# INFORMING WINTER HABITAT MANAGEMENT PRESCRIPTIONS AND POPULATION VITAL RATE ESTIMATES FOR WHITE-TAILED DEER IN NORTHERN MINNESOTA, WINTERS 2017−2018 TO 2019−2020

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## SUMMARY OF FINDINGS

A recent report by the Office of the Legislative Auditor (OLA 2016) addressed the need for the Minnesota Department of Natural Resources (MNDNR) to develop a statewide white-tailed deer (*Odocoileus virginianus*) management plan to improve and maintain adequate numbers for hunting and wildlife viewing. The report acknowledged throughout that improved habitat management should be a key component of this plan. A greater understanding of winter habitat requirements of deer in northern Minnesota has been an ongoing need of wildlife managers to enhance their ability to plan, integrate and implement long-term forest and habitat management strategies with foresters. This need and the state of development of cutting-edge global positioning system (GPS) collar, remote sensing, and geographic information system (GIS) technologies prompted this study to inform a level of understanding of deer habitat requirements essential to prescribing forest manipulations that best support population goals. Herein, we present findings of ongoing analyses of data collected from 73 GPS-collared, adult (≥1.5 yr) female deer during winters 2017−2018 to 2019−2020. Our analyses of deer winter home ranges (HR) and habitat use at the 2nd order, habitat availability at the site level and use at the HR level, strongly indicate notable individual variation in HR size and habitat use. However, on average, over varying winters 2017−2018 to 2019−2020, deer used cover groups in proportion to availability, with hardwoods, moderately dense and dense conifer stands, and forage types receiving the greatest use at both sites, with the exception of the greater availability and use of wetlands at Inguadona Lake than at Elephant Lake. Our ongoing more in-depth analyses, will examine 1) habitat selection at the 3rd order, proportional availability within deer home ranges (HRs) versus use (proportions of location-fixes) at the stand level, 2) fine-scale measurements of stands used and how they were used, and 3) how use was influenced by variations in snow depth and deer density.

## INTRODUCTION

Habitat management is recognized as the ultimate stage of progressive wildlife management (Krausman and Bleich 2013). Recently, a report by the Office of the Legislative Auditor (OLA 2016) recommended the Minnesota Department of Natural Resources (MNDNR) develop a statewide white-tailed deer (*Odocoileus virginianus*) management plan (MNDNR 2018), that included improving population estimates; also, improving habitat management was acknowledged as a necessary key component of this plan to establish and meet population

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goals. But the degree to which timber management is *good* deer management depends on the biologist's level of understanding of the relationship of wildlife to habitat and how well foresters can manipulate habitat to achieve population goals (Thomas 1979). A greater understanding of particularly winter habitat requirements of deer in northern Minnesota has been an ongoing need of wildlife managers to enhance their ability to plan, integrate and implement long-term forest and habitat management strategies and associated activities. The overall goal of our study is to inform that level of understanding necessary for managers to prescribe forest manipulations that best support population goals. These manipulations will consider composition, area, edge, edge: area ratio, shape, and abundance, as well as juxtaposition and interspersion or arrangement of cover types (e.g., conifer shelter, forage openings).

Phase I of this research began as a pilot study during winter 2017-2018, interfacing cutting-edge global positioning system (GPS) collars, remote sensing and geographic information system (GIS) technologies to establish the feasibility of making fine-scale measurements of habitat use and selection by deer at the *stand or cover type level* (hereafter, stand level) under varying environmental winter conditions (DelGiudice et al. 2017; Smith et al. 2019, 2020; Smith 2020). For management to benefit fully from such characterizations of cover type use, we are assessing habitat quality by examining associations with deer nutritional status and survival, another area sorely requiring additional research attention (DelGiudice et al. 2002, 2006, 2020).

Phase I's operational goal required assessing the performance of our Globalstar Recon GPS collars (Model IGW-4660-4, Telonics, Inc., Mesa, Arizona), programmed with Quick Fix Pseudoranging (QFP), in different habitat types pre-deployment (stationary trials), as well as, once recovered from free-ranging deer. Details can be viewed in the aforementioned references, but to summarize, our collars consistently obtained 100% fix-success rates regardless of the cover type being used, had mean transmission rates of location-fixes to our base station during the trials and while deployed on deer of 96.7% and 88.1%, respectively, and exhibited mean spatial errors of 5.7 m and 16.1 m. Using stereo air photointerpretation of color infrared and natural color photos (1:15,840 scale) and Light Detection and Ranging (LiDAR), we successfully described the deer's winter habitat composition at the stand level down to a minimum of 0.5 ha on our Elephant Lake (1,012 total stands) and Inguadona Lake study sites. Employing the most recent version of ArcGIS (ArcGIS Pro 2.2.2, ESRI 2018), we reported preliminary estimates of each deer's winter home range (HR) and generated habitat composition layers for each site and deer HR to facilitate analyses of habitat use and selection by deer at 2$^{nd}$ and 3$^{rd}$ orders (Johnson 1980). Furthermore, using thousands of winter location-fixes, we demonstrated the ability to efficiently and accurately make fine-scale measurements to assess how deer use their habitat at the stand level (4$^{th}$ order) under varying environmental conditions.

Upon fulfilling our Phase 1 study goal and objectives, and recently completing our third winter of data collection, herein our goal is to highlight the beginning of our more in-depth spatial and temporal analyses of habitat availability, use, and selection on our 2 study sites, and to examine individual and cohort variability relative to each study site and among the 3 years (DelGiudice et al. 2019).

## OBJECTIVES

1. Present our ruleset, established for annually maintaining ecologically- and statistically-sound consistency in our analytical approach, as we progress through our spatial and temporal analyses of habitat use and selection at the 2$^{nd}$, 3$^{rd}$, and 4$^{th}$ orders.
2. Present distribution of deer captures during winters 2017−2018, 2018−2019, and 2019−2020.

3. Compare size and proportional habitat composition of the Inguadona Lake (IN) and Elephant Lake (EL) sites during winters 2017−2018, 2018−2019, and 2019−2020.
4. Compare size and proportional habitat composition of winter HRs of deer at the IN and EL sites during winters 2017−2018, 2018−2019, and 2019−2020.
5. Using a 2nd order compositional analysis approach, compare proportional habitat use (deer HR level) to proportional availability (study site level).

## STUDY AREA

The study is being conducted on 2 deer winter range sites in northern Minnesota's forest zone (Figure 1). The 46-$km^2$ IN site is located in the northcentral part of the state, 2 km south of the Chippewa National Forest, and is comprised of state, Cass County, and private land. D'Angelo and Giudice (2016) reported pre-fawning deer densities of 7–9 deer/$km^2$, including both sedentary and seasonally migrating deer (Fieberg et al. 2008). Topography is undulant and ranges between 400 and 425 m above sea level. The area is part of the Pine Moraines region (MNDNR 2015), with uplands dominated by 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*) and lowlands dominated by 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). During winters 2009−2010 to 2019−2020, mean $WSI_{Max}$ was 71 (95% Confidence Interval [CI] = 45−97, range = 21−160). Only 1 winter, 2013−2014, had a $WSI_{Max}$ ≥140.

The 76-$km^2$ EL site is representative of the forest zone in northeastern Minnesota and includes state, federal, St. Louis County, and private land. Pre-fawning deer densities are lower than at the IN site, and actually, are 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 rugged with elevations ranging from 400 to 450 m above sea level. This area is part of the Northern Superior Upland region (MNDNR 2015) with lowlands of northern white cedar; black spruce; and tamarack and uplands of 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). During winters 2009−2010 to 2019−2020, mean $WSI_{Max}$ was 112 (95% CI = 83−142, range = 46−212). Two winters, 2012−2013 and 2013−2014, had a $WSI_{Max}$ ≥140.

Wolf (*Canis lupus*) predation is the primary cause of natural mortality of adult deer at both study sites (Nelson and Mech 1986, DelGiudice et al. 2002). Wolves were most recently (2017) estimated at 2,856, or 4 wolves/100 $km^2$ (Erb et al. 2017). Black bear (*Ursus americanus*) and wolf predation also heavily impact fawn survival (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 winters 2017–2018 (2018), 2018−2019 (2019), and 2019−2020 (2020), we captured 20, 40, and 13 adult (≥1.5 years) female deer. Half each were captured at the IN and EL sites during 2018 and 2019, 8 and 5 deer, respectively, during 2020 (Figure 1). All except 1 deer (captured by Clover trap [DelGiudice et al. 2001]) were captured by net-gunning from helicopter (2018: Hells Canyon Helicopters, Clarkston, Washington; 2019: Quicksilver Air, Inc., Fairbanks, Alaska; 2020: Helicopter Wildlife Services, Austin, Texas). Deer handling included 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 as warranted by any pre-existing injury or wound. New collars deployed during 2018 and 2019 were programmed to obtain 1 location-fix every 2 hours during December–June and 1 location-fix every 4 hours during July–November; however, collars deployed during 2020 obtained hourly location-fixes during December−June and 1 location-fix every 4 hours during July−November. Location data were transmitted to our base station every 10 hours (maximum 6 location-fixes per transmission). All collars included QFP programming, which enabled them to obtain QFP data when a GPS-fix was unsuccessful. These data are stored-on-board, along with activity data collected every 5 minutes using an accelerometer, then downloaded onto a computer once collars are recovered.

We developed the following ruleset to facilitate and ensure annual application of a consistent sound approach for our 2nd and 3rd order analyses of white-tailed deer winter habitat:

1. Winter location-fixes are obtained between 1 November and 30 April.
2. Location-fixes with horizontal error ≥50 m are censored.
3. Location-fixes beyond the base air photointerpretation are censored.
4. Calculate the 95% Kernel Density Estimator (KDE) HR for each GPS-collared deer.
5. Use only those location-fixes within the 95% KDE boundaries for all deer to estimate the annual 100% Minimum Convex Polygon (MCP) study site boundaries at IN and EL.
6. Potable water sources, or portions thereof, within the 100% MCP and 95% KDE HRs, are included in calculations of size and proportional habitat composition.
7. If occasionally a boundary of a deer's 95% KDE HR overlaps the 100% MCP study site boundary, the latter will be extended enough to include that portion of the KDE.

At the 2nd order, the annually expanding or contracting 100% MCP study site boundaries and resulting associated proportional habitat compositions constitute habitat available relative to use, which is the proportional habitat composition of individual deer 95% KDE HR (Aebischer et al. 1993). Subsequently, we will be conducting 3rd order compositional analyses with proportional habitat composition of deer home ranges representing availability and proportions of location-fixes within classified stands representing use; and examining 3rd order resource selection functions and fine-scale measurements of habitat use at the stand level. Third order and stand-level findings will be reported elsewhere.

We calculated 95% KDE HRs for each deer using AdehabitatHR (Worton 1989, Calenge 2006) in program R (R Core Team 2017) to compare size and proportional habitat composition among winters within deer, among deer within winters, and between deer of the 2 study sites. We calculated 100% MCP study site boundaries annually using the Minimum Bounding Geometry tool in ArcGIS Pro (Worton 1987). Compositional analyses of habitat use were conducted according to Aebischer et al. (1993).

## RESULTS AND DISCUSSION

An important aspect of examinations of all data (e.g., HR size, habitat composition and use) collected throughout the long-term study period is to gain an improved understanding and appreciation of the variability among deer within study sites and among winters and between study sites within winters. Ultimately, this understanding will be critical to formulating habitat management prescriptions for deer. Because deer densities are markedly lower on our EL site than at IN, we initiated our pilot study (Phase 1) with boundaries representing a larger study site at EL than at IN. This better assured our ability to capture and GPS-collar the desired number of adult females at that site, as well as at IN. As we completed each winter of the study, beginning with 10 collared females at each site, the deer's collective winter location-fixes and overall distribution were used to subsequently define each study site's boundaries (Figure 1). At IN and EL, the 100% MCP site boundaries were derived from 4,826, 17,965, and 21,976 and 5,530, 19,583, and 24,579 location-fixes, for winters 2018, 2019, and 2020, respectively. The EL site was consistently larger than the IN site, and the size (area) of each has varied markedly among the 3 winters (Table 1 and Figure 2). This was due largely to the distribution of the additional deer captured and collared each winter, but presumably, variation of movements and habitat use of all collared deer relative to varying winter conditions had an effect. We will examine these relationships more closely as our analyses progress.

Overall, the mean and median HR sizes at IN (338 and 140 ha) and EL (287 and 133 ha) were quite comparable (Table 2). However, as expected, there also was a great deal of variation in winter HR size of adult female deer, both within sites and winters, and between sites and among winters (Table 2). The very small minimum HRs sizes were primarily attributable to deer that succumbed rather quickly in the season, most often to wolf predation, and consequently their HRs were estimated using a relatively small number of location-fixes. Noteworthy, some deer were quite mobile, and in 2020, exhibited maximum HR sizes up to 2,188 ha and 1,284 ha at IN and EL (Table 2, Figure 3). Snow conditions were quite variable between sites and among winters; therefore, assessing that potential impact will be an intricate part of our ongoing analyses.

Proportional habitat composition at each site (availability at the 2nd order of analysis) remained relatively stable among the 3 winters, despite their aforementioned changing boundaries and sizes on the landscape, associated with varying winter conditions, movements and HRs of each site's deer (Table 3). However, overall, there were some key apparent differences and similarities in available habitat (by cover group) at IN and EL (Figure 4 and Table 3). The percentage of available dense conifer cover (i.e., optimum snow shelter for deer) at EL was just over 2 times that at IN (19.4% versus 9.3%), whereas moderately dense conifer cover at IN (9.3%) was almost 3 times that EL (3.5%). Hardwood stands were similarly most abundant at IN (38.5%) and EL (37.8%), and the forage cover group, a primary winter food source for deer, similarly accounted for about 10% of each site. Importantly, the understories of these abundant hardwood stands commonly provide valuable browse species as well (DelGiudice et al. 1989, 2013*b*). Mixed hardwoods were proportionally more abundant at EL (10.9%) than at IN (3.9%), whereas wetlands accounted for more of the habitat at IN (19.4%) than at EL (7.3%).

Similar to habitat composition of the study sites, mean habitat composition (by cover group) of winter HRs of the GPS-collar deer (use at the 2nd order of analysis) at each site, generally reflected relative stability among winters, despite varying winter conditions and new collars being deployed on additional deer each winter (Table 4 and Figure 1). Again, as expected, there are notable differences in how individual deer range within each site (Figure 3) and in the habitat composition of their HRs (Table 4), but overall, on average, proportional habitat similarities and differences between deer of the 2 sites, interestingly reflected those we noted at the study site level above. For example, overall, dense conifer cover accounted for about 10% of deer HRs at IN, but about 2 times that (20%) at EL, similar to the 9.3% and 19.4% at the study site level, respectively. Moderately dense cover accounted for a mean 10% and 3.4% of deer HRs at IN and EL, and at the site level, 9.3% and 3.5%, respectively, and the forage cover group was an overall mean 12.3% and 13.0% of IN and EL deer HRs, similar to the 9.3% and 10.5% at the site level. Finally, hardwood stands were an overall mean 38.7% and 33.3% of HRs at IN and EL and 38.5% versus 37.8% availability at the site level. Generally, this suggests that individual deer vary quite markedly with respect to the size and shape of their HR as winter progresses, and among winters, but that on average, they are using or selecting for the habitat cover groups of particular importance in proportion to their availability.

Our compositional analyses showed little in the way of intense habitat selection for cover groups at the IN site during the 3 winters (Table 5). Just about every cover group was used significantly ($P \leq 0.05$) more than "other" (residential, small agricultural plots) or open water (ice), but this was of little biological significance. And there were apparent, although non-significant, patterns of use of specific cover groups. For example, open conifer tended to be used less than dense and moderately dense conifer, forage, and hardwoods, and mixed hardwoods exhibited a consistent pattern of being used less than all 3 conifer groups, forage, and hardwood stands. At EL, similar to at IN, "other" and open water were selected for least, and open conifer also often was significantly ($P \leq 0.05$) selected for less than dense conifer, forage, hardwood and mixed hardwood stands (Table 6). During winter 2019, a reasonably severe winter, dense conifer was selected more intensely than the moderately dense and open conifer groups, forage, and mixed hardwood stands. With respect to ranking the use of habitat cover groups based on our analyses, hardwoods were consistently ranked the highest at both sites, which may be attributable to the value of their understories as a food source (Table 7). Wetlands consistently ranked high at IN, then moderately dense and dense conifer (the former being more abundant), and then forage (Table 7). At EL, forage and mixed hardwoods ranked consistently high over the 3 winters, and dense conifer ranked the highest during winter 2020.

Our analyses of deer winter HRs and habitat use at the 2nd order, habitat availability at the site level and use at the HR level, strongly indicate notable individual variation in HR size and habitat use. However, on average, over varying winters 2018−2020, deer were using cover groups in proportion to availability, with hardwoods, moderately dense and dense conifer stands, and forage types receiving the greatest use at both sites, with the exception of greater availability and use of wetlands at IN than at EL. Our ongoing more in-depth analyses, will examine 1) habitat selection at the 3rd order, proportional availability within deer HRs versus use (proportions of location-fixes) at the stand level, 2) fine-scale measurements of stands used and how they were used, and 3) how use was influenced by variations in snow depth and deer density.

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Table 1. Annual size (ha) of white-tailed deer, winter range study sites at Inguadona Lake and Elephant Lake, northcentral and northeastern Minnesota,winters 2017−2018 to 2019−2020.[a,b]

| | | | | Overall | |
|---|---|---|---|---|---|
| Study site | 2018 | 2019 | 2020 | Mean | SE |
| Inguadona Lake | 2,993 | 5,999 | 6,314 | 5,102 | 864 |
| Elephant Lake | 6,796 | 9,411 | 8,648 | 8,285 | 634 |

[a]Sizes estimated annually by 100% Minimum Convex Polygon (Worton 1987) using all location-fixes within the 95% Kernel Density Estimator winter (1 November−30 April) home ranges (Worton 1989) of all global positioning system-collared deer within each study site.
[b]Number of collared deer was 9, 24, and 22 at IN and 10, 26, and 19 at EL during winters 2018 to 2020, respectively.

Table 2. Annual mean (± SE) and median size (ha) of winter home ranges of global positioning system-collared, adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake and Elephant Lake study sites, northcentral and northeastern Minnesota, winters 2017−2018 to 2019−2020.[a,b]

| Winter/study site | *N* | Mean size (ha) | Median | SE | Min | Max |
|---|---|---|---|---|---|---|
| 2018 | | | | | | |
| IN | 9 | 299 | 116 | 107 | 64 | 1,001 |
| EL | 10 | 160 | 116 | 49 | 34 | 566 |
| 2019 | | | | | | |
| IN | 24 | 307 | 143 | 73 | 33 | 1,214 |
| EL | 26 | 236 | 123 | 58 | 5 | 1,087 |
| 2020 | | | | | | |
| IN | 22 | 388 | 151 | 114 | 4 | 2,188 |
| EL | 19 | 428 | 241 | 98 | 75 | 1,284 |
| Overall | | | | | | |
| IN | 55 | 338 | 140 | 58 | 4 | 2,188 |
| EL | 55 | 287 | 133 | 46 | 5 | 1,284 |

[a]Winter home ranges determined by the 95% Kernel Density Estimator (Worton 1989).
[b]The mean number of location-fixes for winter home range determinations at the Inguadona Lake and Elephant Lake sites was 536, 737, and 999 and 553, 753, and 1,293 for winters 2018, 2019, and 2020, respectively.

Table 3. Annual habitat cover group composition (% of study sites) of winter range of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (IN) and Elephant Lake (EL) sites, northcentral and northeastern Minnesota, winters 2017−2018 to 2019−2020.[a,b]

| | Percent of study area | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Conifer | | | | | | | | | |
| Study stie/Winter | Dense | Moderate | Open | Forage | Hardwood | Mixed hardwood | Wetland | Open water | Other | Total area (ha) |
| IN | | | | | | | | | | |
| 2018 | 10.3 | 11.0 | 3.1 | 10.7 | 36.5 | 4.7 | 20.8 | 2.7 | 0.2 | 3,326 |
| 2019 | 9.1 | 8.8 | 3.2 | 8.6 | 39.5 | 3.2 | 19.6 | 5.8 | 2.2 | 6,316 |
| 2020 | 8.5 | 8.1 | 2.5 | 8.6 | 39.4 | 3.7 | 17.8 | 8.0 | 3.5 | 7,357 |
| Overall | | | | | | | | | | |
| Mean | 9.3 | 9.3 | 2.9 | 9.3 | 38.5 | 3.9 | 19.4 | 5.5 | 2.0 | 5,666 |
| SE | 0.4 | 0.7 | 0.2 | 0.6 | 0.8 | 0.4 | 0.7 | 1.2 | 0.8 | 986 |
| EL | | | | | | | | | | |
| 2018 | 21.6 | 4.2 | 3.1 | 8.8 | 36.8 | 13.4 | 6.2 | 5.0 | 0.9 | 6,958 |
| 2019 | 18.9 | 3.2 | 1.9 | 10.3 | 39.1 | 9.7 | 7.9 | 8.2 | 0.7 | 9,697 |
| 2020 | 17.7 | 3.0 | 1.7 | 12.5 | 37.6 | 9.5 | 7.8 | 9.5 | 0.7 | 9,207 |
| Overall | | | | | | | | | | |
| Mean | 19.4 | 3.5 | 2.2 | 10.5 | 37.8 | 10.9 | 7.3 | 7.6 | 0.8 | 8,621 |
| SE | 0.9 | 0.3 | 0.4 | 0.9 | 0.5 | 1.0 | 0.5 | 1.1 | 0.0 | 689 |

[a]Total area of each site includes the 100% Minimum Convex Polygon (Worton 1987)and any area of each global positioning system-collared deer's 95% Kernel Density Estimated home range (Worton 1989) that extends beyond the site boundaries. This explains the difference in total areas of the 2 study sites compared to their areas reported in Table 1.
[b]Number of collared deer was 9, 24, and 22 at IN and 10, 26, and 19 at EL during winters 2018 to 2020, respectively.

Table 4. Mean (± SE) annual cover group composition of winter home ranges of global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (IN) and Elephant Lake (EL) sites, northcentral and northeastern Minnesota, winters 2017−2018 to 2019−2020.[a,b]

| | Percent of 95% KDE home range | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Conifer | | | | | | | | |
| Study site/winter | Dense | Moderate | Open | Forage | Hardwood | Mixed hardwood | Wetland | Open water | Other |
| IN | | | | | | | | | |
| 2018 | | | | | | | | | |
| Mean | 9.1 | 12.5 | 3.0 | 14.8 | 34.5 | 4.3 | 20.7 | 0.8 | 0.1 |
| SE | 2.0 | 3.8 | 0.8 | 3.5 | 5.4 | 1.2 | 3.7 | 0.4 | 0.1 |
| Min | 1.4 | 1.6 | 0.0 | 0.0 | 0.5 | 0.0 | 1.1 | 0.0 | 0.0 |
| Max | 22.2 | 39.8 | 6.0 | 40.1 | 55.9 | 11.2 | 43.0 | 3.5 | 1.0 |
| 2019 | | | | | | | | | |
| Mean | 9.8 | 10.8 | 5.1 | 9.4 | 39.7 | 4.2 | 16.4 | 4.1 | 0.5 |
| SE | 1.9 | 2.6 | 1.2 | 1.4 | 3.7 | 1.6 | 1.9 | 1.2 | 0.4 |
| Min | 0.0 | 0.0 | 0.0 | 0.0 | 3.6 | 0.0 | 1.1 | 0.0 | 0.0 |
| Max | 35.6 | 60.1 | 20.6 | 26.0 | 72.9 | 39.5 | 34.3 | 25.0 | 9.3 |
| 2020 | | | | | | | | | |
| Mean | 10.4 | 6.8 | 3.4 | 12.9 | 41.8 | 3.9 | 12.7 | 6.9 | 0.7 |
| SE | 2.0 | 1.4 | 0.8 | 2.3 | 3.2 | 1.2 | 1.7 | 1.5 | 0.4 |
| Min | 0.0 | 0.0 | 0.0 | 0.0 | 13.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Max | 30.0 | 24.7 | 12.8 | 43.5 | 76.7 | 26.3 | 26.9 | 23.1 | 8.7 |
| Overall | | | | | | | | | |
| Mean | 9.8 | 10.0 | 3.8 | 12.3 | 38.7 | 4.1 | 16.6 | 3.9 | 0.5 |
| SE | 0.3 | 1.4 | 0.5 | 1.3 | 1.8 | 0.1 | 1.9 | 1.4 | 0.2 |
| EL | | | | | | | | | |
| 2018 | | | | | | | | | |
| Mean | 18.6 | 4.5 | 3.7 | 11.5 | 35.8 | 22.4 | 3.5 | 0.0 | 0.0 |
| SE | 5.9 | 1.3 | 1.8 | 3.7 | 5.9 | 6.3 | 1.0 | 0.0 | 0.0 |
| Min | 0.0 | 0.0 | 0.0 | 0.7 | 7.8 | 0.7 | 0.0 | 0.0 | 0.0 |
| Max | 54.0 | 15.4 | 15.4 | 42.0 | 76.9 | 72.9 | 10.4 | 0.0 | 0.0 |
| 2019 | | | | | | | | | |
| Mean | 19.5 | 2.8 | 1.5 | 14.9 | 35.8 | 11.4 | 7.7 | 4.3 | 1.9 |
| SE | 3.0 | 0.7 | 0.5 | 2.6 | 3.7 | 2.5 | 1.3 | 2.0 | 1.4 |
| Min | 0.0 | 0.0 | 0.0 | 0.0 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Max | 54.0 | 13.4 | 10.3 | 54.0 | 68.8 | 51.3 | 25.8 | 40.6 | 35.9 |
| 2020 | | | | | | | | | |
| Mean | 22.0 | 3.0 | 1.4 | 12.4 | 28.3 | 9.0 | 6.5 | 13.5 | 4.1 |
| SE | 2.7 | 0.7 | 0.5 | 2.8 | 3.1 | 1.4 | 1.1 | 3.8 | 1.7 |
| Min | 7.0 | 0.0 | 0.0 | 0.2 | 1.7 | 1.3 | 0.0 | 0.0 | 0.0 |
| Max | 52.8 | 8.4 | 8.2 | 44.6 | 54.0 | 21.6 | 19.1 | 32.3 | 45.5 |
| Overall | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 20.0 | 3.4 | 2.2 | 13.0 | 33.3 | 14.2 | 5.9 | 5.9 | 2.0 |
| SE | 0.8 | 0.4 | 0.6 | 0.8 | 2.1 | 3.4 | 1.0 | 3.3 | 1.0 |

[a]Winter home ranges were determined by the 95% Kernel Density Estimator (Worton 1989).
[b]Number of collared deer was 9, 24, and 22 at IN and 10, 26, and 19 at EL during winters 2018 to 2020, respectively.

Table 5. Simplified ranking matrices for global positioning system-collared adult (≥1.5 yr), female white-tailed deer, based on comparing proportions of habitat cover groups available within annual 100% Minimum Convex Polygon study site boundaries and the proportions of cover groups within each deer's winter home range at the Inguadona Lake site, northcentral Minnesota, winters 2017−2018 to 2019−2020.[a,b,c]

| | Conifer | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cover group | Dense | Moderate | Open | Forage | Hardwood | Mixed hardwood | Wetland | Other | Open water |
| 2018 | | | | | | | | | |
| Dense conifer | 0 | - | + | + | + | + | - | +++ | +++ |
| Mod conifer | + | 0 | + | + | + | + | + | +++ | +++ |
| Open conifer | - | - | 0 | - | - | + | - | + | + |
| Forage | - | - | + | 0 | - | + | - | + | +++ |
| Hardwood | - | - | + | - | 0 | + | - | +++ | +++ |
| Mixed hardwood | - | - | - | - | - | 0 | - | + | +++ |
| Wetland | + | - | + | + | + | + | 0 | +++ | +++ |
| Other | --- | --- | - | - | --- | - | --- | 0 | + |
| Open water | --- | --- | - | --- | --- | --- | --- | - | 0 |
| 2019 | | | | | | | | | |
| Dense conifer | 0 | - | + | + | - | + | - | +++ | +++ |
| Mod conifer | + | 0 | + | + | - | + | + | +++ | +++ |
| Open conifer | - | - | 0 | - | - | + | - | +++ | + |
| Forage | - | - | + | 0 | - | + | - | +++ | +++ |
| Hardwood | + | + | + | + | 0 | +++ | + | +++ | +++ |
| Mixed hardwood | - | - | - | - | --- | 0 | - | +++ | + |
| Wetland | + | - | + | + | - | + | 0 | +++ | +++ |
| Other | --- | --- | --- | --- | --- | --- | --- | 0 | +++ |
| Open water | --- | --- | - | --- | --- | - | --- | +++ | 0 |
| 2020 | | | | | | | | | |
| Dense conifer | 0 | + | + | - | - | + | - | +++ | + |
| Mod conifer | - | 0 | - | - | --- | + | - | +++ | + |
| Open conifer | - | + | 0 | - | - | + | - | +++ | + |
| Forage | + | + | + | 0 | - | +++ | + | +++ | + |
| Hardwood | + | +++ | + | + | 0 | +++ | +++ | +++ | +++ |
| Mixed hardwood | - | - | - | --- | --- | 0 | - | +++ | + |
| Wetland | + | + | + | - | __ | + | 0 | +++ | +++ |
| Other | --- | --- | --- | --- | --- | --- | --- | 0 | --- |
| Open water | - | - | - | - | --- | - | --- | +++ | + |

[a]Total area of each site includes the 100% Minimum Convex Polygon (Worton 1987)and any area of each global positioning system-collared deer's 95% Kernel Density Estimated home range (Worton 1989) that extends beyond the site boundaries. This explains the difference in total areas of the 2 study sites compared to their areas reported in Table 1.
[b]Number of collared deer was 9, 24, and 22 at IN and 10, 26, and 19 at EL during winters 2018 to 2020, respectively.
[c]Triple + or – signs represent a significant (*P*≤ 0.05) deviation from random (Aebischer et al. 1993). Single + or – signs indicates an apparent, but not significant deviation from random.

Table 6. Simplified ranking matrices for global positioning system-collared adult (≥1.5 yr), female white-tailed deer, based on comparing proportions of habitat cover groups available within annual 100% Minimum Convex Polygon study site boundaries and the proportions of cover groups within each deer's winter home range at the Elephant Lake site, northeastern Minnesota, winters 2017−2018 to 2019−2020.[a,b,c]

| | Conifer | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cover group | Dense | Moderate | Open | Forage | Hardwood | Mixed hardwood | Wetland | Other | Open water |
| 2018 | | | | | | | | | |
| Dense conifer | 0 | - | + | - | - | - | - | +++ | +++ |
| Mod conifer | + | 0 | + | - | - | - | + | +++ | +++ |
| Open conifer | - | - | 0 | --- | --- | --- | - | + | +++ |
| Forage | + | + | +++ | 0 | - | - | + | +++ | +++ |
| Hardwood | + | + | +++ | + | 0 | - | + | +++ | +++ |
| Mixed hardwood | + | + | +++ | + | + | 0 | + | +++ | +++ |
| Wetland | + | - | + | - | - | - | 0 | +++ | +++ |
| Other | --- | --- | - | --- | --- | --- | --- | 0 | +++ |
| Open water | --- | --- | --- | --- | --- | --- | --- | --- | 0 |
| 2019 | | | | | | | | | |
| Dense conifer | 0 | + | +++ | - | - | - | - | +++ | +++ |
| Mod conifer | - | 0 | + | --- | --- | - | --- | + | +++ |
| Open conifer | --- | - | 0 | --- | --- | --- | --- | + | +++ |
| Forage | + | +++ | +++ | 0 | - | + | + | +++ | +++ |
| Hardwood | + | +++ | +++ | + | 0 | + | + | +++ | +++ |
| Mixed hardwood | + | + | +++ | - | - | 0 | - | +++ | +++ |
| Wetland | + | +++ | +++ | - | - | + | 0 | +++ | +++ |
| Other | --- | - | - | --- | --- | + | --- | 0 | +++ |
| Open water | --- | --- | --- | --- | --- | --- | --- | --- | 0 |
| 2020 | | | | | | | | | |
| Dense conifer | 0 | +++ | +++ | +++ | + | +++ | + | + | +++ |
| Mod conifer | --- | 0 | + | - | - | - | + | + | +++ |
| Open conifer | --- | - | 0 | --- | --- | --- | - | - | + |
| Forage | --- | + | +++ | 0 | - | - | + | + | + |
| Hardwood | - | + | +++ | + | 0 | - | + | + | +++ |
| Mixed hardwood | --- | + | +++ | + | + | 0 | + | + | +++ |
| Wetland | - | + | + | - | - | - | 0 | + | + |
| Other | - | - | + | - | - | - | - | 0 | +++ |
| Open water | --- | - | - | - | --- | --- | - | --- | 0 |

[a]Total area of each site includes the 100% Minimum Convex Polygon (Worton 1987)and any area of each global positioning system-collared deer's 95% Kernel Density Estimated home range (Worton 1989) that extends beyond the site boundaries. This explains the difference in total areas of the 2 study sites compared to their areas reported in Table 1.
[b]Number of collared deer was 9, 24, and 22 at IN and 10, 26, and 19 at EL during winters 2018 to 2020, respectively.
[c]Triple + or – signs represent a significant ($P \leq 0.05$) deviation from random (Aebischer et al. 1993). Single + or – signs indicates an apparent, but not significant deviation from random.

Table 7. Ranking of habitat cover groups used by global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake and Elephant Lake study sites, northcentral and northeastern Minnesota, winters 2017−2018 to 2019−2020.[a,b]

| | Inguadona Lake | | | | Elephant Lake | | | | Overall |
|---|---|---|---|---|---|---|---|---|---|
| Cover group | 2018 | 2019 | 2020 | Mean | 2018 | 2019 | 2020 | Mean | Mean |
| Dense conifer | 6 | 5 | 5 | 5.3 | 3 | 4 | 8 | 5.0 | 5.2 |
| Moderate conifer | 8 | 7 | 3 | 6.0 | 5 | 3 | 3 | 3.7 | 4.8 |
| Open conifer | 3 | 3 | 4 | 3.3 | 2 | 2 | 1 | 1.7 | 2.5 |
| Forage | 4 | 4 | 7 | 5.0 | 6 | 7 | 5 | 6.0 | 5.5 |
| Hardwoods | 5 | 8 | 8 | 7.0 | 7 | 8 | 6 | 7.0 | 7.0 |
| Mixed hardwoods | 2 | 2 | 2 | 2.0 | 8 | 5 | 7 | 6.7 | 4.3 |
| Wetlands | 7 | 6 | 6 | 6.3 | 4 | 6 | 4 | 4.7 | 5.5 |
| Other[c] | 1 | 0 | 0 | 0.3 | 1 | 1 | 2 | 1.3 | 0.8 |
| Open water | 0 | 1 | 1 | 0.7 | 0 | 0 | 0 | 0.0 | 0.3 |

[a]Each habitat cover group is ranked by the number of + signs in its respective row in Tables 5 and 6 for the Inguadona Lake and Elephant Lake study sites, respectively.
[b]Number of collared deer was 9, 24, and 22 at IN and 10, 26, and 19 at EL during winters 2018 to 2020, respectively.
[c]Residential (cabins) and small agricultural plots.

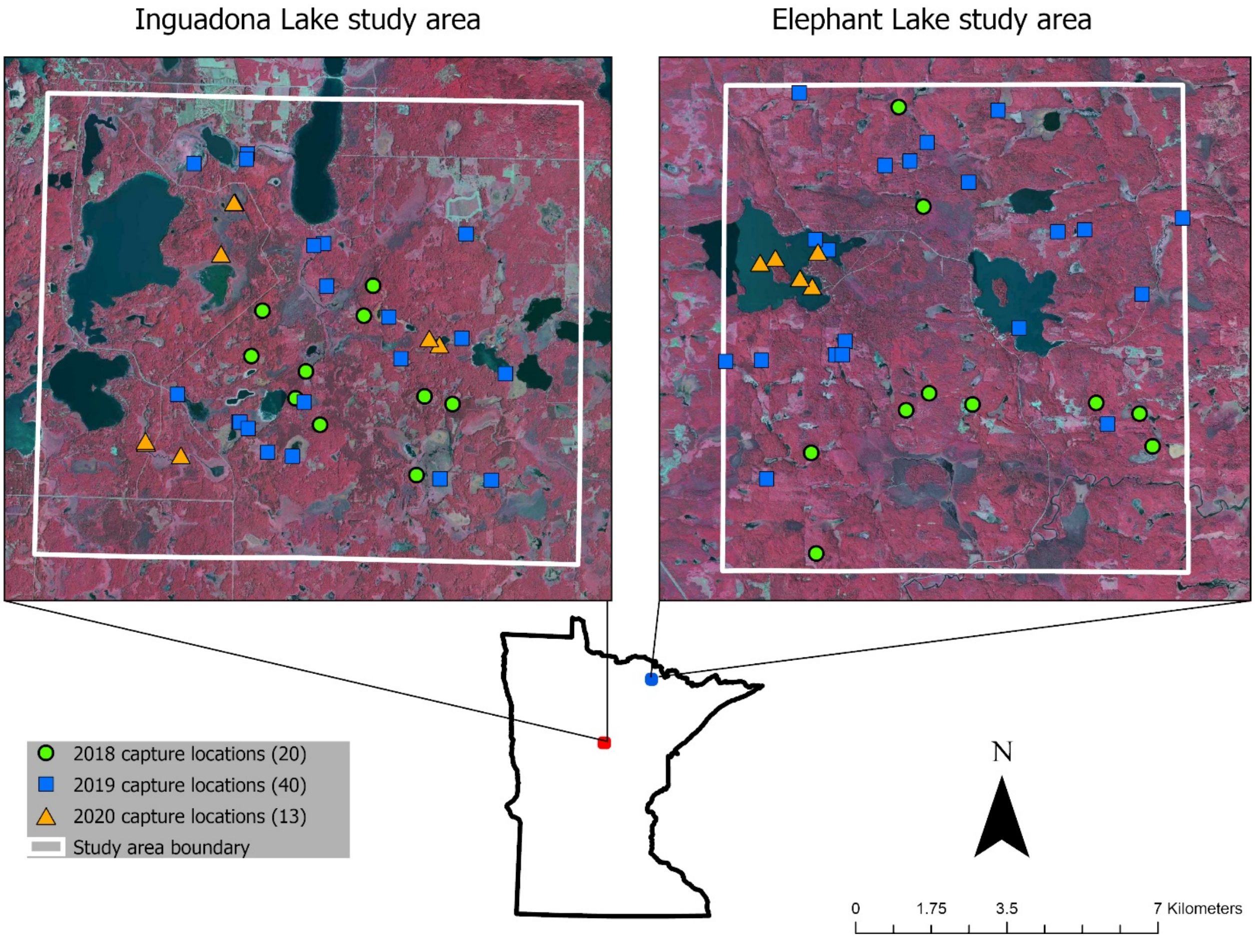



Figure 1. Helicopter net-gun capture locations of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (46 $km^2$) and Elephant Lake (76 $km^2$) study sites, northcentral and northeastern Minnesota, 10−11 March 2018, 5−8 February 2019, and 6 February 2020. One deer was captured via Clover trap at Inguadona Lake in the first winter.

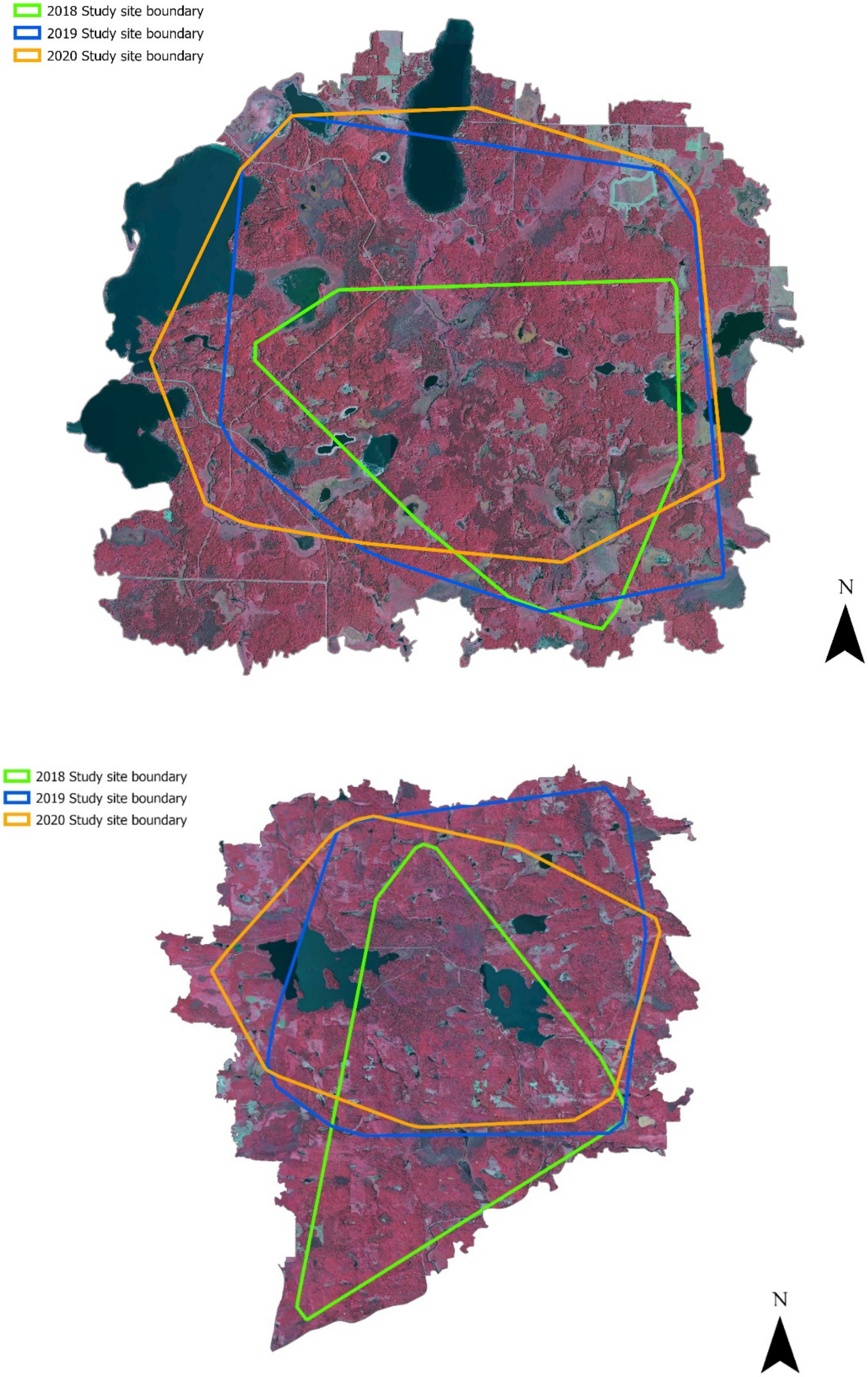
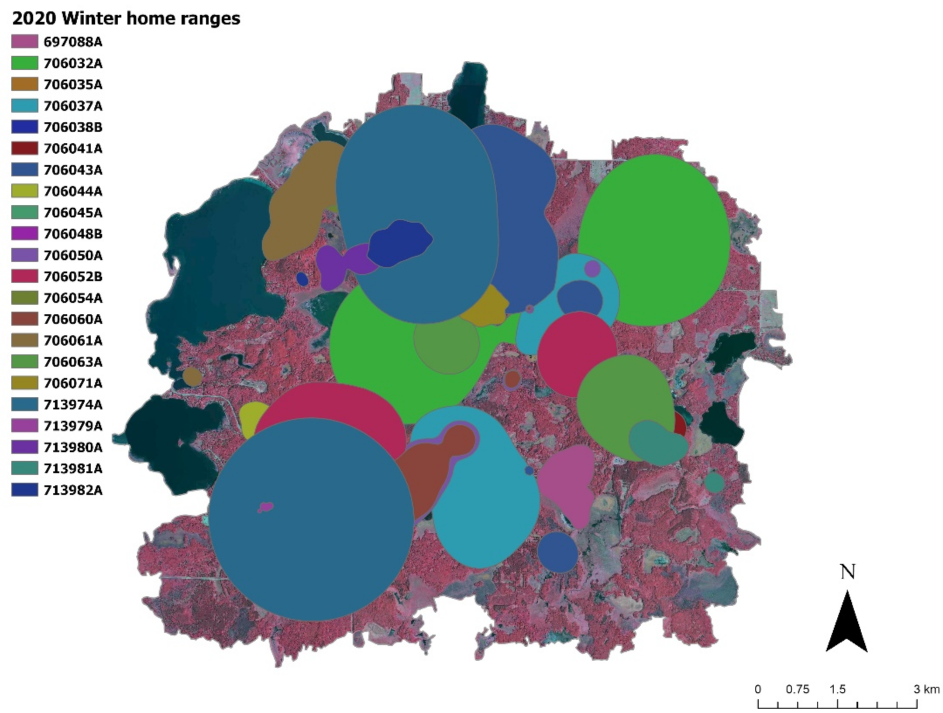



Figure 2. Annual study site boundaries based on 100% Minimum Convex Polygon of location-fixes within global positioning system-collared adult (≥1.5 yr), female deer's home ranges at the Inguadona Lake (Top, *n* = 9, 24, 22) and Elephant Lake (Bottom, *n* = 10, 26, 19) study sites, northcentral and northeastern Minnesota, winters 2017−2018 to 2019−2020.



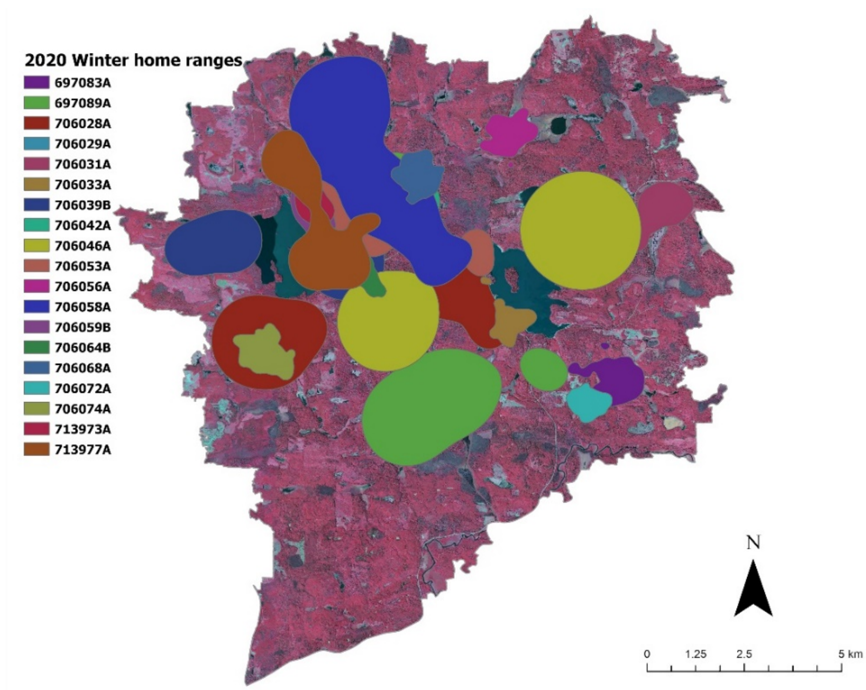
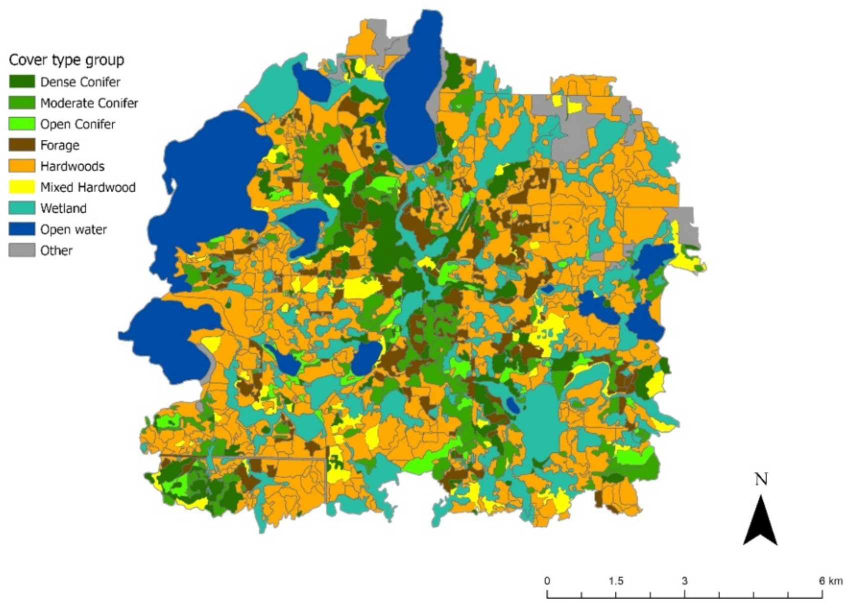




Figure 3. Winter home ranges (95% Kernel Density Estimate, Worton 1989) of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (top, $n$ = 22) and Elephant Lake (bottom, $n$ = 19) study sites, northcentral and northeastern Minnesota, 1 November 2019−1 May 2020.



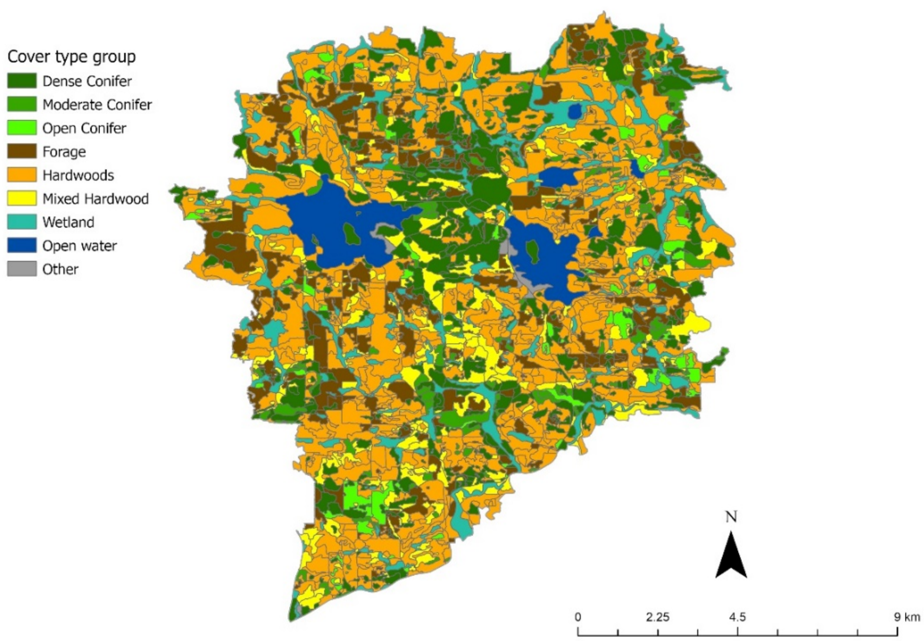




Figure 4. Habitat composition (by cover type group) of winter range of adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (top) and Elephant Lake (bottom) study sites, northcentral and northeastern Minnesota, winter 2019−2020, accomplished by cover type (stand level) air photointerpretation and Light Detection and Ranging (LiDAR). Cover types were classified to a minimum size of 0.5 hectares, then aggregated into cover groups (see legend). Cover type codes are presented in Table 1 in Smith et al. (2019).