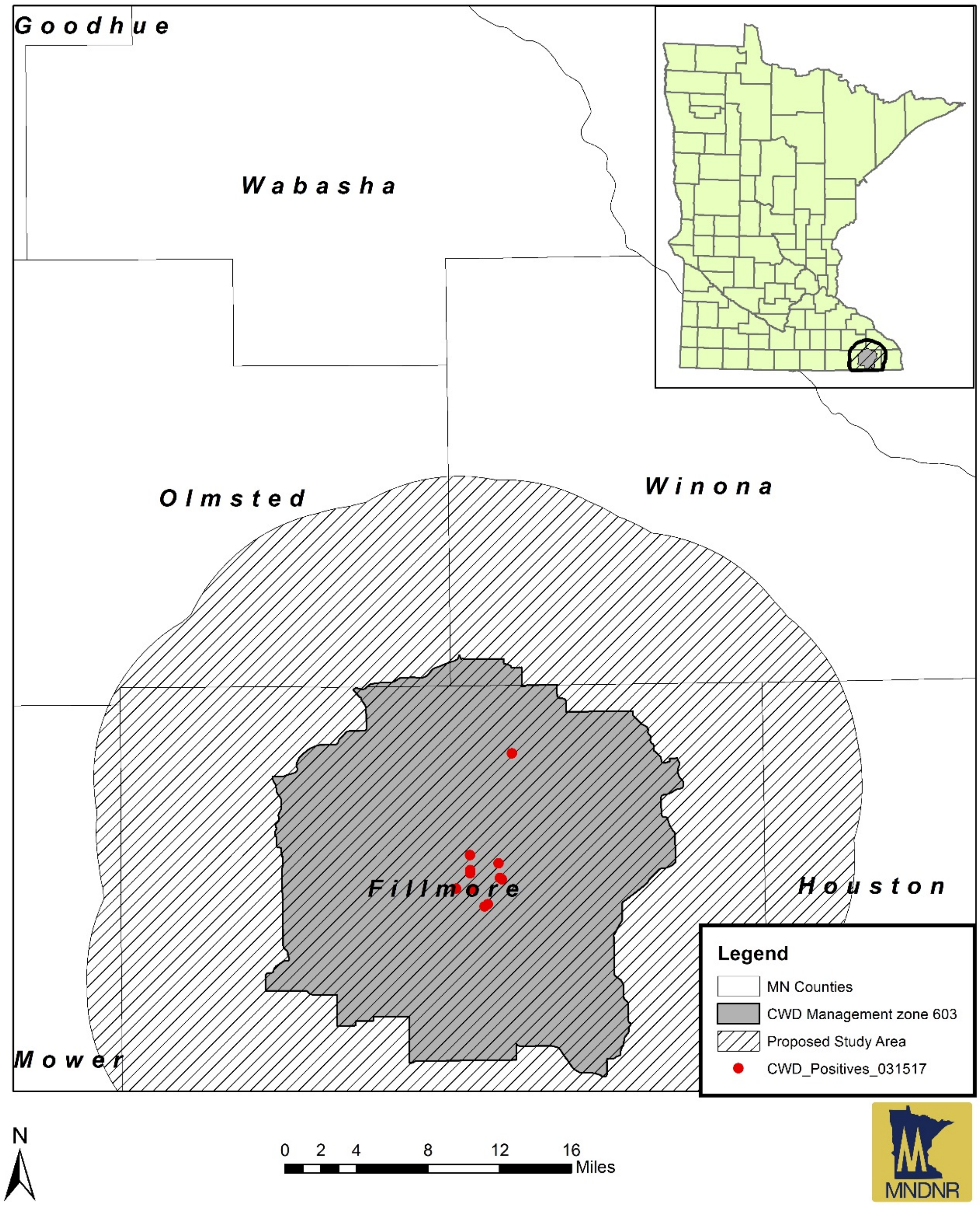

Figure 2. Approximate study area boundaries in and around the chronic wasting disease management zone (Deer Permit Area 603) in Minnesota. This area is largely private land, so the final disposition of sampling locations for GPS collaring deer will depend on permissions we receive from cooperating landowners, weather patterns, and local scale landscape characteristics that facilitate helicopter capture of wild white-tailed deer.

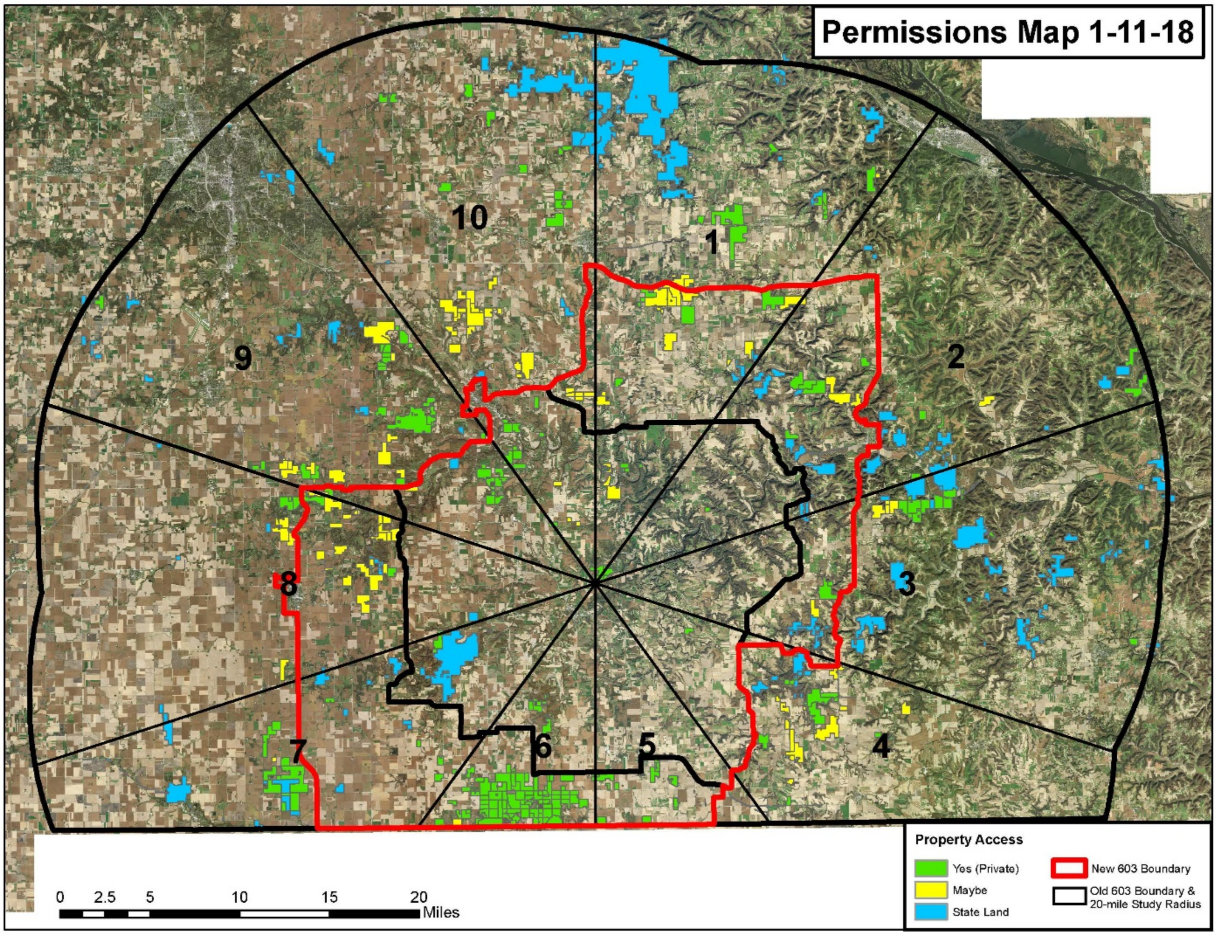

Figure 3. Spatial distribution of study area capture quadrants used as a basis for establishing Minnesota's 2018 deer capture goals. The target optimal capture distribution was established as six juvenile male, three juvenile female, and 2-3 adult male deer captured per quadrant.

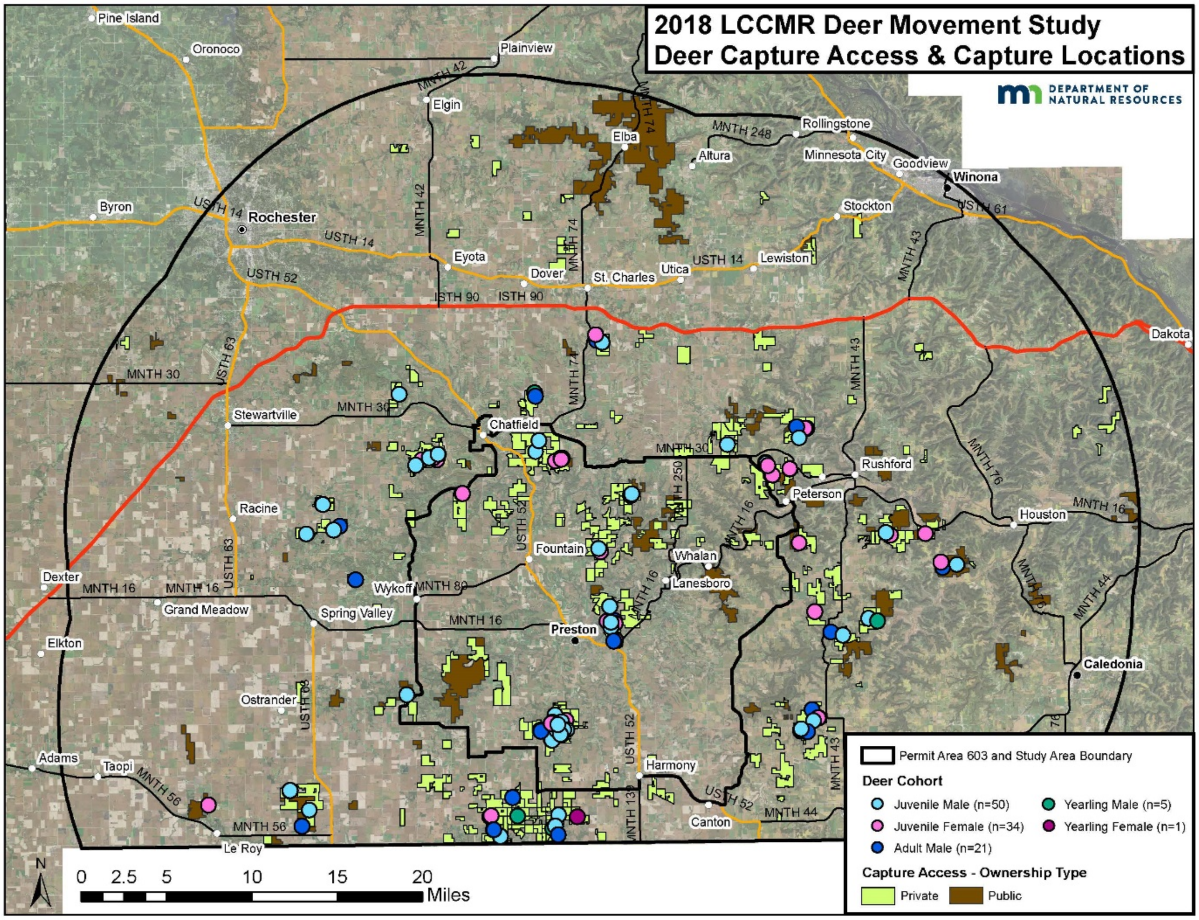

Figure 4. Spatial distribution of private (67,924 acres) and public (37,549 acres) properties secured in the study area for the 2018 deer capture season. Points represent the locations where white-tailed deer were captured, collared with GPS units, and released in the study area centered on CWD management zone 603 in Fillmore County, Minnesota, between 03/18/2018 and 03/23/2018.