ESTABLISHING THE FEASIBILITY OF MAKING FINE-SCALE MEASUREMENTS OF HABITAT USE BY WHITE-TAILED DEER IN NORTHERN MINNESOTA, WINTERS 2017–2018 AND 2018–2019

Bradley D. Smith,[1] Glenn D. DelGiudice, and William J. Severud[2]

SUMMARY OF FINDINGS

The Minnesota Department of Natural Resources (MNDNR) began a 2-year pilot study of white-tailed deer (*Odocoileus virginianus*) habitat in northcentral and northeastern Minnesota during winters 2017–2018 and 2018–2019. This study is using cutting-edge global positioning system (GPS)-collar, remote sensing, and geographical information system (GIS) technologies to monitor and assess deer habitat use on 2 winter ranges. During March 2018−May 2019, we recovered 30 of 60 collars that had been fitted to free-ranging deer. These collars stored 34,758 locations on-board (100% fix-success) and successfully transmitted 27,177 (88%) GPS locations. The mean horizontal error was 16 m (± 0.07) and median error was 10 m. We classified a total of 604 and 1,012 cover type polygons at the stand level within the Inguadona Lake and Elephant Lake study sites, respectively. Spatially, dense conifer stands accounted for 12% and 23% and forage openings for 12% and 11% of the 2 study sites. During winter 2017−2018, collared deer using dense conifer stands were a mean of 146 m (± 8) and 240 m (± 5) from the nearest forage opening at the Inguadona and Elephant Lake sites, whereas they were a mean of 136 m (± 5) and 190 m (± 4) from the center of the stand they were using. Deer using forage openings were a mean of 247 m (± 7) and 179 m (± 7) to the nearest dense conifer stand at the 2 sites and 206 m (± 5) and 146 m (± 3) from the center of the opening in use. The mean area of dense conifer stands being used was 8 ha (± 0.2) and 47 ha (± 2) at Inguadona Lake and Elephant Lake, respectively. The ability to make fine-scale measurements of available habitat and how it is being used by deer will allow us to characterize the area, shape, juxtaposition, and arrangement of cover types and assess their value on winter ranges in a way that can be incorporated into integrated habitat and forest management prescriptions.

INTRODUCTION

Based on recommendations from the Office of the Legislative Auditor, the Minnesota Department of Natural Resources (MNDNR) developed a statewide white-tailed deer (*Odocoileus virginianus*) management plan to maintain deer numbers within management units near population goals for improved hunting and wildlife viewing (MNDNR 2018). Habitat management is a key component of this plan. Because winter is the nutritional bottleneck for northern deer, has the greatest impact on their natural survival rates, and may have a pronounced impact on spring fawning, wildlife managers focus most of their efforts on improving

[1] University of Minnesota, Department of Fisheries, Wildlife, and Conservation Biology, 2003 Upper Buford Circle, Ste. 135, St. Paul, MN 55108

[2] University of Minnesota, Department of Forest Resources, 1530 Cleveland Ave N, St. Paul, MN 55108

winter habitat as a means of positively influencing population performance (DelGiudice et al. 2002, 2006, 2013*a*). During winter 2017–2018, the MNDNR initiated a deer habitat study in northcentral and northeastern Minnesota, which is using a combination of global positioning system (GPS) collar, remote sensing, and geographic information system (GIS) technologies to better understand deer use of cover types and how area, shape, juxtaposition, and arrangement of conifer stands, forage openings, and other cover types influence their use and well-being (DelGiudice et al. 2017).

Previous studies of deer use of winter habitat and requirements in northern Minnesota, Canada, and the Great Lakes region that relied primarily on very high frequency (VHF) telemetry collars were restricted by inherent constraints compared to the use of more advanced GPS collars (Morrison et al. 2003; Potvin et al. 2003; DelGiudice et al. 2013*a*,*b*, 2017). Constraints included lower location-fix accuracy (≥95 m), limited temporal distribution of location-fixes (i.e., daytime locations only), fair weather flying only (i.e., safe flying conditions), relatively infrequent location-fixes (i.e., small numbers of seasonal locations per individual deer), and greater costs (time and monetary) required to collect the data (Pellerin et al. 2008, Kochanny et al. 2009). Because of these limitations, more precise information regarding winter habitat use by deer is essential to a more thorough understanding of their seasonal requirements and improved habitat management prescriptions.

Advancements in technology have allowed for notable enhancements in performance of GPS collars. With improved accuracy and precision of location-fixes and higher fix- and transmission-success rates, GPS collars facilitate collection of a plethora of near real time data, including habitat use and selection, movement rates, and interspecific interactions. Before collar deployment and assessing winter habitat use by deer, the influence of canopy closure and cover type on their performance required testing (Rempel et al. 1995, Dussault et al. 1999). Studies have shown that different habitats have diverse, adverse effects on GPS collar performance (e.g., accuracy, fix-success) associated specifically with varied canopy cover, stem density, basal area, and topography (Moen et al. 1996, Rempel and Rogers 1997, Dussault et al. 1999). However, recently, Telonics, Inc., a GPS collar manufacturer in Mesa, Arizona, incorporated programming for Quick Fix Pseudoranging (QFP) into their Globalstar Recon collars, which enhances their ability to obtain accurate location-fixes with as little as a 3−5-second view of a satellite constellation, compared to the 30–90 seconds required for a typical GPS location-fix. This is particularly valuable to studies of habitat use by deer and other ungulates.

Use of improved GPS collar technology has the potential to maximize collection of accurate location data not obtainable in studies using VHF telemetry or less sophisticated GPS collars, and to facilitate fine-scale measurements of habitat use. These data permit 24-hour monitoring of habitat use to better understand (1) individual variability associated with selection of forest cover types, and (2) how structure, size, shape, arrangement, interspersion, and perimeter (edge):area influence habitat use at the stand level (DelGiudice et al. 2017).

OBJECTIVES

1. To assess performance of GPS collars recovered from free-ranging deer, including horizontal error, fix-success rates, and reliance on QFP locations
2. To classify and inventory cover types on the Inguadona Lake (IN) and Elephant Lake (EL) study sites

3. To provide examples of fine-scale measurements of winter habitat use by deer

STUDY AREA

The study includes 2 deer winter range sites located in northern Minnesota's forest zone (Figure 1). The IN site is located in the northcentral part of the state in Cass county, 2 km south of the Chippewa National Forest border. This site is 46 km^2 and is a mosaic of state, county, and private land, with most of the latter occurring along lake shores. Reported pre-fawning deer densities in this area were 7–9 deer/km^2 (D'Angelo and Giudice 2016), and included both residential deer (year-round) and seasonal migrators (Fieberg et al. 2008). Topography is undulant with elevations of 400–425 m above sea level. The area is classified as part of the Pine Moraines region (MNDNR 2015), and includes uplands dominated by deciduous and mixed deciduous-conifer stands and lowlands dominated by mixed conifers. The uplands included red (*Pinus resinosa*), white (*P. strobus*) and jack pine (*P. banksiana*); paper birch (*Betula papyrifera*); black ash (*Fraxinus nigra*); red maple (*Acer rubrum*); balsam fir (*Abies balsamea*); and trembling aspen (*Populus tremuloides*; DelGiudice 2013*a*.). Lowlands included northern white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), balsam fir, and tamarack (*Larix laricina*).

The MNDNR calculates an annual Winter Severity Index (WSI) by accumulating 1 point for each day with an ambient temperature ≤ –17.7° C and an additional point for each day with a snow depth ≥38 cm during November–May. During 1981−2010, mean January temperature was –13° C and mean annual snowfall was 110 cm (MNDNR Climatology 2018). Over the past 8 years, WSI in the IN site indicated moderately severe or severe conditions in just 1 winter (2013–2014; WSI ≥140; MNDNR Climatology 2018).

The EL site, located in St. Louis county, is representative of the forest zone in northeastern Minnesota. The EL site is 76 km^2 and includes state, federal, county, and private land. Pre-fawning deer densities are lower than at the IN site and remain below management's goal of 3–5 deer/km^2 since the 2 severe winters of 2010–2011 and 2013–2014 (D'Angelo and Giudice 2016). Topography is undulant with elevations ranging from 400 to 450 m above sea level. The area is part of the Northern Superior Upland region (MNDNR 2015) with lowland conifer stands and upland conifer and mixed deciduous-conifer stands. The lowlands included northern white cedar, black spruce, and tamarack. The uplands included northern white cedar; balsam fir; red, white and jack pine; aspen; and paper birch (MNDNR 2015). Mean January temperature was –15° C and mean annual snowfall was 165 cm during 1981−2010 (MNDNR Climatology 2018). Since 2011, WSI reflected moderately severe to severe winters in 3 years over the past 8-year period (2010–2011, 2012–2013, 2013–2014; MNDNR Climatology 2018).

The primary source of natural mortality of adult deer at both study sites was wolf (*Canis lupus*) predation (DelGiudice et al. 2002). The most recent wolf population estimate (2017) in northern Minnesota was 2,856, or 4 wolves/km^2 (Erb et al. 2017). Black bear (*Ursus americanus*) and wolf predation have been major causes of fawn mortality (Kunkel and Mech 1994, Carstensen et al. 2009). As of 2014, the bear population of northern Minnesota was estimated at about 15,000 (Garshelis and Tri 2017).

METHODS

During winter 2017–2018, 10 adult (≥1.5 years) female deer were captured at each study site (Figure 1). A total of 19 deer were captured via net-gunning from helicopter (Hells Canyon Helicopters, Clarkston, Washington), and 1 deer at the IN site was ground-captured using a

Clover trap (DelGiudice et al. 2001). An additional 20 adult female deer were net-gunned at each of the 2 sites during 5–8 February 2019 (Figure 1; Quicksilver Air, Inc., Fairbanks, Alaska). Handling of animals consisted of blind-folding, hobbling, recording a rectal temperature (° C), measuring chest girth and hind leg length (cm), affixing an ear-tag to each ear, fitting a GPS collar, and administering a broad-spectrum antibiotic. Collars were programmed to obtain 1 location-fix every 2 hours during December–June and 1 location-fix every 4 hours during July–November. Location data were transmitted to a base station every 10 hours (maximum 6 locations per transmission). These collars included QFP programming, which will obtain a QFP location only when a GPS-fix is unsuccessful (see Introduction for more information on QFP); they are stored-on-board along with activity data collected every 5 minutes using an accelerometer. These data are retrieved and downloaded once collars are recovered.

We classified cover types at the forest stand level on the 2 study sites using a mirror stereoscope (Model MS27, Sokkia Co., Ltd., Tokyo) and 9"x 9" color infrared aerial photographs (1:15,840 scale) taken during October 2010 and 2012, to capture the color contrast of peak autumn foliage. We used National Agriculture Imagery Program (NAIP) coverage from 2013, 2015, and 2017 to adjust for changes over time (Smith et al. 2019). We also relied on Light Detection and Ranging (LiDAR), collected during May 2011 and April 2012 at EL and IN, respectively, at a resolution of 1 pulse per m^2. Derived products from the LiDAR point cloud were used to extract accurate tree heights and calculate percent forest canopy closure at the stand level, and to assist with delineating stand boundaries while digitizing the photointerpretation.

We delineated forest stands according to a classification system developed to assign dominant and co-dominant tree species, height class, and canopy closure class (for conifer stands, Figure 1; Smith et al. 2019). Forage sites—defined as open areas with regeneration <2 m in height—swamps and lakes were also delineated. We interpreted forest stands to a minimum size of 0.5 ha (DelGiudice et al. 2013*a*). Habitat *training sites* (i.e., for ground-truthing) were established at locations of fresh deer snow-urine (i.e., urine in snow) collection. The snow-urine samples were being collected and analyzed to assess the nutritional status of deer (DelGiudice et al. 1989, 2017), but these locations also allowed documentation of vegetation information relevant to the habitat classification system and aerial photointerpretation being conducted during winter 2017−2018 and 2018–2019.

We conducted a preliminary assessment of the feasibility of making fine-scale habitat measurements for a better understanding of the variability of individual use of cover types. We examined habitat use based on pooled location-fixes from winter 2017–2018 home ranges (Figure 3). We characterized cover types by structure (forest stands only), area, and arrangement of conifer forest cover and forage openings. Specifically, we analyzed 4,775 and 5,255 winter location-fixes at the IN and EL sites, respectively, and assigned the following characteristics: cover type being used; dominant and co-dominant tree species; stand height and canopy closure classes; distance (m) from fix to center of stand being used; distance (m) to nearest conifer cover class, if not in use; distance (m) to nearest opening/foraging site, if not in use; area of cover type in use; and edge:area ratio of cover type in use. We made measurements efficiently and accurately using the tool "Near" in the most recent version of ArcGIS (ArcGIS Pro 2.2.2, ESRI 2018). We calculated a 95% Kernel Density Estimate (KDE) of each deer's home range during winters 2017−2018 and 2018−2019 using adehabitat (Calenge

2006) in R (R Core Team), which will facilitate comparisons of habitat composition within home ranges and between the 2 study sites.

RESULTS AND DISCUSSION

We recovered GPS collars from 30 deer (10 March 2018–31 May 2019), downloaded and analyzed the data as we had done during the pre-deployment collar-testing (Smith et al. 2019). The GPS transmission-success rate was 88% and fix-success of the 34,758 expected locations was 100%, with 3,903 (11%) being QFP fixes (Table 1). Overall mean horizontal error estimated by Telonics was 16 m (± 0.07) and median horizontal error was 10 m. The Telonics horizontal error estimate was slightly higher than the actual location error we calculated during our pre-deployment testing (Smith et al. 2019). Fix-success rates from recovered collars were consistent with rates from collars used in the pre-deployment test. Higher horizontal error estimates and lower transmission rates may be due to the increased frequency of dense conifer use on winter ranges (Morrison et al 2003; DelGiudice et al 2013*a, b*; Smith et al. 2019). The mean location error estimates are far superior (smaller) to those reported from previous GPS-collar studies (32−100 m; Rempel et al. 1995, Moen et al. 1996, Dussault et al. 1999). The addition of QFP locations is critical to our habitat study, providing 100% fix-success rates in important cover types that typically hinder location-fix success.

Overall, 95% KDEs of winter home ranges were highly variable on both sites during both winters (Tables 2 and 3). Home ranges tended to be larger for deer at IN than at EL during both winters, and were greater at both sites during winter 2018−2019 (Table 3) compared to 2017−2018 (Table 2); however, as assessed by 95% confidence intervals (mean ± 1.96 × SE), none of these differences were statistically significant. Home ranges for deer during winter 2017−2018 are depicted in Figure 3.

A total of 604 and 1,012 cover type stands were classified for the IN and EL sites, respectively (Figure 2). Dense conifer stands comprised 23% of the EL site compared to 12% of the IN site (Table 4). Northern white cedar dominated the dense conifer cover at the EL site. The IN site consists of more red pine plantations, which usually provide moderate canopy cover. The proportion of forage openings was similar at both sites, 11% and 12% at IN and EL (Table 4). When deer were using dense conifer stands, they were a mean of 146 m (± 8) and 240 m (± 5) from forage openings at IN and EL, respectively (Table 5). Mean distance to the center of the dense conifer stand in use was 136 m (± 5) and 190 m (± 4) (Table 5), and mean area of those stands was 8 ha (± 0.2) and 47 ha (± 2.0). Similarly, when deer were using forage openings, they were a mean of 247 m (± 7) and 179 m (± 7) from dense conifer cover at IN and EL, respectively, and 206 m (±5) and 146 m (±3) to the center of the opening in use (Table 5). The mean area of forage openings being used was 19 ha (± 0.4) and 8 ha (± 0.2). Deer were a mean of 35 m (± 0.5) and 38 m (± 0.5) to the nearest edge at the 2 sites. We did not find a difference in edge:area ratios for the different stand types being used (Table 5). Other landscape metrics also will be explored to better describe the shape, juxtaposition, and interspersion of cover types being used. Our preliminary measurements are consistent with findings of previous research suggesting dense conifer cover should be arranged within 355 m of forage openings (Morrison et al. 2003, Potvin et al. 2003, Beyer et al. 2010). Data represent only late-winter 2017−2018, but these preliminary analyses demonstrate the feasibility of making these fine-scale habitat measurements using our combined GPS collar, remote sensing, and GIS technologies. Analyses of habitat use data sets from winter 2018−2019 are in progress and will help capture additional individual and winter variability relative to varying snow depths and ambient temperatures.

Future work will include expanding the habitat classification and inventory of the 2 sites relative to the additional ~33,000 deer locations from winter 2018−2019, and we will continue analyses to further assess and understand winter habitat use and requirements as snow depth and temperature change during the progression of winter. Prior to winter 2020−2021, we plan to select a third study site, this one well within northeastern Minnesota's moose range. Habitat will be similarly classified and inventoried to allow examination and comparison of deer use at the stand level. Ultimately, the ability to make these fine-scale habitat measurements using GPS collars, remote sensing, and GIS as winters progress and vary annually will allow us to assess the area, shape, juxtaposition, and arrangement of dense conifer cover, forage openings, and other cover types to assist managers in formulating prescriptions that effectively integrate forest and habitat management strategies and practices.

ACKNOWLEDGMENTS

We thank B. Matykiewicz, B. Wagner, M. Pike and C. Marvet for their technical assistance with all aspects of the fieldwork. We gratefully acknowledge P. Backman and P. Coy for their skills and efforts applied to deer mortality investigations and collar recovery. P. Backman also shared valuable background knowledge of the Elephant Lake site. C. Humpal skillfully conducted laboratory analyses of our deer snow-urine and bone marrow samples. We also acknowledge the USDA Forest Service's LaCroix and Deer River Ranger Districts for providing housing during the winter field seasons. This project is supported by the Minnesota Department of Natural Resources Section of Wildlife and the Wildlife Restoration (Pittman-Robertson) Program. The Minnesota Deer Hunters Association provided supplemental funding for post-doctoral research assistance.

LITERATURE CITED

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516-519.

Carstensen, M., G. D. DelGiudice, B. A. Sampson, and D. W. Kuehn. 2009. Survival, birth characteristics, and cause-specific mortality of white-tailed deer neonates. Journal of Wildlife Management 73:175–183.

D'Angelo, G. J., and J. H. Giudice. 2016. Monitoring population trends of white-tailed deer in Minnesota-2016. Minnesota Department of Natural Resources, St. Paul, Minnesota, USA.

DelGiudice, G. D., J. R. Fieberg, and B. A. Sampson. 2013*a*. A long-term assessment of the variability in winter use of dense conifer cover by female white-tailed deer. PLoS ONE 8:e65368.

DelGiudice, G. D., J. Fieberg, M. R. Riggs, M. C. Powell, and W. Pan. 2006. A long-term age-specific survival analysis of female white-tailed deer. Journal of Wildlife Management 70:1556–1568.

DelGiudice, G. D., B. A. Mangipane, B. A. Sampson, and C. O. Kochanny. 2001. Chemical immobilization, body temperature, and post-release mortality of white-tailed deer captured by clover trap and net-gun. Wildlife Society Bulletin 29:1147–1157.

DelGiudice, G. D., L. D. Mech, and U. S. Seal. 1989. Physiological assessment of deer populations by analysis of urine in snow. Journal of Wildlife Management 53:284-291.

DelGiudice, G. D., A. Norton, J. F. Knight. 2017. Informing winter habitat management prescriptions and population vital rate estimates for white-tailed deer in northcentral and northeastern Minnesota. Phase I research proposal. Minnesota Department of Natural Resources, St. Paul, Minnesota, USA.

DelGiudice, G. D., M. R. Riggs, P. Joly, and W. Pan. 2002. Winter severity, survival, and cause-specific mortality of female white-tailed deer in north-central Minnesota. Journal of Wildlife Management 66:698–717.

DelGiudice, G. D., B. A. Sampson, and J. H. Giudice. 2013*b*. A long-term assessment of the effect of winter severity on the food habits of white-tailed deer. Journal of Wildlife Management 77:1664–1675.

DelGiudice, G. D., W. J. Severud, and B. S. Smith. 2018. Winter survival and cause-specific mortality of white-tailed deer in northern Minnesota: updating with GPS collars. *In* L. Cornicelli, M. Carstensen, B. Davis, N. Davros, and M. A. Larson, editors. Summaries of Wildlife Research Findings 2017. Minnesota Department of Natural Resources, St. Paul, Minnesota, USA. *In prep*.

Dussault, C., R. Courtois, J.-P. Ouellet, and J. Huot. 1999. Evaluation of GPS telemetry collar performance for habitat studies in the boreal forest. Wildlife Society Bulletin 965–972.

Environmental Systems Research Institute (ERSI). 2018. ArcGIS Pro 2.2.2. Redlands, California, USA.

Erb, J., C. Humpal, and B. Sampson. 2017. Minnesota wolf population update 2017. Minnesota Department of Natural Resources, St. Paul, Minnesota, USA.

Fieberg, J., D. W. Kuehn, and G. D. DelGiudice. 2008. Understanding variations in autumn migration of northern white-tailed deer by long-term study. Journal of Mammalogy 89: 1529−1539.

Garshelis, D., and A. Tri. 2017. Status of Minnesota black bears, 2016. Minnesota Department of Natural Resources, St. Paul, Minnesota, USA.

Kochanny, C. O., G. D. DelGiudice, and J. Fieberg. 2009. Comparing Global Positioning System and Very High Frequency telemetry home ranges of white-tailed deer. Journal of Wildlife Management 73:779–787.

Kunkel, K. E., and L. D. Mech. 1994. Wolf and bear predation on white-tailed deer fawns in northeastern Minnesota. Canadian Journal of Zoology 72:1557–1565.

Midwestern Regional Climate Center. 2018. cli-MATE, MRCC application tools environment. http://mrcc.isws.illinois.edu/CLIMATE/. Accessed 1 June 2018.

Minnesota Department of Natural Resources (MNDNR). 2015. Ecological classification system. Minnesota Department of Natural Resources, St. Paul, Minnesota, USA. <http://www.dnr.state.mn.us/ecs/index.html>. Accessed 25 March 2018.

Minnesota Department of Natural Resources (MNDNR). 2018. Minnesota white-tailed deer management plan 2019–2028. Draft. Minnesota Department of Natural Resources, St. Paul, Minnesota, USA.

Minnesota State Climatology Office (MN Climatology). 2018. Past climate data. Minnesota Department of Natural Resource, St. Paul, Minnesota, USA. <https://www.dnr.state.mn.us/climate/historical/summary.html>. Accessed 25 March 2018.

Moen, R., J. Pastor, Y. Cohen, and C. C. Schwartz. 1996. Effects of moose movement and habitat use on GPS collar performance. Journal of Wildlife Management 60:659–668.

Morrison, S. F., G. J. Forbes, S. J. Young, and S. Lusk. 2003. Within-yard habitat use by white-tailed deer at varying winter severity. Forest Ecology and Management 172:173–182.

Pellerin, M., S. Saïd, and J.-M. Gaillard. 2008. Roe deer *Capreolus capreolus* home-range sizes estimated from VHF and GPS data. Wildlife Biology 14:101–110.

Potvin, F., B. Boots, and A. Dempster. 2003. Comparison among three approaches to evaluate winter habitat selection by white-tailed deer on Anticosti Island using occurrences from an aerial survey and forest vegetation maps. Canadian Journal of Zoology 81:1662–1670.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rempel, R. S., and A. R. Rodgers. 1997. Effects of differential correction on accuracy of a GPS animal location system. Journal of Wildlife Management 61:525–530.

Rempel, R. S., A. R. Rodgers, and K. F. Abraham. 1995. Performance of a GPS animal location system under boreal forest canopy. Journal of Wildlife Management 59:543–551.

Smith, B. D., G. D. DelGiudice, and W. J. Severud. 2019. Establishing the feasibility of making fine-scale measurements of habitat use by white-tailed deer in northern Minnesota, winter 2017–2018. Summaries of wildlife research findings, 2018. Minnesota Department of Natural Resources, Unpublished report, St. Paul, USA.

Table 1. Summary statistics of location-fix data downloaded from global positioning system (GPS) collars[a] recovered from 30 adult (≥1.5 yr), female white-tailed deer during March 2018–May 2019, and associated performance metrics. Collars were deployed at the Inguadona Lake (IN) and Elephant Lake (EL) study sites, northcentral and northeastern Minnesota.

Collar ID	Study site	Mean horizontal error[b] (m)	Median horizontal error (m)	Overall fix-success rate (%)	Percent QFP locations	GPS-fix transmission-success rate[c] (%)
697084A	IN	17	10	100	18	71
697085A	IN	16	10	100	13	77
697086A	IN	15	10	100	10	80
697092A	IN	13	10	100	9	86
697095A	IN	14	10	100	0	91
697096A	IN	17	10	100	12	81
697098A	IN	15	10	100	18	74
699964A	IN	17	10	100	15	77
699966A	IN	16	10	100	13	61
706038A	IN	15	10	100	1	96
706039A	IN	18	10	100	0	99
706040A	IN	13	10	100	0	100
706057A	IN	14	10	100	0	99
706059A	IN	14	10	100	1	98
706070A	IN	12	10	100	1	96
697087A	EL	17	10	100	12	59
697090A	EL	17	10	100	15	77
697091A	EL	16	10	100	7	85
697093A	EL	18	10	100	15	72
697094A	EL	15	10	100	9	84
697097A	EL	17	11	100	17	67
699965A	EL	16	10	100	8	66
699967A	EL	17	10	100	14	73
706030A	EL	16	10	100	6	88
706036A	EL	18	12	100	10	86
706048A	EL	15	10	100	2	97
706052A	EL	12	10	100	0	100
706055A	EL	13	10	100	2	96
706062A	EL	24	14	100	2	96
706064A	EL	15	10	100	6	94
Overall		16	10	100	11	88

[a] Globalstar Recon GPS units (Model IGW-4660-4; Telonics, Inc., Mesa, Arizona).
[b] Horizontal error was calculated by Telonics and downloaded with the location data. Quick Fix Pseudoranging (QFP) locations were recorded only when a GPS-fix was unsuccessful.
[c] Transmission-success rate is calculated from the GPS locations only (i.e., QFP locations excluded).

Table 2. Overall mean (± SE) size (ha) of winter home ranges (95% Kernel Density Estimator) of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake and Elephant Lake study sites, northcentral and northeastern Minnesota, 12 March−1 May 2018.

Study site	*n*	Mean	SE	Range
Inguadona Lake	9	289	108	53−1,020
Elephant Lake	10	157	51	33− 584

Table 3. Overall mean (± SE) size (ha) of winter home ranges (95% Kernel Density Estimator) of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake and Elephant Lake study sites, northcentral and northeastern Minnesota, 1 November 2018−1 May 2019.

Study site	*N*	Mean	SE	Range
Inguadona Lake	24	358	77	60−1,209
Elephant Lake	26	267	73	5−1,473

Table 4. Cover type composition (% of study sites) of winter range of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake and Elephant Lake study sites, northcentral and northeastern Minnesota, winters 2017−2018 and 2018−2019.

Stand type	Elephant Lake	Inguadona Lake
Open conifer	4	3
Moderate conifer	5	10
Dense conifer	23	12
Hardwood	32	31
Mixed hardwood/conifer	12	3
Forage	12	11
Total area (km^2)	76	46

Table 5. Mean fine-scale measurements of winter habitat use by adult (≥1.5 yr), female white-tailed deer at the stand level at the Inguadona Lake and Elephant Lake sites, northcentral and northeastern Minnesota, 12 March−1 May 2018.[a]

Stand type[b]	Distance[c] to forage (m)	Distance to dense conifer (m)	Distance to edge (m)	Distance to center (m)	Area (ha)	Edge:area (m:m^2)
Inguadona Lake						
Open conifer	291	68	34	108	8	0.026
Moderate conifer	119	205	28	158	14	0.020
Dense conifer	146	NA	21	136	8	0.031
Hardwood	280	345	34	180	16	0.022
Mixed hardwood/conifer	367	557	28	84	4	0.025
Forage	NA	247	44	206	19	0.023
Elephant Lake						
Open conifer	282	150	41	204	18	0.018
Moderate conifer	74	180	22	100	5	0.025
Dense conifer	240	NA	48	190	47	0.020
Hardwood	312	278	41	277	30	0.016
Mixed hardwood/conifer	239	242	39	174	15	0.022
Forage	NA	179	23	146	8	0.029

[a]Locations are from winter 2017−2018 home ranges calculated using the 95% Kernel Density Estimator.

[b]Stand type indicates the stand being used. Open, moderate, and dense conifer represent the 3 canopy closure classes used for conifer stands only; open = 0−39%, moderate = 40−69%, and dense = 70−100%. Mixed hardwood stands are stands with hardwood as the dominant species and conifer as the co-dominant.

[c]Distances were measured using the Near tool in ArcGIS Pro 2.2.2. Mean calculations are based on all of the winter (12 Mar−1 May 2018) locations of all GPS-collared deer using these stand types within the respective study sites.

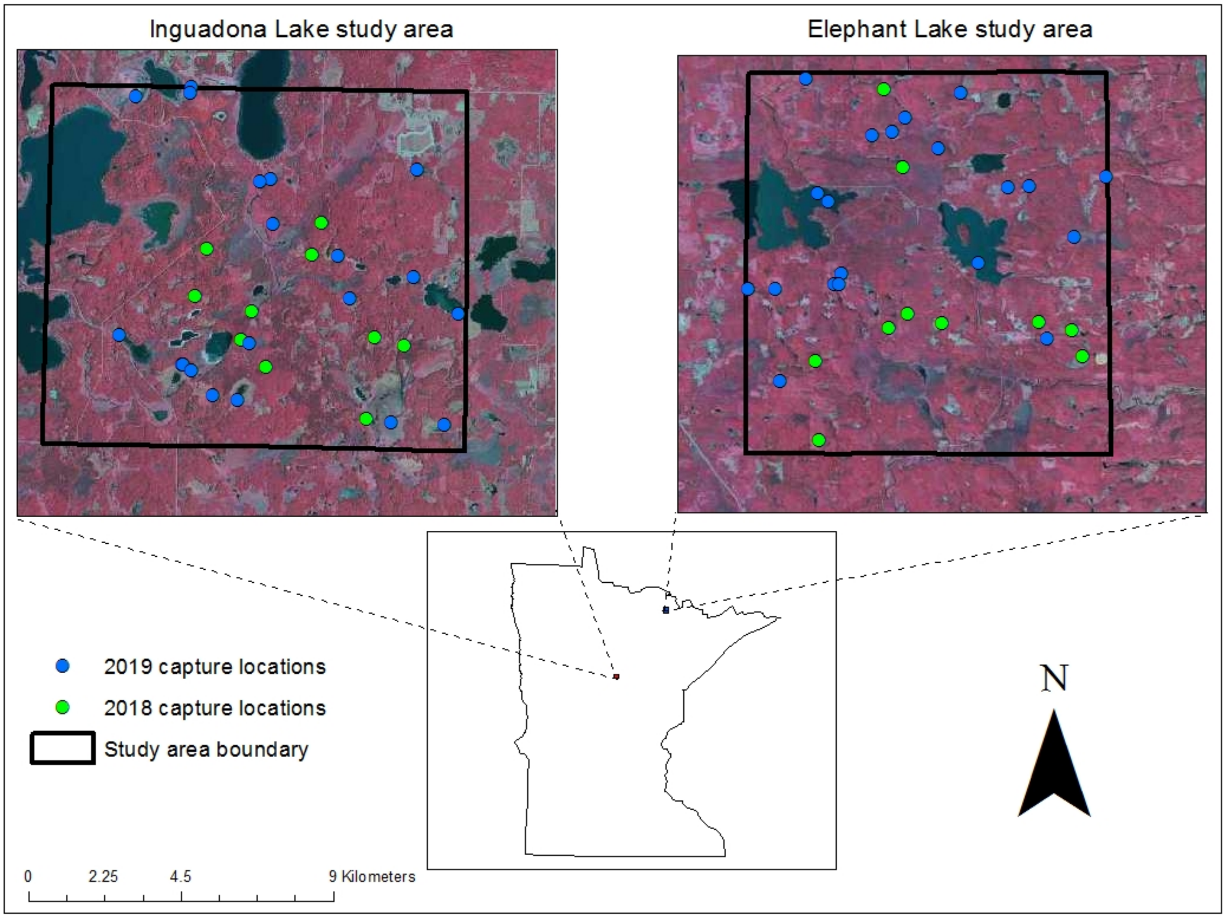
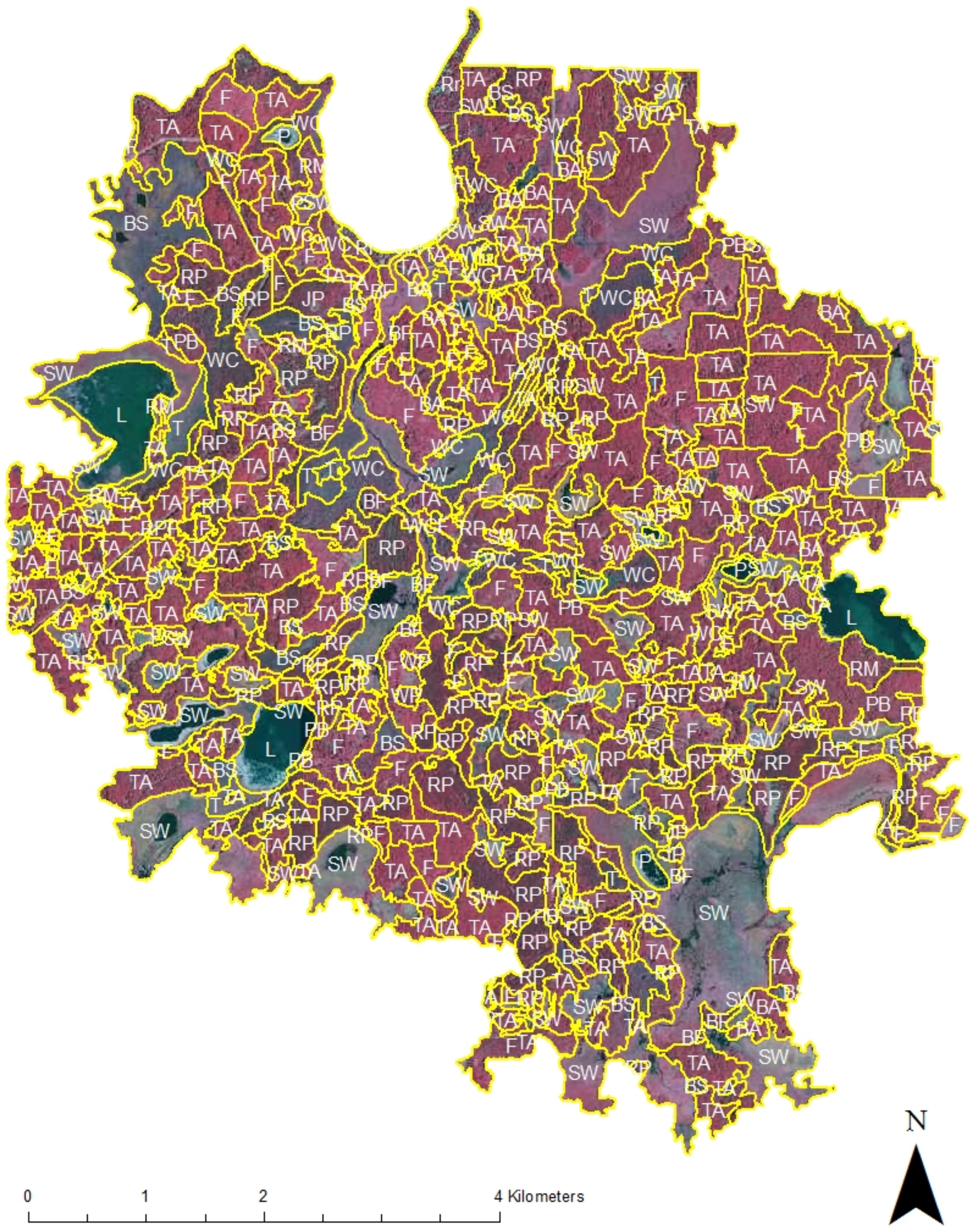


Figure 1. Helicopter net-gun capture locations of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (46 km^2) and Elephant Lake (76 km^2) study sites, northcentral and northeastern Minnesota, 10−11 March 2018 and 5−8 February 2019. One deer was captured via Clover trap at Inguadona Lake in the first winter.


0
1
2
4 Kilometers
N

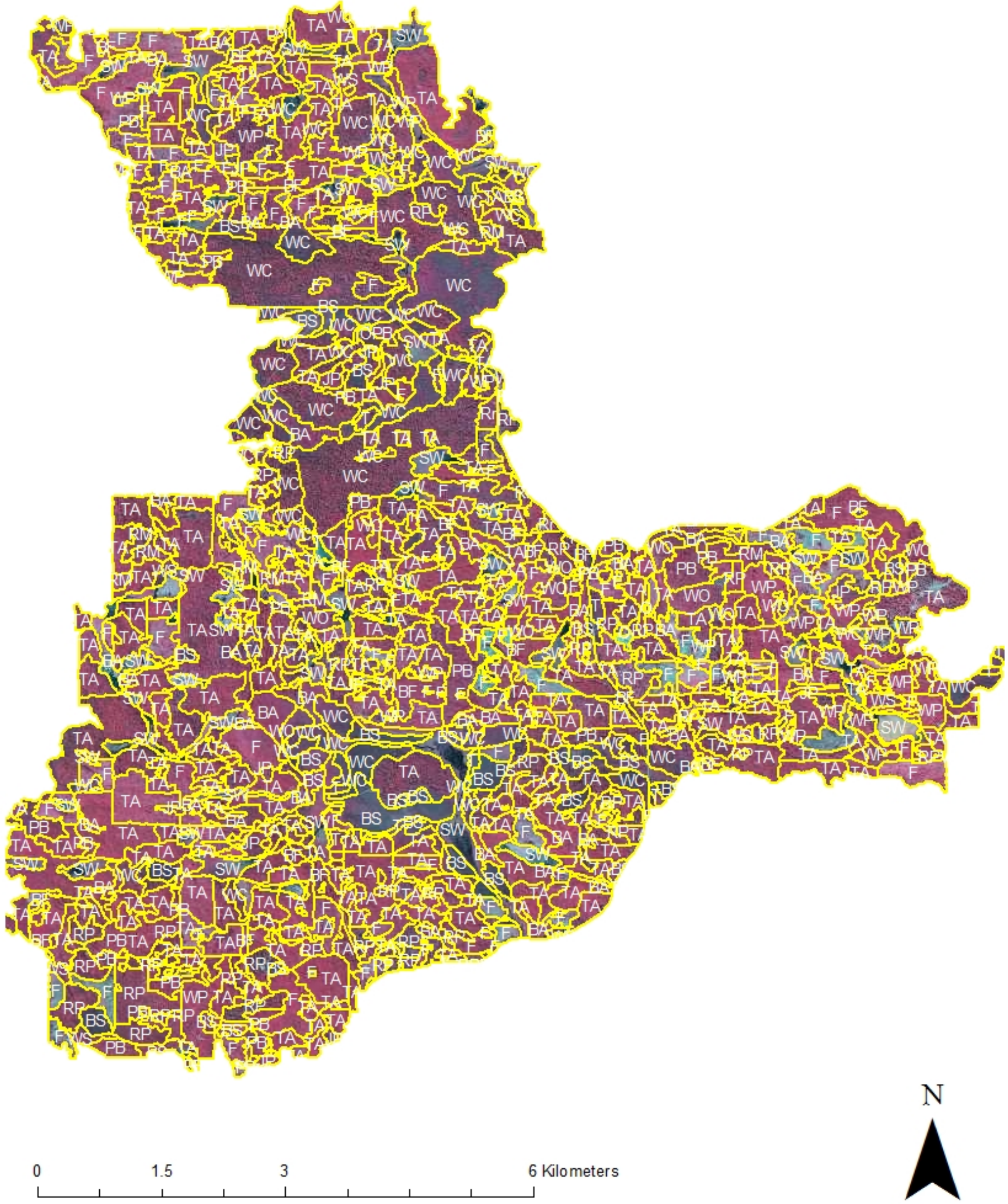
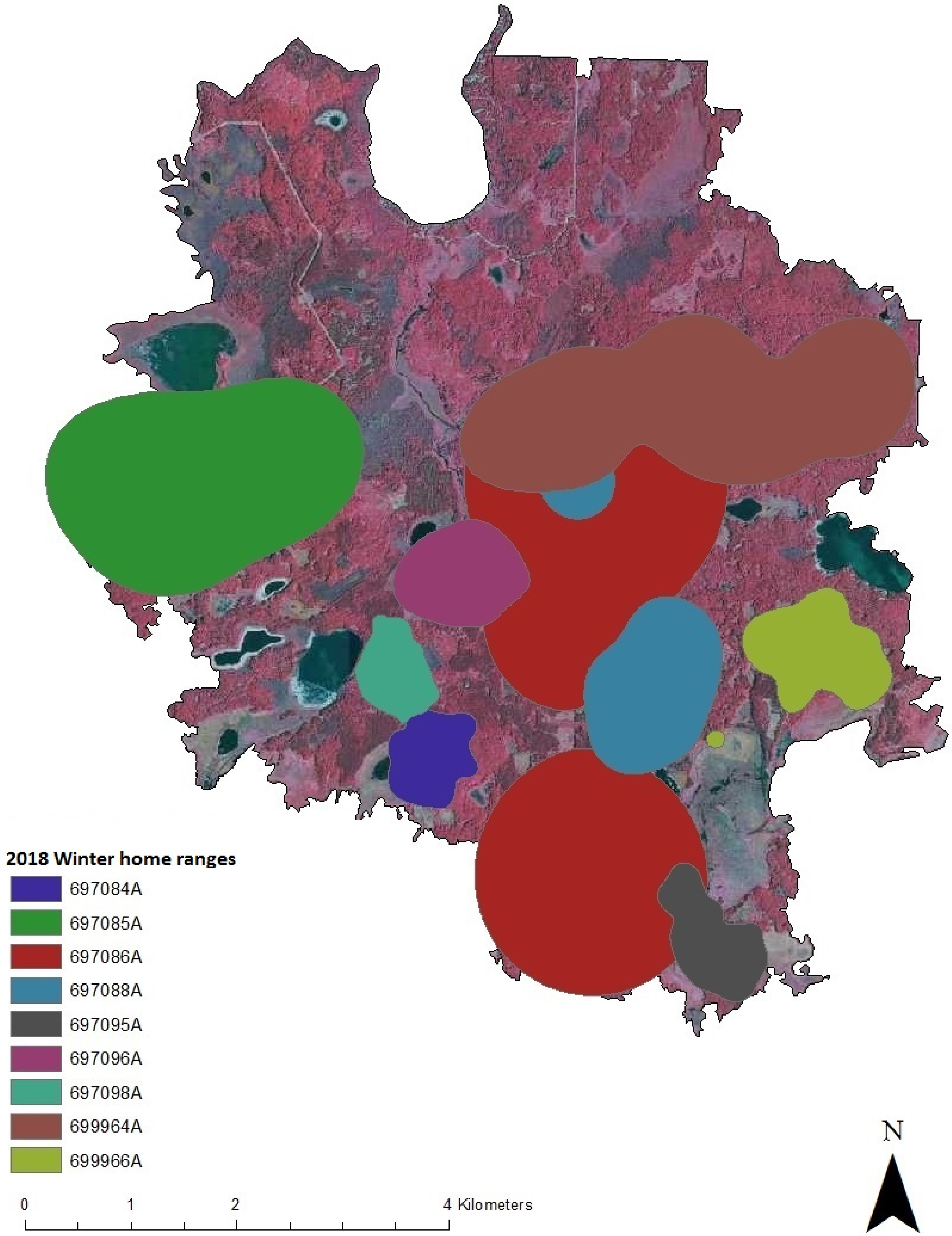


Figure 2. Classification and inventory of adult (≥1.5 yr), female white-tailed deer habitat at the stand level (only dominant tree species and forage are presented here) at the Inguadona Lake (top) and Elephant Lake (bottom) study sites, northcentral and northeastern Minnesota, winters 2017−2018 and 2018−2019, accomplished by air photointerpretation and Light Detection and Ranging (LiDAR). Stands and non-forest cover types were classified to a minimum size of 0.5 hectares. Cover type codes are presented in Table 1 in Smith et al. 2019.


2018 Winter home ranges
697084A
697085A
697086A
697088A
697095A
697096A
697098A
699964A
699966A
0
1
2
4 Kilometers
N

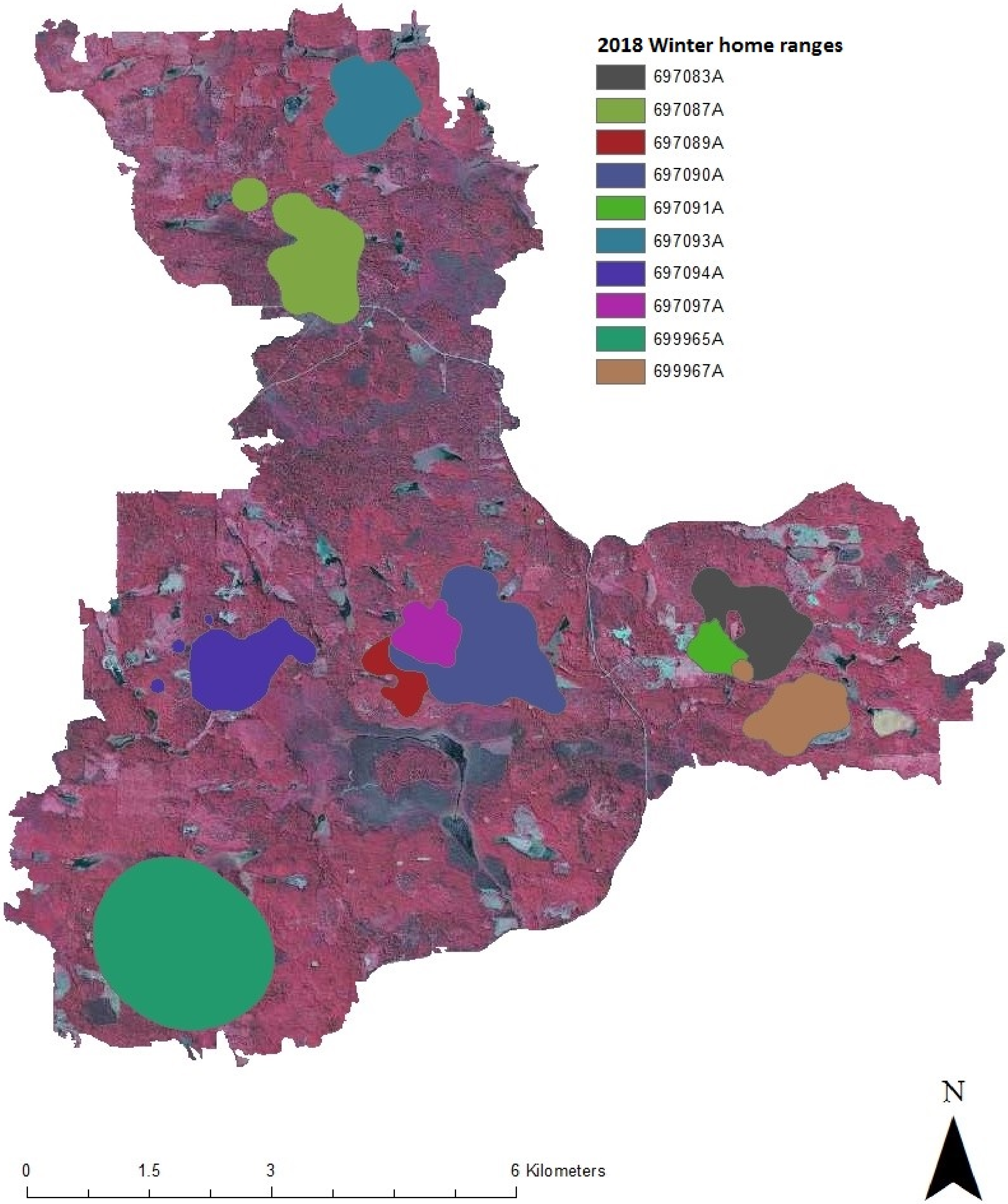

2018 Winter home ranges
697083A
697087A
697089A
697090A
697091A
697093A
697094A
697097A
699965A
699967A
0
1.5
3
6 Kilometers
N

Figure 3. Winter home ranges (95% Kernel Density Estimate) of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (top, n = 9) and Elephant Lake (bottom, n = 10) study sites, northcentral and northeastern Minnesota, 12 March−1 May 2018.