Establishing the Feasibility of Making Fine-scale Measurements of Habitat Use by White-tailed Deer in Northern Minnesota

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Dedication

I dedicate this thesis to my wife, Tiffany, who has been by my side every step of the way.

You inspire me to achieve my goals and challenge me to be a better version of myself.

Abstract

Advances in technology enhance our ability to understand wildlife-habitat relationships. The Minnesota Department of Natural Resources' new statewide white-tailed deer (*Odocoileus virginianus*) management plan aims to enhance its ability to maintain regional deer numbers near population goals. Habitat management is acknowledged as a key component to achieving the plan's objectives. Informed habitat management prescriptions, based on an improved understanding of optimal size, shape, and arrangement of forest stands and foraging sites, and edge relationships, will contribute to a more successful integration of long-term forest and deer habitat management strategies. The objectives of my study were to establish the feasibility of combining cutting-edge Global positioning system (GPS) collar, remote sensing, and Geographic Information System technologies to 1) classify and inventory available habitat on deer winter ranges and 2) characterize how deer use habitat at the stand level to facilitate an improved understanding of their habitat requirements in northern Minnesota. During winter 2017–2018, 20 adult female deer were captured and fitted with GPS collars on 2 study areas (10/site) in northcentral (Inguadona Lake [IN]) and northeastern (Elephant Lake [EL]) Minnesota, with an additional 40 collars (20/site) deployed during winter 2018–2019. Prior to the deployment of GPS collars on free-ranging deer, I conducted stationary tests to evaluate the location-fix-success and spatial accuracy of 48 collars placed in 4 different cover types. The overall mean location error of the GPS collars was 5.7 m (± 0.15, range = 0–189), with errors in dense conifer (10.3 ± 0.52, range = 0–189 m) being greater than in hardwood stands (6.2 ± 0.22, range = 0–91 m), browse patches (3.2 ± 0.08, range = 0–26 m), and openings (3.2 ± 0.08, range = 0–32 m).

With incorporation into the collars of quick fix pseudoranging (QFP) programming, I recovered 100% of the location-fixes during the stationary tests and from 30 collars deployed on free-ranging deer. Spatially, dense conifer stands accounted for 21% and 9%, and moderately dense conifer stands for 4% and 10% of the EL and IN sites, respectively. The proportion of forage openings was 9% on both sites. The mean size (area) of available dense conifer stands was similar on both study sites (6.7, 95% CI = 4.94–8.54 ha vs 6.0, 95% CI = 4.68–7.23 ha). Available forest stands were generally circular, providing a larger core area and less edge, with a mean edge:area ratio <400 m/ha. Deer use of cover types was highly variable among individuals. Mean individual use of dense conifer stands was 23% (range = 0–79%) and 9% (range = 0–29%), and mean use of forage openings was 13% (range = 0–42%) and 24% (range = 0–70%) at the EL and IN sites, respectively. To better understand deer use at the stand level and the arrangement of cover types, I measured the distance from each location-fix to the nearest dense conifer stand and forage opening. While using forage openings, deer were a mean of 177 m (± 7, range = 0–833) and 195 m (± 4, range = 0–882) from dense conifer stands at EL and IN. Likewise, individuals using dense conifer stands were a mean of 241 m (± 6, range =0–777) and 147 m (± 8, range =0–1,030) from forage openings at the respective sites. The use of an integrated technological approach is essential to a more thorough understanding of seasonal habitat requirements of deer. The ability to retrieve 100% of location-fixes with high spatial accuracy will allow us to confidently assess winter habitat use by white-tailed deer as winter progresses and assist managers in formulating prescriptions that effectively integrate forest and habitat management strategies and activities.

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CHAPTER 1

USING QUICK FIX PSEUDORANGING TECHNOLOGY TO INCREASE FIX-SUCCESS OF GLOBAL POSITIONING SYSTEM COLLARS FOR WHITE-TAILED DEER

INTRODUCTION

Advancements in technology have allowed for notable enhancements in the performance of global positioning system (GPS) telemetry. With improved accuracy and precision of location-fixes and higher fix- and transmission-success rates, GPS collars allow near real-time accumulation of more complete location-fix datasets, which facilitates immediate monitoring of habitat use, movement rates, and intra- and inter-specific interactions (Hebblewhite and Haydon 2010, Moorcroft and Powell 2012, Zeller et al. 2016, Broekhuis et al. 2019). The combined use of more recently developed GPS and geographical information system (GIS) technologies is increasingly generating high-quality datasets not previously achievable employing traditional techniques, such as personal observation, very high-frequency (VHF) telemetry, or even early GPS collars (Frair et al. 2010, Tomkiewicz et al. 2010, Latham et al. 2015, Ironside et al. 2017).

As with any evolving technology, there are inherent errors associated with GPS collars. The spatial accuracy of location-fixes is dependent on the number and configuration of satellites used in obtaining a GPS-fix (Sager-Fradkin et al. 2007, Hansen and Riggs 2008). A minimum of 3 satellites is required to calculate a 2-dimensional (2D) fix and ≥4 satellites for more accurate 3-dimensional (3D) fixes (Rempel et al. 1995, Moen et al. 1996, D'Eon et al. 2002). Cover types can have adverse effects on GPS collar performance (e.g., spatial accuracy, fix-success), associated specifically with varied canopy cover, stem density, basal area, and topography (Moen et al. 1996, Rempel and Rodgers 1997, Dussault et al. 1999, D'Eon et al. 2002). Typically, errors are caused by a reduced view of the satellites by the GPS collar's antenna. Biases occur in habitat use analyses when missed GPS-fixes and increased location error are more likely to occur in certain cover types; this results in misleading data interpretations and incorrect inferences about habitat use (Frair et al. 2010, Hebblewhite and Haydon 2010). Fix-success rate, the number of GPS-fixes stored in log memory of the collar compared to the total number of scheduled fixes, is the largest source of bias for current GPS units (Frair et al. 2004, Hebblewhite et al. 2007), with location-fixes in open or sparsely forested types most likely to be obtained successfully.

Recently, quick fix pseudoranging (QFP) technology was incorporated into GPS collars (Globalstar Recon collars, Telonics, Mesa, Arizona, USA), 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-fix. This technology, initially developed for marine animals, collects “pseudoranges” (distances between the GPS collar and satellites) with a minimal view of the sky, and calculates a location-fix with similar spatial accuracy to 3D-locations using satellite navigational data during post-processing (Tomkiewicz et al. 2010, Patil et al. 2011). Quick fix pseudoranging technology has the potential to increase location-fix success for terrestrial species that frequently inhabit areas where dense canopies are prevalent and have commonly reduced the GPS collar antenna’s view of satellite constellations; this can be particularly valuable to studies of habitat use by deer (family Cervidae) and other ungulates. It has been incorporated into terrestrial mammal and avian studies (Tomkiewicz et al. 2010), but there is no research published on the performance of QFP-enabled GPS collars fitted to ungulates.

During winter 2017–2018, the Minnesota Department of Natural Resources (MNDNR) initiated a study of winter habitat use by white-tailed deer (*Odocoileus virginianus*) in northern Minnesota, using a combination of QFP-enabled GPS collars, remote sensing, and GIS technologies, to better understand their use of cover types at the stand level, and thus, their habitat requirements. This study relies on fine-scale measurements of habitat use to determine how size, shape, juxtaposition, and arrangement of conifer stands, forage openings, and other cover types influence their use as winter progresses (see Chapter 2 for details). Before collar deployment on free-ranging deer, the influence of vegetation type and structure (e.g., canopy closure) on collar performance requires thorough testing (Rempel et al. 1995, Dussault et al. 1999, Tomkiewicz et al. 2010). Stationary collar tests have the propensity to overestimate the performance of GPS collars when compared to analyses of collars fitted to free-ranging animals (Cargnelutti et al. 2007, Frair et al. 2010). Therefore, collars should be evaluated in both settings to account for additive variation from animal movement and habitat use.

In my study, the overall goals were to 1) evaluate the performance of GPS collars equipped with QFP technology with stationary tests prior to deploying them for the aforementioned long-term study, and 2) continue that evaluation once fitted to free-ranging deer used in that study. The underlying goal relative to the long-term study was to determine whether these unique collars would allow us to make reasonably reliable measurements of deer use of cover types at the stand level. My specific objectives were to 1) assess location-fix accuracy and success, and transmission-success in different cover types (dense conifer, hardwoods, browse, and open field); and 2) evaluate collar performance (fix-accuracy and success, and transmission-success) while deployed on free-ranging deer.

STUDY AREA

My study includes 2 deer winter range sites located in northern Minnesota's forest zone. The Inguadona Lake (IN) site (46°55'32" N, 94°07'48" W) is located in the northcentral part of the state in Cass County, 2 km south of the Chippewa National Forest border. This site is 30 km^2 and is a mosaic of state, county, and private land, with most of the latter occurring along lakeshores. 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). The topography is undulant with elevations of 400–425 m above sea level. The area is 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*); white oak (*Quercus alba*); and trembling aspen (*Populus tremuloides*; DelGiudice et al. 2013*a*). Lowlands included northern white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), balsam fir, and tamarack (*Larix laricina*).

The Elephant Lake (EL) site (48°11'35"N, 92°46'53"W), located in St. Louis County, is representative of the forest zone in northeastern Minnesota. The EL site is 86 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 severe winters of 2010–2011 and 2013–2014 (D'Angelo and Giudice 2016). The 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 stands. The lowlands included northern white cedar, black spruce, and tamarack. The uplands included northern white cedar; balsam fir; red, white, and jack pine; trembling aspen; and paper birch.

Pre-deployment collar-testing was conducted at Carlos Avery Wildlife Management Area (WMA) in Forest Lake, Minnesota (45°17'21" N, 93°07'45" W). The WMA is 100 km^2 of public land, managed by the MNDNR, approximately 35 km north of downtown Minneapolis, Minnesota. The topography is flat with an elevation of 275 m above sea level. The management area consists of coniferous and mixed hardwood forests, wetlands, grassland prairie, and small lakes.

METHODS

Global Positioning System Collar

For this study, I employed Globalstar Recon GPS collars (Model TGW-4660-4; Telonics, Inc., Mesa, Arizona, USA). These units have 1-way communication with a Globalstar data-transfer link and store-onboard capabilities. The GPS antenna is located dorsally, with the battery pack installed ventrally. The expected battery life is 1,390–1,663 days. The GPS-fix data (2D- and 3D-fixes) are transmitted to our base station every 10 hours, with a maximum of 6 location-fixes per Globalstar message. The GPS unit attempts to transmit a “message” a maximum of 3 times (separated by roughly 8 min). When all 3 message attempts fail, the data are not transmitted but stored in log memory, and the next 6 location-fixes are attempted. Telonics provided horizontal error estimates (hereafter, “horizontal error”) for each 2D and 3D location-fix using a proprietary algorithm that incorporates signal strength, satellite count, horizontal dilution of precision (HDOP), and collar-specific residual errors (Telonics 2017). The horizontal error associated with transmitted GPS-fixes have reduced precision (rounded to the nearest 5 m) due to data compression for transmission purposes. Full resolution horizontal error estimates are stored onboard. The collars are equipped with QFP programming, which prompts QFP data collection only when a GPS-fix is unsuccessful. The GPS unit attempts to obtain a GPS-fix for a maximum of 90 seconds; if unsuccessful after that search period, raw pseudorange data collected during the attempt are stored in log memory and converted to a location-fix during post-processing (Chris Lusko, Telonics Inc., personal communication). Because QFP data files tend to be large, they are not transmitted, but rather are stored onboard. Horizontal error estimates are not provided for QFP location-fixes, but location error was <20 m for 95% of the QFP locations during tests conducted by the manufacturer (Telonics 2017).

Evaluation of Cover Type Effects

I tested the performance of 48 GPS collars prior to the capture and handling of free-ranging deer. Specifically, I tested location-fix spatial accuracy and success rate, and transmission rate of collars placed in 4 cover types at the Carlos Avery WMA: dense conifer (>70% canopy closure), mixed hardwoods (leaf-off conditions), browse (aspen, willow [*Salix* spp.], and beaked hazel [*Corylus cornuta*]), and open field (0% canopy closure). The cover types are representative of those available and used by deer on the winter range study sites in northern Minnesota (DelGiudice et al. 2013*a*, *b*). I used a spherical convex densitometer (Model A 43887; Forestry Suppliers, Jackson, Mississippi, USA) to confirm percent canopy closure for the dense conifer cover type. I placed collars 1 m above ground on an available tree branch or wooden stake, and ≥10 m away from other collars. Each unit was programmed to collect a GPS-fix every 2 hours. A differentially corrected location-fix (average of ≥60 waypoints) was recorded at the focal point of each collar placement and used as the "true location" of the collar. I acquired the true location using a Trimble Juno and Terrasync antennae (Trimble Navigation Limited, Westminster, Colorado, USA), with a mean horizontal error of 0.19 m (± 0.045 [SE], range = 0.10–0.60). I conducted 2 trials, 1 to assess each shipment of GPS collars coinciding with the different years of deer capture. During the first trial, I tested 12 GPS collars, 3 placed in each of the 4 cover types for 6 days (1 to 6 December 2017, 72 fix-attempts/collar). About 5 cm of snow fell during that time interval. The second trial was 5 days (11 to 15 January 2019, 60 fix-attempts/collar) and included 36 collars, 9 in each cover type. The same dense conifer, hardwood, and browse stands were used during the 2 trials, but the open field cover type was moved for the second trial due to frozen ground conditions. Collars not included in the testing (n = 12) were placed in an open area for 1 day to confirm full functionality.

Free-Ranging Deer Evaluation

During winter 2017–2018, 10 adult (≥1.5 years) female deer were captured at each study site. A total of 19 deer were captured via net-gunning from helicopter (Hells Canyon Helicopters, Clarkston, Washington, USA), and 1 deer at the IN site was captured using a Clover trap (immobilized with 100 mg xylazine/300 mg ketamine and reversed with 15 mg yohimbine; DelGiudice et al. 2006). An additional 20 adult female deer were net-gunned at each of the 2 sites during 5–8 February 2019 (Quicksilver Air, Inc., Fairbanks, Alaska, USA). Capture and handling protocols adhered to the American Society of

Mammalogists guidelines (Sikes et al. 2011). Handling of animals included blind-folding, hobbling, recording a rectal temperature (° C), measuring chest girth and hind leg length (cm), affixing ear-tags, fitting a GPS collar, and administering a broad-spectrum antibiotic as needed (Liquamycin LA-200, Zoetis; Parsippany-Troy Hills, New Jersey, USA). Collars were programmed to obtain 1 location-fix every 2 hours during December–June and 1 location-fix every 4 hours during July–November.

During 2017−2018, 14 of the GPS collars included cotton breakaways designed to remain on the deer ≥2 years. The other 46 collars, from both years, were equipped with a pre-programmed, automatic collar-release mechanism (CR-5; Telonics, Inc., Mesa, Arizona, USA), and were scheduled to drop-off at 2.5 years post-capture to allow recovery before the battery-life was depleted. Each collar was equipped with a mortality sensor, an accelerometer, and a VHF transmitter. A mortality notification with the most recent GPS coordinates was sent via email when a limited amount of movement was detected over an 8-hour period (see Chapter 2 for details). The notification prompted an immediate investigation to determine the cause of death and recover the GPS collar. Subsequently, store-onboard data were downloaded for analysis. Similar to the collar-testing trials, I assessed the performance of collars retrieved from free-ranging deer by examining horizontal error estimates, location-fix and transmission-success rates, and percentage of QFP locations received.

Data Analysis

I projected all location-fixes to the Universal Transverse Mercator (UTM) Zone 15 coordinate system and the North American Datum 1983 (NAD83) datum using ArcGIS software (ArcGIS Pro 2.4.2; Environmental Systems Research Institute, Redlands, California, USA). Performance quality may vary among GPS collars produced in different shipments (A.M. McGraw, Wisconsin Department of Natural Resources [WIDNR], personal communication); consequently, I employed a 2-sample-t-test to determine if there was a difference in mean location error of the 2 of collars used in the trials. There was no difference between the 2 years (t = -0.134, df = 2914, P = 0.89); therefore, I combined the 2 trials into 1 dataset for all statistical analyses. I calculated location error using Euclidean distance from each location-fix to the corresponding true location of the collar (Rempel et al. 1995). The fix-success rate was calculated by summing the number of location-fixes downloaded from log memory by the maximum number of expected fix-attempts based on the amount of time deployed. The transmission-success rate is the number of GPS-fixes transmitted divided by the total number of scheduled location-fixes (with QFP locations excluded). I used a paired t-test to test for a difference between calculated location error and the Telonics estimated horizontal error. I applied an ANOVA to test for effects of cover type on location accuracy and fix-success rate; pairwise comparison with Bonferroni correction was used to examine data for differences between cover types. I used Program R 3.42 (R Core Team 2017) for all statistical analyses and results were considered significant at $P \leq 0.05$.

RESULTS

During the pre-deployment collar-testing, 96% (2,916 fixes) of an expected 3,019 GPS-fixes (3D = 3,019 and 2D = 0) were successfully transmitted (GPS-fixes only). Collars placed in dense conifer stands had the lowest transmission-success rate (87%, range = 54−100%, n = 12 collars, 665 location-fixes transmitted/751 expected) when compared to ≥98% for collars in all other cover types (Table 1). Fix-success rate was 100% (3,024 fixes) for store-onboard location-fixes with <1% (5 fixes) being QFP locations. All QFP locations were obtained in dense conifer cover and mean location error was 7.2 m (± 1.14, range = 4.7–10.7). Overall mean location error (including QFPs) was 5.7 m (± 0.15, range = 0–188). Location error was different ($F_{3, 3,020}$ = 134.1; P <0.001) among cover types, with collar errors in dense conifer being greater than in browse, hardwood, and open (Table 1, P <0.001). Location error was greater for collars in hardwood than in browse (P<0.001) and open (P<0.001), whereas, there was no difference (P>0.05) between browse and open. Of the 3,024 total location-fixes (including QFPs), 88% (2,673 fixes) were within 10 m and 97% (2,932 fixes) were within 20 m of the corresponding true locations. When comparing overall measured location error with estimated horizontal error, the latter (Table 1; 10.6 ± 0.13, range = 2.5–99.5 m) was 84% greater (t = -40.76, df = 3,018; P<0.001).

I recovered GPS collars from 30 deer (10 Mar 2018–31 May 2019) with a total of 34,758 location-fixes. Collars were deployed for a mean of 79.5 days (± 7.22, range = 1.8–153.8). Fix-success rate was 100%, with locations being 88.7% 3D (30,842 fixes), 11.2% QFP (3,903 fixes), and 0.02% 2D (Table 2, 7 fixes). Overall transmission-success of the expected 30,849 GPS-fixes (QFPs excluded) was 88% (27,177 fixes) and mean transmission-success rate of the individual collars was 91% (± 1.61, range = 67–100%). The mean horizontal error estimate was 16.1 m (± 0.07, range = 2.4–177). For GPS-fixes, 56% (17,302 fixes) had horizontal error estimates <10 m, 78% (23,949 fixes) <20 m, and 95% (29,861 fixes) <40 m.

DISCUSSION

Results from both my stationary and free-ranging collar tests showed that the incorporation of QFP locations improved our fix-success rate by 11% and effectively reduced the amount of habitat bias resulting from missed fix-attempts to zero. Fix-success rate tends to be the primary factor influencing habitat bias when relying on GPS-collar data in the development of resource step-selection functions (Hebblewhite and Haydon 2010, Moorcroft and Powell 2012). Decreases in expected fix-rates from free-ranging animals of 5–33% have been reported (Frair et al. 2010). Contrary to previous studies (Moen et al. 1996, D'Eon et al. 2002, Frair et al. 2004, Cargnelutti et al. 2007), cover type and canopy closure did not limit the fix-success of our collars, which is critical for evaluating winter habitat use by white-tailed deer and improving our understanding of their requirements. Deer have an increased propensity to seek conifer stands with dense canopy closure as snow depths increase in winter (Morrison et al. 2003, DelGiudice et al. 2013*a*). I conducted my stationary collar tests during leaf-off conditions only. The value of QFP locations became even clearer during the free-ranging collar assessments when during summer (1 July –30 November, leaf-on conditions) and winter, they accounted for 19% and 8% of seasonal location-fixes, respectively.

Similar to fix-success, transmission rates have been negatively affected by canopy cover, animal behavior, as well as transmission schedule (Schwartz and Arthur 1999, Tomkiewicz et al. 2010). Importantly, my stationary tests of these high functioning collars also demonstrated that dense canopy closure (≥70%) reduced fix-transmission rates. This appeared to be supported by reduced transmission rates from collars fitted to free-ranging deer, presumably related to movement and habitat use. Missed transmissions due to canopy cover often accumulate over time, resulting in large gaps in datasets (e.g., 1−3 days) when compared to store-onboard data. When possible, store-onboard data should be used for the most thorough analyses, but transmitted data may be sufficient for 24-hour monitoring and certain field objectives.

Location-error associated with our GPS collars was consistent with the 5−30-m errors reported by studies after the removal of selective availability (intentional degradation of GPS accuracy by the military) in 2000 (Frair et al. 2010, Montgomery et al. 2010, Tomkiewicz et al. 2010). Location-errors were greater in forested cover types than in the open with a clear view of the sky, but our collars still exhibited a relatively high spatial accuracy. It is important to know the accuracy and precision of location-fixes associated with different brands or models of GPS collars to be deployed, as well as with different manufactured batches of the same collar (Hansen and Riggs 2008; A. M. McGraw, WIDNR, personal communication). From the biologist's perspective, many years of experience with VHF and GPS collars marketed from various manufacturers, justifies their uncertainty relative to the degree and consistency of quality control applied to each GPS collar purchased and deployed in the field on wild animals. When spatial accuracy of location-fixes obtained by these collars is negatively influenced by tree density or the structural characteristics of commonly used cover types, and there is no way to overcome this challenge; it may not only bias habitat use and selection analyses but preclude reliable fine-scale measurements of how deer use cover types at the stand level. This kind of information can be critical to formulating prescriptions that facilitate effective integration and coordination of improved, long-term deer habitat and forest management (Thomas et al. 1979; DelGiudice 2017; Smith et al. 2019; see Chapter 2). Horizontal error is a conservative estimate that was consistently greater than my measured location error. It is common practice to censor locations with high spatial inaccuracy by eliminating less precise 2D-fix-attempts (D'Eon and Delparte 2005, Lewis et al. 2007) and establishing HDOP and PDOP value thresholds for screening (Moen et al. 1996, Rempel and Rodgers 1997, D'Eon and Delparte 2005, Lewis et al. 2007). D'eon and Delparte (2005) determined that PDOP thresholds are inconsistent among collar manufacturers and models, and have the potential to suggest omitting up to 37% of the collected data. However, horizontal error estimates of my tested collars incorporate these different methods into their algorithm and can be used for data-censoring based on acceptable precision relative to study objectives.

My findings demonstrate that QFP technology can be of considerable value to movement studies, where consecutive locations are required to calculate step lengths, or habitat selection studies, where bias associated with missing data can create unreliable or even false inferences. Collars can also be programmed to collect only QFP locations if location accuracy is not most important to study objectives. The short amount of time to obtain a fix can increase battery efficiency by 6–20% (Tomkiewicz et al. 2010), allowing studies to monitor individuals for extended periods of time, similar to the capabilities of long-term VHF studies (DelGiudice et al. 2013*a*, *b*). The ability to retrieve 100% of location-fixes with high spatial accuracy will allow us to confidently assess winter habitat use by white-tailed deer as winter progresses and assist managers in formulating prescriptions that effectively integrate forest and habitat management strategies and activities.

TABLES

Table 1. Summary statistics by habitat type for store-onboard data from global positioning system (GPS) collars.[a] Twelve collars were tested in each cover type at the Carlos Avery Wildlife Management Area, Minnesota, USA, 1–8 December 2017 11–16 January 2019.

Cover type	Mean location error (m)[b]	SE	Maximum location error (m)[c]	Number of successful fixes	Overall fix-success rate (%)	Percentage of GPS locations successfully transmitted (%)[d]
Browse	3.2	0.08	25.5	756	100	99.5
Conifer	10.3	0.52	188.9	756	100	88.5
Hardwood	6.2	0.22	90.8	756	100	98.3
Open	3.2	0.08	32.0	756	100	100
Overall	5.7	0.15	188.9	3,024	100	96.7

[a] Globalstar Recon GPS units (Model IGW-4660-4; Telonics, Inc., Mesa, Arizona).

[b] Location error was calculated by taking the Euclidean distance from the GPS location and the “true location” for each GPS-fix. True locations were obtained using a Trimble Juno and Terrasync antennae at the focal point of each collar (see Methods).

[c] Minimum location error was zero for all cover types.

[d] Transmission-success rate is calculated from the GPS locations only (i.e., Quick fix pseudoranging (QFP) locations excluded; QFP fixes = 5, all in dense conifer cover).

Table 2. Summary statistics of location-fix data and associated performance metrics downloaded from global positioning system (GPS) collars[a] recovered from 30 adult (≥1.5 yr), female white-tailed deer, 10 March 2018–31 May 2019. Collars were deployed at the Inguadona Lake (IN) and Elephant Lake (EL) study sites, northcentral and northeastern Minnesota, USA.

Collar ID	Study site	Number of location-fixes	Mean horizontal error[b] (m ± SE)	Overall fix-success rate (%)	Percent QFP locations[c]	GPS-fix transmission-success rate[d] (%)
697084A	IN	2,186	17.0 ± 0.31	100	18.3	87.2
697085A	IN	842	16.2 ± 0.47	100	13.3	88.9
697086A	IN	1,829	15.4 ± 0.29	100	9.6	88.6
697092A	IN	22	13.4 ± 1.51	100	9.1	95.0
697095A	IN	355	13.6 ± 0.58	100	0.0	91.3
697096A	IN	3,479	16.5 ± 0.23	100	11.6	91.5
697098A	IN	828	15.3 ± 0.38	100	17.6	90.3
699964A	IN	2,141	16.7 ± 0.31	100	14.7	90.6
699966A	IN	3,068	16.0 ± 0.24	100	12.6	69.3
706038A	IN	240	15.3 ± 0.88	100	1.3	97.5
706039A	IN	78	17.8 ± 1.81	100	0.0	98.7
706040A	IN	487	12.7 ± 0.41	100	0.4	100
706057A	IN	498	14.1 ± 0.51	100	0.4	99.4
706059A	IN	343	14.5 ± 0.62	100	0.9	98.8

706070A	IN	186	12.4 ± 0.53	100	1.1	96.7
697087A	EL	458	16.9 ± 0.58	100	12.4	67.3
697090A	EL	2,185	17.1 ± 0.30	100	15.3	91.3
697091A	EL	2,532	15.5 ± 0.27	100	6.9	91.4
697093A	EL	953	18.2 ± 0.47	100	15.4	85.6
697094A	EL	3,460	14.8 ± 0.20	100	8.6	92.3
697097A	EL	2,081	17.3 ± 0.31	100	16.5	80.4
699965A	EL	583	16.0 ± 0.53	100	7.5	71.1
699967A	EL	2,713	17.5 ± 0.27	100	13.7	85.0
706030A	EL	1,081	15.8 ± 0.37	100	6.1	93.9
706036A	EL	630	18.1 ± 0.57	100	10.0	95.9
706048A	EL	460	15.4 ± 0.61	100	1.5	98.7
706052A	EL	111	11.9 ± 0.69	100	0.0	100
706055A	EL	101	12.7 ± 0.76	100	2.0	98.0
706062A	EL	46	23.6 ± 3.17	100	2.2	97.8
706064A	EL	782	14.9 ± 0.41	100	5.6	99.2
Overall		34,758	16.1 ± 0.07	100	11.3	88.1

[a] Globalstar Recon GPS units (Model IGW-4660-4; Telonics, Inc., Mesa, Arizona, USA).

[b] Horizontal error was calculated by Telonics and downloaded with the location data.

[c] Quick fix pseudoranging (QFP) locations were recorded only when a GPS-fix was unsuccessful.

[d] Transmission-success rate is calculated from the GPS locations only (i.e., QFP locations excluded).

CHAPTER 2

ESTABLISHING THE FEASIBILITY OF MAKING FINE-SCALE MEASUREMENTS OF HABITAT USE BY WHITE-TAILED DEER IN NORTHERN MINNESOTA

INTRODUCTION

Knowledge of winter habitat use by white-tailed deer (*Odocoileus virginianus*) is fundamental to our understanding of how these animals fulfill their biological requirements while exposed to a highly variable environment (Ozoga 1968, Morrison et al. 2003, Beyer et al. 2010). Weather conditions at northern latitudes have the greatest effect on their use of winter habitat; as snow depths increase beyond 18 cm, energy requirements for mobility increase, and forage availability and body condition decrease (Moen 1976, Dumont et al. 2000, DelGiudice et al. 2013*b*). Restricted mobility and reduced endurance of deer additionally increase their vulnerability to wolf (*Canis lupus*) predation (Nelson and Mech 1986*a*, *b*; DelGiudice 1998; DelGiudice et al. 2002). Deer adapt by reducing their movements, localizing in areas where dense conifer cover is prevalent, or migrating to winter ranges where food and snow shelter are more available (Nelson 1995, Sabine et al. 2002, Fieberg et al. 2008, Beyer et al. 2010).

In the northern Great Lakes region, wintering complexes are typically dominated by dense stands (≥70% canopy cover) of northern white cedar (*Thuja occidentalis*), eastern hemlock (*Tsuga canadensis*), eastern white pine (*Pinus strobus*), and balsam fir (*Abies balsamea*,), which retain up to 45% of the snow-load in their canopies. (Tierson et al. 1985, Van Deelen et al. 1999, Hofmeyer et al. 2009, DelGiudice et al. 2013*a*). At snow depths ≥50 cm in the open, habitat selection by deer increasingly favors snow shelter. Consequently, during severe winters, dense conifer cover in close proximity to high-quality foraging sites is important to survival (Thomas et al. 1979; DelGiudice et al. 2002, 2006, 2013*a*, *b*).

Deer browse is commonly found in natural openings, regenerating hardwood stands, and recently logged areas, which promotes future growth of nutritious shade-intolerant species and provides seasonal food from cut treetops normally unattainable by deer (Thomas et al. 1979, Morrison et al. 2003, Potvin and Boots 2004). Deer have a diverse winter diet (up to 36 species) in northern Minnesota, but foraging sites have most commonly (76%) included 4 available species: beaked hazel (*Corylus cornuta*), mountain maple (*Acer spicatum*), trembling aspen (*Populus tremuloides)*, and speckled alder (*Alnus incana*); beaked hazel and mountain maple alone have accounted for 68% of total stems browsed (DelGiudice et al. 2013*a*).

In response to recommendations from the Office of Legislative Auditor, the Minnesota Department of Natural Resources' (MNDNR) recently developed a statewide deer management plan to improve estimates of regional deer populations and vital statistics and gain a better understanding of habitat requirements for integration into forest management planning, strategies, and activities. Prompted by the new management plan, the MNDNR initiated a long-term study utilizing cutting-edge global positioning system (GPS) collars to improve understanding of optimal size, shape, and arrangement of forest stands and foraging sites (and edge relationships) used by deer in northern Minnesota (DelGiudice et al. 2019, Smith et al. 2019). The use of GPS technology—with improved location-fix accuracy (± 5–30 m), high rates of fix success, increased temporal distribution of location-fixes (i.e., 24-hr monitoring), and reduced cost (time and monetary) required to collect data (Pellerin et al. 2008, Kochanny et al. 2009)—has the potential to provide accurate location data not available via very high frequency (VHF) telemetry studies, and to facilitate fine-scale measurements of habitat use (Smith et al. 2019; see Chapter 1).

The goals of my research was to establish the feasibility of employing an integrated technological approach in the field and laboratory to 1) quantify available deer habitat on winter ranges at the stand level, and 2) characterize how deer use that habitat at the stand level to facilitate an improved understanding of their habitat requirements on 2 study sites, 1 in northcentral and 1 in northeastern Minnesota. Using novel GPS collars, equipped with quick fix pseudoranging (QFP) technology; remote sensing (e.g., aerial imagery, light detection and ranging [LiDAR]); and the most current geographic information system (GIS), my specific objectives were to 1) accurately classify and inventory available cover types, including forest stands, by 1−3 dominant tree species, height class, and percent canopy closure class (conifers only); openings (forage and other); and water, using a classification system relevant to deer biological requirements; 2) compare cover type composition within winter home ranges of deer on the 2 study sites; 3) characterize available and used cover types at the stand level according to dominant tree species and structure, area, shape, arrangement, edge, and edge:area ratio; and 4) make fine-scale measurements of deer use of these cover types (e.g., area and distances to edge and center of cover type, and distances to nearest conifer cover and forage openings).

STUDY AREA

As described in Chapter 1, my study area included 2 deer winter range sites, Elephant Lake (EL; 86 km^2) and Inguadona Lake (IN; 38 km^2) in northeastern and northcentral Minnesota (Figure 1). These sites allow natural comparisons of potential influences of differences in winter severity, habitat composition, and deer density on habitat use and requirements. The uplands included red (*P. resinosa*), white, and jack pine (*P. banksiana*); northern white cedar; paper birch (*Betula papyrifera*); black ash (*Fraxinus nigra*); red maple (*Acer rubrum*); balsam fir; white oak (*Quercus alba*); and trembling aspen (DelGiudice et al. 2013*b*). Lowlands included northern white cedar, black spruce (*Picea mariana*), balsam fir, and tamarack (*Larix laricina*).

Winter conditions range from mild to severe with snow cover regularly present from November to April. During 1981–2010, the average January temperature was –15° C and –13° C and mean annual snowfall was 165 cm and 110 cm for the EL and IN sites, respectively (MN Climatology 2018). The MNDNR calculates an annual Winter Severity Index (WSI) by accumulating 1 point for each day with an ambient temperature ≤–17.8° C and an additional point for each day with snow cover ≥38 cm during November–May. Annual maximum WSI values <100, 100−180, and >180 are assessed as mild, moderately severe, and severe, respectively, relative to impacts on deer survival and reproduction (DelGiudice et al. 2002, 2006). Maximum WSI at EL and IN at the end of winter 2017−2018 was 130 and 60, respectively.

The primary source of natural mortality of adult female deer at both study sites was wolf (*Canis lupus*) predation (DelGiudice et al. 2002). The wolf population estimate in northern Minnesota as of 2017 was 2,856, or 4 wolves/100 km^2 (Erb et al. 2017). Black bear (*Ursus americanus*) and wolf predation have been the primary 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 or 23 bear/100 km^2 (Garshelis and Tri 2017).

METHODS

As described in Chapter 1, 20 (10/site) adult female deer were captured and fitted with a Globalstar Recon GPS collar (Model IGW-4660-4; Telonics, Inc., Mesa, Arizona, USA) on 10–11 March 2018. Collars were programmed to obtain 1 location-fix every 2 hours from December to June (see Chapter 1 for additional collar specifications). Each collar was equipped with QFP technology, which improves location-fix acquisition in dense stands (see Chapter 1), a mortality sensor, and VHF component. The mortality sensor records an "Active" reading based on slight changes in the gravitational force of the collar's 3-axis accelerometer when sampled every second. A mortality email notification with GPS-coordinates and a link to aerial imagery is sent when less than 5 active seconds are recorded over an 8-hour time interval (DelGiudice et al. 2019).

Thorough field investigations were conducted at each mortality location to determine cause of death based on site and carcass evidence. When the mortality occurred within 7 days of capture, I assigned "capture-related" as the ultimate cause, regardless of the proximate cause (DelGiudice et al. 2002, 2006, 2019). I calculated a Kaplan–Meier (KM) survival estimate, pooled for the 2 study sites, from the date of capture to the end of winter, 11 March–31 May 2018. The KM survival curve was created using R package, *KMsurv* (R Core Team 2017).

Habitat Classification

I classified cover types at the stand level on the 2 study sites using a mirror stereoscope (Model MS27; Sokkia Co., Ltd., Tokyo, Japan) and 9"x 9" color infrared aerial photographs (1:15,840 scale) shot during October 2010 and 2012 (Minnesota Geospatial Commons 2017, unpublished data), to capture the color contrast of peak autumn foliage.

Digital orthorectified versions of the aerial photos with 0.5-m resolution were used for "heads-up" digitizing of the interpretation in ArcGIS (ArcGIS Pro 2.4.2; Environmental Systems Research Institute, Redlands, California, USA), which was then stored as polygons in a vector format. I used the National Agriculture Imagery Program (NAIP) coverage from 2013, 2015, and 2017 to account for changes over time (e.g., logging operations, windstorms).

Light detection and ranging was collected May 2011 and April 2012 at EL and IN, respectively, with a point spacing of 1.5 m, a horizontal error of 1.2 m, and root mean squared error of 5 cm (Minnesota Geospatial Offices 2017, unpublished data). Derived products from the LiDAR point cloud, included a normalized digital surface model (nDSM) with 1-m resolution for accurate tree canopy heights and percent forest canopy closure at the stand level. The nDSM was created by subtracting the digital elevation model (DEM), representing all ground returns, from the digital surface model (DSM), representing all points above ground (Corcoran et al. 2015). I calculated percent canopy closure for conifer stands by averaging the percent of nDSM points ≥2 m for a 10-m x 10-m grid and assigned them to 1 of 3 classes (open, <40%; moderate, 40%–69%; and dense, ≥70%; Ma et al. 2017).

I delineated forest stands according to a classification system developed to assign 1–3 dominant tree species, canopy height class, and percent canopy closure class (Appendix A). I also interpreted forage openings, defined as open areas with regeneration <2 m in height, swamps, and lakes. I interpreted forest stands to a minimum size of 0.5 ha (DelGiudice et al. 2013*a*), but deer habitat areas (i.e., openings) created by the Minnesota Deer Hunters Association were delineated to 0.2 ha. I combined classes into 6 similar cover type groups based on dominant and co-dominant tree species and percent canopy closure for conifer classes (dense, moderate, and open), hardwoods, mixed hardwood-conifer, forage, wetlands, and other, which includes agriculture, residential, and open water. I used Minnesota Forest Stand Inventory (FIM; MNDNR 2018, unpublished data) data and vegetation data collected at field training sites—locations of fresh deer snow-urine (i.e., urine voided in snow) collection (see DelGiudice et al. 1989, 2017); at each training site, we recorded dominant species of the forest stand, estimated tree height, DBH of dominant tree species, percent canopy closure, and snow depth—to aid photointerpretation.

Home Range Analysis

Prior to calculating home ranges, I excluded GPS-fixes with a horizontal error ≥50 m to limit spatial uncertainty (see Chapter 1). I calculated a 100% minimum convex polygon (MCP; Worton 1987) of all deer locations, pooled for winter 2017−2018 (11 Mar–30 Apr 2018) at each site, to serve as our operational study area for 2nd order habitat use analyses (Johnson 1980), rather than relying on an arbitrary human-construct. I calculated a 95% kernel density estimate (KDE; Worton 1989) of each deer's winter home range, to facilitate comparisons of 3rd order habitat use within individual home ranges and between the 2 study sites (Johnson 1980). For deer that migrated (movement ≥2 km) outside of the study area before the end of winter, I used the last point before migration as an end-date for home range calculation (Fieberg et al. 2008). Cover type polygons that partially occurred beyond the home range boundaries were retained intact to preserve their biological integrity (e.g., measurements of area, edge) for cover type analyses at the stand level; therefore, the total area of cover types per study site was greater than the calculated

MCP study site polygon. Percent availability was defined as the total area of each cover type polygon inside the home range (including boundaries extending beyond) divided by the total area of all classes. I used the adehabitatHR package (Calenge 2006) within program R software (R Core Team 2017) to calculate both MCP and KDE home ranges.

I conducted an assessment of the feasibility of making fine-scale habitat measurements for a better understanding of the variability of individual use of cover types. We used each deer's 95% KDE home range polygon to remove location-fixes outside of the home range boundaries for analysis. We characterized cover types by structure (forest stands only), area, edge, and arrangement of conifer forest cover and forage openings. Specifically, we analyzed winter location-fixes at the EL and IN sites separately, and assigned the following characteristics: dominant and co-dominant tree species of cover type being used; stand height and canopy closure classes; distances (m) from fix to center and edge of stand being used; distance to nearest dense and moderately dense conifer cover class, if not in use; distance to nearest forage opening site, if not in use; and area (ha), total edge (m), and edge:area (m/ha) ratio of cover type in use. I converted all data to the UTM (Zone 15) coordinate system and projected using NAD 1983 datum. Distance measurements were made using the tool "Near" in the most recent version of ArcGIS software (ArcGIS Pro 2.4.2).

RESULTS

GPS-collared Deer and Home Range

I recovered and downloaded complete datasets (100% of expected location-fixes) from 16 of the 19 GPS collars. I used transmitted locations from the 3 unrecovered collars (still deployed on deer) with a mean transmission-success rate of 88% (see Chapter 1). I analyzed a total of 5,278 location-fixes at the EL site and 4,641 at the IN site, with 6.4% (337 and 298 at EL and IN) of the locations at each site being QFP-fixes. There was a mean of 528 (± 18 [SE], range = 415–576, n = 10) and 515 (± 33, range = 328–716, n = 9) winter location-fixes per deer at EL and IN, respectively. Overall, removal of GPS-fixes with horizontal error estimates ≥50 m and location-fixes outside of each individual's 95% KDE home range boundaries, resulted in 3.8% of the locations censored. All 10 deer at the EL site were non-migratory and 3 deer (33%, n = 9) migrated from the IN site during 18–25 April 2018.

The size of 95% KDE winter home ranges was highly variable (Table 1). The mean home range size for the entire winter study period (12 Mar–30 Apr) was 157 ha (95% CI = 57–209) and 262 ha (95% CI = 54–321) at EL and IN, respectively. When we separated the study period into 2 phases to assess potential effects of winter progression, mean home range size (80, 95% CI = 51−96 ha) during Phase 1 (12–31 Mar 2018) tended to be smaller at EL compared to IN (275, 95% CI = 58–430 ha), but non-significantly so. During Phase 2 (1–30 Apr 2018) home range sizes were similar at the 2 sites (Table 1).

Based on an overlap of 95% confidence intervals, home range sizes did not differ between deer that survived winter and deer that did not (Table 1). Winter survival of the 20 GPS-collared adult female deer decreased to 0.68 (95% CI = 0.5–0.93) by the end of May 2018 (Figure 2). Consequently, the overall natural winter mortality rate was 0.32 (n = 19); all of the deer were killed by wolves. One additional mortality occurred within 2 days of capture on the IN site; although preyed upon by wolves, I assessed it as capture-related and censored it from the analysis. Natural mortality was similar at EL (0.32) and IN (0.33).

Habitat Classification and Availability

I classified a total of 1,030 and 465 cover types at the stand level on the EL and IN sites, respectively, using the 100% MCP home range to define each site's boundaries. The total area of cover types at EL and IN was 8,616 ha and 3,825 ha, associated with 1,619,619 m and 759,105 m of edge, respectively. Hardwoods were the most abundant cover type group on both sites, accounting for 40% and 39% of the total area at EL (Table 2) and IN (Table 3), and 38% of total edge at both sites. Dense and moderately dense conifer stands comprised 21% and 4% of EL, compared to 9% and 10%, respectively, at IN . Northern white cedar was the most abundant species in the dense conifer cover group at EL, accounting for 60% of the group's total area and 13% of the overall study site (Table 2). Conifer cover at IN was primarily red pine (13%), affording 51% and 35% of the moderately dense and dense canopy cover (Table 3). The proportion of forage openings was 9% on both sites. Mean stand size and mean edge were similar among cover types and study sites (Tables 4 and 5). Mean edge:area ratios were similar for all cover types and cover groups, characterized as more circular in shape, providing less available edge and larger cores, except for paper birch (Tables 4 and 5). Paper birch had a mean edge:area ratio of 43 m/ha (95% CI = 32.2–54.3) and 77 m/ha (95% CI = 62.9–91.9) at EL (Table 4) and IN (Table 5), respectively.

I pooled 95% KDE home ranges for individual deer, which consisted of 372 cover types at the stand level for EL (Table 6) and 492 for IN (Table 7). The mean number of stand-level cover types was 37 (± 8.49, range = 13–109) and 55 (± 8.49, range = 13–189) per deer at EL and IN, respectively (Appendix B). The mean proportion of total area available in the home range of individual deer was 39.3% (± 5.59) and 30.0% (± 5.96) for hardwood, 15.5% (± 4.7) and 6.1% (± 1.33) for dense conifer, and 2.6% (± 0.65) and 12.9% (± 3.88) for moderately dense conifer at EL (Table 6) and IN (Table 7), respectively. Forage accounted for a mean of 12% of home ranges in both study sites. Northern white cedar (6.8% ± 4.03) and white pine (6.4% ± 1.61) were the most abundant conifer cover types within home ranges at EL, whereas red pine (12.9% ± 3.44) was the most available conifer within IN home ranges. Hardwood and mixed hardwood stands accounted for 34.1% (± 4.44) and 21.5% (± 5.92), respectively, of the total edge in home ranges within the EL site (Table 6). Hardwood and wetland cover groups dominated the proportion of total edge for IN with 30.8% (± 4.88) and 22.1% (± 5.67), respectively (Table 7). Forage openings occurred within all of deer home ranges at both sites (Appendix C), whereas, northern white cedar occurred in only 50% and 56% of the home ranges at EL and IN, respectively (Appendix B). White pine occurred within 90% of home ranges at EL and red pine was present within 100% of home ranges at IN.

Overall, stand-level characteristics of cover types, specifically size and edge, were quite variable among individual home ranges (Figure 3; Appendices D and E). The mean size (area) of dense conifer stands was similar on both study sites (6.7, 95% CI = 4.94–8.54 ha vs 6.0, 95% CI = 4.68–7.23 ha at EL and IN, respectively). Open conifer and hardwoods had the greatest mean stand size on EL with 12.2 ha (95% CI = 3.49–20.85) and 11.9 ha (95% CI = 9.45–14.33), respectively, whereas, wetlands had the largest mean size (17.4, 95% CI = 8.34–26.54 ha) and edge (2,510, 95% CI = 1,748–3,271 m) at IN (Figure 4). Assessed by overlap in 95% confidence intervals, we did not find differences among mean edge:area ratios of cover type groups in deer home ranges (Figure 4), although, balsam fir stands were smaller in size and more irregular in shape at IN, with a mean edge:area ratio of 466 m/ha (95% CI = 394–538), compared to at EL, where balsam fir stands had larger core areas and lower mean edge:area ratios (290, 95% CI = 226–354 m/ha; Figure 3).

Stand-Level Cover Type Use and Measurements

Deer use was measured by the percentage of GPS-fixes in each available cover type and was highly variable among individuals (Appendices F and G). Hardwood stands were the only cover type group used by every deer on both study sites, with a mean individual use of 31% (range = 2–88%) and 39% (range = 0.2–65%) at EL and IN, respectively (Table 8). Dense conifer was used a mean 23% (range = 0–79 %) at EL, with northern white cedar and white pine used a mean of 10% and 14%; however, the use of cedar was attributed to only 2 deer (Table 8, Appendix H)**.** Forage openings were used by 9 of 10 (90%) deer at EL and 8 of 9 (89%) deer at IN, with a mean use of 13% (range = 0–42 %) and 24% (range= 0–70 %), respectively. The size of dense conifer and hardwood stands used tended to be larger at EL, whereas forage and moderately dense conifer stands were larger at IN (Table 9). When using forage openings at EL, deer were a mean of 177 m (± 7, range =0–833) from dense conifer and 209 m (± 7, range = 0–586) from moderately dense conifer (Table 10). When using forage openings at the IN site, deer were a mean of 195 m (± 4, range = 0–882) from dense conifer and 204 m (± 4, range = 0–644) moderately dense conifer (Table 10). Deer using dense conifer were a mean of 241 m (± 6, range = 0–777) and 147 m (± 8, range = 0–1,030) from forage at EL and IN, respectively. On average, deer were closer to edges in all cover types when compared to the center of the cover type in use (Table 10).

DISCUSSION

Overall, the performance of these unique GPS collars, with the addition of QFP technology, provided the detailed datasets necessary to complete my objectives. Specifically, QFP programming, accounting for 6.4% of total scheduled location-fixes, facilitated an unbiased assessment of habitat use by deer, including fine-scale measurements of how they used cover types at the stand level, using 100% of location-fixes expected from recovered collars. This major advantage, and the high spatial accuracy of the location-fixes, together will be key to improving our understanding of their habitat requirements.

The spring migration rate of deer at IN (33%) in northcentral Minnesota was similar to the 35% rate in northeastern Minnesota reported by McGraw (2019), but notably lower than previously observed during a long-term study (1991−2005) in northcentral Minnesota (68%, Fieberg et al. 2008). Additionally, all deer at EL appeared to be non-migratory, contrary to what we expected based on the site's history as a wintering complex and long-term observations of management (P. Backman, MNDNR, Section of Wildlife, personal communication). Spring migrations rates near 80% for adult female deer in northeastern Minnesota, also based on long-term study, have been reported (Nelson 1995). These long-term studies have shown that annual fall and spring migration rates can be highly variable, and suggested that data collection during short-term study periods can be quite misleading (Fieberg and DelGiudice 2008, Fieberg et al. 2008).

The average size of winter home ranges of deer at both sites was similar to that reported for recent studies in northeastern Minnesota (175 ± 37 ha; McGraw 2019) and Michigan (210 ± 20 ha; Nielson and Stroud-Settles 2018); but considerably larger than historic home ranges in northern Minnesota (30–70 ha; Nelson and Mech 1979, Mooty 1987). The historic home ranges were derived from VHF telemetry data, and using different estimators; consequently, it is difficult to assess whether the differences in average home range size are real and attributable to a combination of natural factors, such as snow depth, habitat differences, or deer densities or are analytical artifacts (Mooty 1987, Van Deelen 1998, Kochanny et al. 2009, Nielson and Stroud-Settles 2018).

Overall, I assessed winter severity as moderately severe (WSI = 130) at EL, compared to mild (WSI = 60) at IN. Snow depths peaked at 55 cm and 46 cm on 25 February 2018, at EL and IN, respectively, about 2 weeks prior to the start of my study. Throughout my actual study period, maximum snow depth at El was 40 cm, and about half that at IN (22 cm). The most notable difference in snow depth between the 2 sites was during 12 March–1 April 2018 (Phase I), when the mean home range at EL was 71% smaller than at IN, likely due to the deeper snow at EL restricting deer movements (Moen 1976, DelGiudice et al. 1989). Natural mortality of adult female collared deer was similarly high (low survival) during the study period at both sites, all attributable to wolf predation (DelGiudice et al. 2019), and somewhat unexpected, given the differences in maximum snow depths and WSI values (DelGiudice et al. 2002, 2006). I expected to detect a difference in home range sizes of survivors and non-survivors, hypothesizing that either non-survivors would require larger home ranges in an attempt to fulfill their energy requirements, or that they might be restricted to smaller home ranges and experience ultimately fatal nutritional consequences. The absence of a difference in deer survival between EL and IN or home range size between survivors and non-survivors may at least be partially attributable to the limited sample sizes of GPS-collared deer on both sites.

We will investigate these relationships in more depth with increased sample sizes as the parent study progresses.

Due to late winter deer capture operations (10–11 Mar 2018), only a snapshot of overall winter conditions and their potential influence on my study deer was examined, but it included the end of winter when adult females are most energetically stressed due to gestation, reduced food availability and fat stores, and are most vulnerable to predation (Nelson and Mech 1986*a*, DelGiudice et al. 2002, Garroway and Broders 2005). Despite the relatively mild winter, wolf predation was particularly high at both sites compared to relationships of mortality rates and WSI values reported from a previous long-term (1991−2003) study in northcentral Minnesota (DelGiudice et al. 2006, 2019). Rather, my mortality (wolf predation) rates were similar to those reported during historically severe winters 1995−1996 and 2013–2014 (WSI >180) in northcentral and northeastern Minnesota (DelGiudice et al. 2002, McGraw 2019). An implicit assumption of any study of habitat selection, use, or preference is that animals will choose the optimal habitat available to increase survival and reproduction (Garshelis 2000, Buskirk and Millspaugh 2006). The relatively low snow depths during my study, but high mortality rate on both sites, suggests these 2 sites may be limited by quantity or availability of quality habitat (e.g., forage, dense cover, or their arrangement), contributing to poor body condition and hindering their ability to avoid predation in late winter (DelGiudice et al. 2019).

Results generated from my habitat classification and inventory indicated that dense conifer cover occurred at a lower prevalence on both sites and within individual deer home ranges than I expected. Previous studies in the Upper Great Lakes region and Canada have suggested that to afford sufficient snow shelter, winter ranges should be comprised of ≥50% dense conifer cover (Morrison et al. 2003, Potvin and Boots 2004). Dense conifer stands accounted for more than 40% of the area in only 1 deer's home range in my study, and both study sites (defined by 100% MCP) had <25% dense conifer cover. The availability of dense conifer cover on both sites is potentially concerning, because its value as snow shelter appears to be a critical key to assisting deer in surviving deep snow cover, a more important weather factor than ambient temperature (DelGiudice et al. 2002, 2006). However, the relatively low availability of dense cover may be attributable to the distribution of GPS-collared deer and the MCP-delineation of the sites during the relatively mild winter. Similar to my results, DelGiudice et al. (2013*b*) also concluded that dense conifer cover (<12% availability) at the IN site might be limiting to deer in severe winters. Red pine was the primary conifer species at IN, but does not typically provide as effective snow shelter as cedar and white pine (Voigt et al. 1997). Northern white cedar and white pine were the most abundant conifer species at EL, with white pine experiencing higher deer use.

In areas of high deer density, regeneration of important conifer species such as northern white cedar and white pine can be difficult, due to high browsing pressure, slow seed development, and vulnerability to drought (Hofmeyer et al. 2009, Witt and Webster 2010, Bressette et al. 2012). On average, northern white cedar may require 42 years to reach a height that is no longer accessible to deer browsing, and it is highly susceptible to inadvertent damage during harvest operations (Hofmeyer et al. 2009). For this reason, forest stands dominated by northern white cedar are transitioning to hardwood species.

Interestingly, forage openings had the same availability on both sites, but deer at IN used forage openings nearly 2 times more than at EL. Adequate food availability reduces the physiological need for dense conifer as thermal cover (Moen 1968, Dumont et al. 2000, Sabine et al. 2002). Despite the differences in snow depth, deer densities, and composition of dense conifer cover between the 2 sites, forage opening availability does not seem to be limiting, but overall food availability remains unknown. We assessed forage availability for open areas only; therefore, I did not account for availability in the understory of hardwood stands, which was the most abundant cover type group within home ranges and the most used on both study sites (Table 8). Forage openings and south-facing hardwood stands are often used more in late winter and early spring when snow cover has been reduced (Beyer et al. 2010). Mixed hardwood-conifer stands were more abundant in home ranges on EL than IN, and average percent use was higher at EL. Mixed hardwood-conifer stands allow access to browse and may afford some value as snow shelter, which can be particularly important during moderate winters (Mooty et al. 1987; Sabine et al. 2001; Morrison et al. 2002, 2003).

Because logging and harvest operations are often conducted at the stand level, it is important to characterize the size, shape (edge:area ratio), and spatial arrangement of cover types used by white-tailed deer at the stand level (Thomas et al. 1979). The edge to area ratio of available and used cover types was similar among cover types with all used forest stands being <400 m/ha. This is consistent with recommendations of Morrison et al. (2003), that suggest deer are more likely to use cover providing stands with an edge to area ratio <0.04 m/m^2 (400 m/ha) and that are circular in shape with larger cores than available edge. Although on average all of our available and used cover types met this recommendation, this may have been the result of consistent long-term, forest management strategies and techniques used in northern Minnesota. At the EL site, deer used dense conifer stands that were larger than those typically available within home ranges (17 ha [± 0.47] vs 6.7 ha [± 0.91]; Table 9, Figure 4), but the optimal size of dense conifer stands is poorly understood (Beyer et al. 2010). Thomas et al. (1979) recommended that thermal cover for white-tailed deer be a minimum of 91 m wide and suggested that the effectiveness of cover providing stands decreases as stand size decreases. It is better for dense conifer stands to be larger than smaller, although too large may not be optimal, because deer often do not utilize the center of large stands in winter (Thomas et al. 1979, Beyer et al. 2010, DelGiudice et al. 2013*a*). Voigt et al. (1997) recommended that large conifer stands be strip- or patch-cut to provide forage openings of 0.5–2 ha in size to promote optimal use. The average size of forage openings used (7.6 ha) at the EL site was similar to availability (7.1 ha), but used openings (14.4 ha) were larger than generally available (7.4 ha) at the IN site. I observed mean size of forage openings at IN were larger than what has been recommended for a maximum size of 1–11 ha (Thomas et al. 1979, Voigt et al. 1997, Beyer et al. 2010). Small forage openings provide access to food, while still being in close proximity to the edge of cover. Generally, the degree of use decreases as the size of forage openings increase and the distance from edge of dense conifer cover increases (Thomas et al. 1979). Portions of large clear-cuts do not afford ready access to cover, and thus may be underutilized in winter, but such openings may be more important to deer in summer (Voigt et al. 1997).

Distance from location-fixes in forage openings to stands of dense and moderately dense conifer cover (<210 m) was similar on both sites and consistent with findings of Morrison et al. (2003); these authors suggested that such shelter should be within 215 m of forage at moderate and deep snow depths (20–50 cm and >50 cm; Moen 1976, Sabine et al. 2001, Morrison et al. 2003). Additionally, deer selected areas within 290 m of conifer stands with moderate canopy cover (Morrison et al. 2003). These measurements represent pooled locations for the end of winter; it is important to measure and examine the variability of distances to cover and forage as winter progresses and snow depth increases. Another study in Michigan recommended that forage should be within 100 m of available cover at snow depths <50 cm and within 30 m when snow is ≥ 50 cm (Voigt et al. 1997). In the Blue Mountains of Oregon and Washington, Thomas et al. (1979) suggested incorporating proximity measurements into management prescriptions by arranging cover and forage so that deer will be within 185 m of available dense conifer while using forage openings. This translates into a maximum forage opening with a radius of 185 m (10.7 ha) for optimal arrangement.

I am not suggesting that this study provides the robust data or analyses necessary for formulating forest management prescriptions at the population and landscape levels. Rather this study's intended contribution to that goal and its realized strength is having established the feasibility of a technical approach for assessing individual variability of use of cover types relative to environmental variability, which over the long-term, has significant potential for informing and improving our understanding of the habitat requirements of northern white-tailed deer at the landscape scale. Deer adjust their movements and habitat use throughout the entire wintering period based on recent snowfall and environmental conditions (Nelson and Mech 1991, Morrison et al. 2003, DelGiudice 2013*b*). The goal of this first winter of the parent long-term study was to gain insight into cover type availability on each study site and establish the feasibility of interfacing novel GPS collars with high-resolution aerial photography and LiDAR to characterize winter habitat and make fine-scale measurements of individual deer use. The next step is to apply this approach to resource selection functions (RSF) encompassing multiple winters, with a greater sample size of deer, and across additional study areas of varying forest compositions, deer densities, and snow depths.

LITERATURE CITED

Beyer, D., B. Rudolph, K. Kintigh, C. Albright, K. Swanson, L. Smith, D. Begalle, and R. Doepker. 2010. Habitat and behavior of wintering deer in northern Michigan: a glossary of terms and associated background information. Michigan Department of Natural Resources and Environment, Wildlife Division Report 3520.

Bressette, J. W., H. Beck, and V. B. Beauchamp. 2012. Beyond the browse line: complex cascade effects mediated by white-tailed deer. Oikos 121:1749–1760.

Broekhuis, F., E. K. Madsen, K. Keiwua, and D. W. Macdonald. 2019. Using GPS collars to investigate the frequency and behavioural outcomes of intraspecific interactions among carnivores: a case study of male cheetahs in the Maasai Mara, Kenya. PLOS ONE 14:e0213910.

Buskirk, S. W., and J. J. Millspaugh. 2006. Metrics for studies of resource selection. Journal of Wildlife Management 70:358–366.

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.

Cargnelutti, B., A. Coulon, A. J. M. Hewison, M. Goulard, J. M. Angibault, and N. Morellet. 2007. Testing global positioning system performance for wildlife monitoring using mobile collars and known reference points. Journal of Wildlife Management 71:1380–1387.

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.

Corcoran, J., J. Knight, K. Pelletier, L. Rampi, and Y. Wang. 2015. The effects of point or polygon based training data on Random Forest classification accuracy of wetlands. Remote Sensing 7:4002–4025.

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

DelGiudice, G. D. 1998. Surplus killing of white-tailed deer by wolves in northcentral Minnesota. Journal of Mammalogy 79:227–235.

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. M. Hayward, editor. PLoS ONE 8:e65368. Doi:10.1371/journal.pone.0065368.

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. 2006. 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, 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: Winter Food Habits of Northern Deer. Journal of Wildlife Management 77:1664–1675.

DelGiudice, G. D., W. J. Severud, and B. S. Smith. 2019. Winter survival and cause-specific mortality of white-tailed deer in northern Minnesota: updating with GPS collars. Pages 258–264 *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, USA.

D'Eon, R. G., and D. Delparte. 2005. Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of PDOP in data screening. Journal of Applied Ecology 42:383–388.

D'Eon, R. G., R. Serrouya, and G. Smith. 2002. GPS Radiotelemetry error and bias in mountainous terrain. Wildlife Society Bulletin 30:430−439.

Dumont, A., M. Crête, J. P. Ouellet, and J. Huot. 2000. Population dynamics of northern white-tailed deer during mild winters: evidence of regulation by food competition. Canadian Journal of Zoology 78:764–776.

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 27:965–972.

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

Fieberg, J., and G. D. DelGiudice. 2008. Exploring migration data using interval-censored time-to-event models. Journal of Wildlife Management 72:1211-1219.

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

Frair, J. L., J. Fieberg, M. Hebblewhite, F. Cagnacci, N. J. DeCesare, and L. Pedrotti. 2010. Resolving issues of imprecise and habitat-biased locations in ecological analyses using GPS telemetry data. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2187–2200.

Frair, J. L., S. E. Nielsen, E. H. Merrill, S. R. Lele, M. S. Boyce, R. H. M. Munro, G. B. Stenhouse, and H. L. Beyer. 2004. Removing GPS collar bias in habitat selection studies. Journal of Applied Ecology 41:201–212.

Garroway, C. J., and H. G. Broders. 2005. The quantitative effects of population density and winter weather on the body condition of white-tailed deer (Odocoileus virginianus) in Nova Scotia, Canada. Canadian Journal of Zoology 83:1246–1256.

Garshelis, D. L. 2000. Delusions in habitat evaluation: measuring use, selection, and importance. Pages113–164 *in* L. Boitani and T. K. Fuller, editors. Research Techniques in Animal Ecology: Controversies and Consequences. Columbia University Press, New York.

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

Hansen, M. C., and R. A. Riggs. 2008. Accuracy, precision, and observation rates of global positioning system telemetry collars. Journal of Wildlife Management 72:518–526.

Hebblewhite, M., and D. T. Haydon. 2010. Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2303–2312.

Hebblewhite, M., M. Percy, and E. H. Merrill. 2007. Are all global positioning system collars created equal? Correcting habitat-induced bias using three brands in the central Canadian Rockies. Journal of Wildlife Management 71:2026–2033.

Hofmeyer, P. V., L. S. Kenefic, and R. S. Seymour. 2009. Northern white-cedar ecology and silviculture in the northeastern United States and southeastern Canada: a synthesis of knowledge. Northern Journal of Applied Forestry 26:21–27.

Ironside, K. E., D. J. Mattson, D. Choate, D. Stoner, T. Arundel, J. Hansen, T. Theimer, B. Holton, B. Jansen, J. O. Sexton, K. Longshore, T. C. Edwards, and M. Peters. 2017. Variable terrestrial GPS telemetry detection rates: addressing the probability of successful acquisitions. Wildlife Society Bulletin 41:329–341.

Johnson, D. H. 1980. The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. Ecology 61:65–71.

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.

Latham, A. D. M., M. C. Latham, D. P. Anderson, J. Cruz, D. Herries, and M. Hebblewhite. 2015. The GPS craze: six questions to address before deciding to deploy GPS technology on wildlife. New Zealand Journal of Ecology 39:143–152

Lewis, J. S., J. L. Rachlow, E. O. Garton, and L. A. Vierling. 2007. Effects of habitat on GPS collar performance: using data screening to reduce location error. Journal of Applied Ecology 44:663–671.

Ma, Q., Y. Su, and Q. Guo. 2017. Comparison of canopy cover estimations from airborne LiDAR, aerial imagery, and satellite imagery. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 10:4225–4236.

McGraw, A. M. 2019. Moose and deer resource selection and co-occurance in northeast Minnesota. Dissertation, University of Minnesota, Duluth, USA.

Minnesota Department of Natural Resources [MNDNR]. 2015. Ecological classification system. Minnesota Department of Natural Resources, St. Paul, USA. <http://www.dnr.state.mn.us/ecs/index.html>. Accessed 18 December 2018.

Minnesota State Climatology Office [MN Climatology]. 2018. Past climate data. Minnesota Department of Natural Resource, St. Paul, USA. <https://www.dnr.state.mn.us/climate/historical/summary.html>. Accessed 18 Dec 2018.

Moen, A. N. 1968. Surface temperatures and radiant heat loss from white-tailed deer. Journal of Wildlife Management 32:338.

Moen, A. N. 1976. Energy conservation by white-tailed deer in the winter. Ecology 57:192–198.

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.

Montgomery, R. A., G. J. Roloff, and J. M. V. Hoef. 2011. Implications of ignoring telemetry error on inference in wildlife resource use models. Journal of Wildlife Management 75:702–708.

Montgomery, R. A., G. J. Roloff, J. M. Ver Hoef, and J. J. Millspaugh. 2010. Can we accurately characterize wildlife resource use when telemetry data are imprecise? Journal of Wildlife Management 74:1917–1925.

Moorcroft, P. R., and R. A. Powell. 2012. Mechanistic approaches to understanding and predicting mammalian space use: recent advances, future directions. Journal of Mammalogy 93:903–916.

Mooty, J. J., P. D. Karns, T. K. Fuller. 1987. Habitat use and seasonal range size of white-tailed deer in northcentral Minnesota. Journal of Wildlife Management 51:644–648.

Morrison, S. F., G. J. Forbes, and S. J. Young. 2002. Browse occurrence, biomass, and use by white-tailed deer in a northern New Brunswick deer yard. Canadian Journal of Forest Research 32:1518–1524.

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.

Nielsen, C. K., and J. K. Stroud-Settles. 2018. Home range and habitat use of female white-tailed deer (Odocoileus virginianus) in the northern Lower Peninsula of Michigan. Mammal Study 43:179-185.

Nelson, M. E. 1995. Winter range arrival and departure of white-tailed deer in northeastern Minnesota. Canadian Journal of Zoology 73:1069–1076.

Nelson, M. E., and L. D. Mech. 1986*a*. Mortality of white-tailed deer in northeastern Minnesota. Journal of Wildlife Management 50:691–698.

Nelson, M. E., and L. D. Mech. 1986*b*. Relationship between snow depth and gray wolf predation on white-tailed deer. Journal of Wildlife Management 50:471–474.

Ozoga, J. J. 1968. Variations in microclimate in a conifer swamp deeryard in northern Michigan. Journal of Wildlife Management 32:574–585.

Patil, B., R. Patil, and A. Pittet. 2011. Energy saving techniques for GPS based tracking applications. Pages 1–10 in. 2011 Integrated Communications, Navigation, and Surveillance Conference Proceedings. IEEE, Herndon, VA, USA. <http://ieeexplore.ieee.org/document/5935335/>. Accessed 18 Dec 2019.

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., and B. Boots. 2004. Winter habitat selection by white-tailed deer on Anticosti Island 2: relationship between deer density from an aerial survey and the proportion of balsam fir forest on vegetation maps. Canadian Journal of Zoology 82:671–676.

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.

Sabine, D. L., S. F. Morrison, H. A. Whitlaw, W. B. Ballard, G. J. Forbes, and J. Bowman. 2002. Migration behavior of white-tailed deer under varying winter climate regimes in New Brunswick. Journal of Wildlife Management 66:718–728.

Sager-Fradkin, K. A., K. J. Jenkins, R. A. Hoffman, P. J. Happe, J. J. Beecham, and R. G. Wright. 2007. Fix success and accuracy of global positioning system collars in old-growth temperate coniferous forests. Journal of Wildlife Management 71:1298–1308.

Schwartz, C. C. S., and S. M. Arthur. 1999. Radiotracking large wilderness mammals: integration of GPS and Argos technology. Ursus 11: 261–273.

Sikes, R. S., W. L. Gannon, and The Animal Care and Use Committee of the American Society of Mammalogists. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. Journal of Mammalogy 92:235–253.

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. Pages 243–255 *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, USA.

Telonics. 2017. Gen4 GPS systems manual. Document number PB008383 Rev C. Telonics Inc., Mesa, Arizona, USA.

Thomas, J. W., H. Black, R. J. Scherzinger, and R. J. Pedersen. 1979. Chapter 8: deer and elk. Pages 104−127 in J. W. Thomas, technical editor. Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. Agricultural Handbook No. 553, U. S. Forest Service, Washington, D. C., USA.

Tierson, W. C., G. F. Mattfeld, R. W. Sage Jr., and D. F. Behrend. 1985. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Management 49:760–769.

Tomkiewicz, S. M., M. R. Fuller, J. G. Kie, and K. K. Bates. 2010. Global positioning system and associated technologies in animal behaviour and ecological research. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2163–2176.

Van Deelen, T. R. 1999. Deer-cedar interactions during a period of mild winters: implications for conservation of conifer swamp deeryards in the Great Lakes Region. Natural Areas Journal 19:263−274.

Van Deelen, T. R., H. Campa, III, M. Hamady, and J. B. Haufler. 1998. Migration and seasonal range dynamics of deer using adjacent deeryards in northern Michigan. Journal of Wildlife Management 62:205–213.

Verme, L. J. 1973. Movements of white-tailed deer in Upper Michigan. Journal of Wildlife Management 37:545−552.

Voigt, D. R., J. D. Broadfoot, and J. A. Baker. 1997. Forest management guidelines for the provision of white-tailed deer habitat. Ontario Ministry of Natural Resources, Forest Management Branch, part of Technical Series, version 1.0.

Witt, J. C., and C. R. Webster. 2010. Regeneration dynamics in remnant Tsuga canadensis stands in the northern Lake States: potential direct and indirect effects of herbivory. Forest Ecology and Management 260:519–525.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164– 168.

Worton, B. J. 1987. A review of models of home range for animal movement. Ecological Modelling 38:277– 298.

Zeller, K. A., K. McGarigal, S. A. Cushman, P. Beier, T. W. Vickers, and W. M. Boyce. 2016. Using step and path selection functions for estimating resistance to movement: pumas as a case study. Landscape Ecology 31:1319–1335.

Table 1. Mean size (ha) and 95% confidence interval (CI) of 95% kernel density estimated home ranges of global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018. The study period was divided into 2 phases of winter to assess potential effects of winter conditions as the season progressed; Phase 1 (12–30 Mar 2018), Phase 2 (1–30 Apr 2018), and pooled locations for the entire winter (12 Mar–30 Apr 2018).

Study site	Number of deer	Mean size (ha)	Lower CI	Upper CI	Min	Max
Phase 1						
EL	10	80	51	96	21	149
IN	9	275	58	430	55	1,099
Phase 2						
EL	10	170	32	229	34	791
IN	9	277	29	369	42	1,177
2018 Winter						
EL	10	157	57	209	32	586
IN	9	262	54	321	54	1,024
Survivor (EL)[a]	7	104	53	139	32	235
Non-survivor (EL)	3	281	-20	455	102	586
Survivor (IN)	6	336	37	460	63	1,024
Non-survivor (IN)	3	114	18	174	54	212

[a] Deer that survived through 31 May 2018 were considered survivors for winter 2018, whereas those that died before that date were non-survivors.

Table 2. Stand-level composition of cover types and cover groups within the Elephant Lake (EL) study site. Site boundaries were calculated using a 100% minimum convex polygon of pooled winter locations from 10 global positioning system-collared adult (≥1.5 yr), female white-tailed deer in northeastern Minnesota, 12 March–30 April 2018. Open water classes (lakes and ponds) were excluded from percent area and edge calculations.

Cover type	Stand count	Total area (ha)	Percent area[a]	Total edge (m)	Percent edge[b]
Black ash	81	367	4.69	101,410	6.39
Balsam fir	28	116	1.48	35,798	2.26
Black spruce	41	282	3.60	55,149	3.48
Forage	121	737	9.42	160,048	10.09
Jack pine	15	52	0.66	13,448	0.85
Paper birch	48	217	2.77	51,196	3.23
Red maple	7	67	0.85	15,952	1.01
Red pine	66	369	4.71	81,473	5.14
Residential	8	69	0.88	14,763	0.93
Swamp	69	671	8.57	159,129	10.03
Tamarack	12	40	0.51	12,573	0.79
Trembling aspen	348	3,447	44.08	627,544	39.56
N. white cedar	110	1,027	13.14	171,017	10.78
White oak	20	108	1.38	23,749	1.50
White pine	46	221	2.82	51,708	3.26

White spruce	10	33	0.42	11,484	0.72
Lake	2	795		33,178	
Cover type group[c]					
Dense conifer	244	1,620	20.72	321,022	20.25
Forage	121	737	9.42	160,048	10.23
Hardwoods	345	3,126	39.97	596,112	37.58
Mixed hardwood	159	1,080	13.80	223,739	14.00
Moderate conifer	59	294	3.75	66,241	4.18
Open conifer	25	225	2.88	45,388	2.80
Other	10	864	0.88	14,763	0.93
Wetland	69	671	8.57	159,129	10.03

[a] Total area of all cover types, excluding “open water,” was 7,821 ha. The total was used as the denominator when calculating percent area within the study site.

[b] Total edge of all cover types, excluding open water, was 1,586,442 m. This total was used as the denominator when calculating percent edge within the study site.

[c] Grouped cover types are based on dominate species of cover type classes and percent canopy cover for conifer stands.

Table 3. Stand-level composition of cover types and cover groups within the Inguadona Lake (IN) study site. Site boundaries were calculated using a 100% minimum convex polygon of pooled winter locations from 9 global positioning system-collared adult (≥1.5 yr), female white-tailed deer in northcentral Minnesota, 12 March–30 April 2018. Open water classes (lakes and ponds) were excluded from percent area and edge calculations.

Cover type	Stand count	Total area (ha)	Percent area[a]	Total edge (m)	Percent edge[b]
Agriculture	2	10	0.27	2,269	0.30
Black ash	12	50	1.36	11,564	1.55
Balsam fir	10	36	0.98	11,405	1.53
Black spruce	25	88	2.39	23,899	3.20
Forage	47	341	9.27	80,396	10.76
Jack pine	2	4	0.11	1,465	0.20
Paper birch	16	99	2.68	19,019	2.55
Red maple	3	21	0.57	4,092	0.55
Red pine	72	487	13.25	98,962	13.25
Swamp	89	896	24.36	163,604	21.91
Tamarack	11	77	2.10	15,627	2.09
Trembling aspen	154	1,428	38.81	281,565	37.70
N. white cedar	13	128	3.49	28,610	3.83
White oak	2	3	0.09	1,280	0.17
White pine	4	10	0.28	3,123	0.42
Lake	3	136	NA	10,404	NA

Pond	2	10	NA	1,820	NA
Cover type group[c]					
Dense conifer	53	343	9.31	77,339	10.35
Forage	47	341	9.27	80,396	10.76
Hardwood	162	1,452	39.46	280,536	37.57
Mixed hardwood	25	149	4.05	37,083	4.97
Moderate conifer	59	354	9.64	74,979	10.11
Open conifer	25	135	3.67	30,773	4.12
Other	7	157	0.27	14,494	0.30
Wetland	89	896	24.36	163,604	21.91

[a] Total area of all cover types, excluding "open water," was 3,679 ha. This total was used as the denominator when calculating percent area within the study site.

[b] Total edge of all cover types, excluding open water, was 746,881 m. This total was used as the denominator when calculating percent edge within the study site.

[c] Grouped cover types are based on dominate species of cover type classes and percent canopy cover for conifer stands.

Table 4. Mean stand-level characteristics (area, edge, and edge:area) and 95% confidence intervals (CI) at the Elephant Lake (EL) study site. Site boundaries were calculated using a 100% minimum convex polygon of pooled winter locations from 10 global positioning system-collared adult, female white-tailed deer in northeastern Minnesota, 12 March–30 April 2018.

Cover type	Stand count	Mean stand size (ha)	Lower CI	Upper CI	Mean edge (m)	Lower CI	Upper CI	Mean edge:area (m/ha)	Lower CI	Upper CI
Black ash	81	4.5	3.5	5.6	1,252	1,080	1,424	372	341	403
Balsam fir	28	4.1	2.6	5.7	1,278	1,034	1,523	390	330	449
Black spruce	41	6.9	4.6	9.1	1,345	1,093	1,597	258	223	293
Forage	121	6.1	4.7	7.5	1,323	1,115	1,530	458	405	510
Jack pine	15	3.5	2.3	4.7	897	689	1,104	330	260	400
Paper birch	48	4.5	2.8	6.3	1,067	852	1,282	43	32	54
Red maple	7	9.5	5.6	13.4	2,279	1,465	3,093	364	316	411
Red pine	66	5.6	4.0	7.2	1,234	1,012	1,457	250	203	297
Residential	8	8.6	3.6	13.6	1,845	964	2,726	320	288	352

Swamp	69	9.7	6.6	12.8	2,306	1,728	2,885	262	196	328
Tamarack	12	3.3	2.2	4.4	1,048	757	1,338	367	318	417
Trembling aspen	348	9.9	8.8	11.0	1,803	1,676	1,930	371	281	461
N. white cedar	110	9.3	7.1	11.6	1,555	1,340	1,769	257	243	270
White oak	20	5.4	3.2	7.6	1,187	909	1,465	268	245	290
White pine	46	4.8	2.6	7.0	1,124	824	1,425	310	243	377
White spruce	10	3.3	2.2	4.4	1,148	787	1,510	369	324	415
Lake	2	397.5	188.0	607.1	16,589	11,934	21,244	393	305	481
Cover type group										
Dense conifer	244	6.6	5.5	7.8	1,316	1,198	1,434	312	294	330
Forage	121	6.1	4.7	7.5	1,323	1,115	1,530	458	405	510
Hardwood	345	9.1	8.0	10.1	1,728	1,600	1,856	277	263	291
Mixed hardwood	159	6.8	5.5	8.0	1,407	1,268	1,546	310	286	334
Moderate conifer	59	5.0	3.4	6.6	1,123	938	1,307	308	277	338
Open conifer	25	9.0	4.6	13.4	1,816	1,233	2,398	321	253	388

Other	10	86.4	-20.0	192.8	4,794	818	8,770	218	141	296
Wetland	69	9.7	6.6	12.8	2,306	1,728	2,885	367	318	417

Table 5. Mean stand-level characteristics (area, edge, and edge:area) and 95% confidence intervals (CI) at the Inguadona Lake (IN) study site. The study site boundary was calculated using a 100% minimum convex polygon of pooled winter locations from 9 global positioning system-collared adult, female white-tailed deer in northcentral Minnesota, 12 March–30 April 2018.

Cover type	Mean stand count	Size (ha)	Lower CI	Upper CI	Mean edge (m)	Lower CI	Upper CI	Mean edge:area (m/ha)	Lower CI	Upper CI
Agriculture	2	5.0	3.6	6.3	1,135	795	1,475	239	104	374
Black ash	12	4.2	0.7	7.7	964	559	1,368	433	319	547
Balsam fir	10	3.6	1.4	5.8	1,141	661	1,620	435	319	550
Black spruce	25	3.5	1.7	5.4	956	642	1,270	411	343	478
Forage	47	7.3	5.3	9.2	1,711	1,412	2,009	323	282	363
Jack pine	2	1.9	1.9	2.0	733	603	862	379	306	453
Paper birch	16	6.2	0.3	12.0	1,189	597	1,781	77	63	92
Red maple	3	7.0	-1.6	15.5	1,364	523	2,204	187	128	245
Red pine	72	6.8	5.3	8.3	1,374	1,160	1,589	389	284	494

Swamp	89	10.1	5.0	15.1	1,838	1,353	2,324	423	374	473
Tamarack	11	7.0	0.9	13.2	1,421	719	2,122	300	264	335
Trembling aspen	154	9.3	7.8	10.8	1,828	1,605	2,051	429	379	480
N. White cedar	13	9.9	3.8	15.9	2,201	1,167	3,234	369	255	484
White oak	2	1.6	-0.4	3.5	640	27	1,253	298	268	327
White pine	4	2.5	0.9	4.1	781	451	1,111	292	222	362
Lake	3	45.5	29.8	61.1	3,468	2,488	4,448	467	274	660
Pond	2	5.1	2.1	8.2	910	636	1,184	373	216	529
Cover type group										
Dense conifer	53	6.5	4.5	8.4	1,459	1,141	1,777	332	290	375
Forage	47	7.3	5.3	9.2	1,711	1,412	2,009	323	282	363
Hardwood	162	8.9	7.4	10.4	1,721	1,519	1,924	315	284	346
Mixed hardwood	25	6.0	2.4	9.5	1,483	823	2,143	351	290	413
Moderate conifer	659	5.9	4.2	7.6	1,259	1,006	1,512	331	289	373
Open conifer	25	5.4	2.4	8.4	1,231	844	1,618	373	303	443

Other	7	22.4	5.3	39.4	2,071	1,027	3,114	155	90	219
Wetland	89	10.1	5.0	15.1	1,838	1,353	2,324	423	374	473

Table 6. Mean (± SE) total area and edge, and percent availability of cover types and cover type groups for pooled individual 95% kernel density estimated home ranges of 10 global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) site, northeastern Minnesota, 12 March−30 April 2018.

		Home range							
Cover type	Stand count	Mean total area (ha)	SE	Mean total edge (m)	SE	Mean % area	SE	Mean % edge	SE
Agriculture	0	0	0	0	0	0	0	0	0
Black ash	23	13.1	6.19	3,185	1,356	3.2	1.10	4.2	1.27
Balsam fir	11	10.0	3.74	2,086	723	4.2	1.91	4.1	1.75
Black spruce	11	5.1	3.02	1,291	799	0.9	0.51	1.1	0.60
Forage	49	34.9	7.82	7,970	1,703	12.0	3.18	14.0	3.40

Jack pine	2	0.7	0.45	244	154	0.2	0.15	0.3	0.23
Paper birch	24	18.6	5.43	3,284	1,043	7.2	2.73	5.7	1.97
Red maple	0	0	0	0	0	0	0	0	0
Red pine	22	15.6	12.63	3,253	2,529	2.5	1.46	2.8	1.51
Swamp	23	19.1	4.27	4,772	970	5.7	1.33	7.4	1.42
Tamarack	0	0	0	0	0	0	0	0	0
Trembling aspen	134	155.7	34.95	26,807	6,098	49.1	5.24	44.1	5.02
N. white cedar	28	23.3	14.64	4,510	2,701	6.8	4.03	6.6	3.67
White oak	8	5.5	3.39	1,052	621	1.7	1.25	1.6	1.15
White pine	35	20.5	6.24	4,490	1,148	6.4	1.61	7.6	1.59
White spruce	2	0.7	0.46	289	207	0.2	0.14	0.4	0.26
Cover type group[a]									

Dense conifer	76	51.2	17.95	10,976	3,405	15.5	4.37	17.2	3.97
Forage	49	34.9	7.82	7,970	1,703	12.0	3.18	14.0	3.40
Hardwood	111	132.0	33.10	22,543	5,779	39.3	5.59	34.1	4.44
Mixed hardwood	78	60.9	15.56	11,784	2,935	21.8	6.81	21.5	5.92
Moderate conifer	23	10.1	3.94	2,630	1,062	2.6	0.65	3.2	0.73
Open conifer	12	14.6	9.14	2,556	1,623	3.0	1.52	2.6	1.31
Other	0	0	0	0	0	0	0	0	0
Wetland	23	19.1	4.27	4,772	970	5.7	1.33	7.4	1.42

[a] Grouped cover types are based on dominate species of cover type classes and percent canopy cover for conifer stands. Open, moderate, and dense conifer represent the 3 canopy closure classes used for conifer stands; open = 0−39%, moderate = 40−69%, and dense = 70−100%. Mixed hardwood stands have hardwood as the dominant species and conifer as the co-dominant.

Table 7. Mean (± SE) total area and edge, and percent availability of cover types and cover type groups of pooled individual 95% kernel density estimated home ranges of 9 global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (IN) site, northcentral Minnesota, 12 March−30 April 2018.

	Home range								
Cover type	Stand count	Mean total area (ha)	SE	Mean total edge (m)	SE	Mean % area	SE	Mean % edge	SE
Agriculture	1	0.6	0.59	107	101	0.1	0.07	0.1	0.06
Black ash	7	4.9	4.12	1,193	988	0.4	0.27	0.6	0.38
Balsam fir	7	2.0	0.99	842	422	0.7	0.47	1.4	0.94
Black spruce	19	10.5	4.52	2,410	876	2.7	1.31	3.1	1.29
Forage	63	50.3	16.36	12,134	3,978	11.3	3.27	12.1	2.85

Jack pine	2	0.4	0.40	163	153	0.1	0.06	0.1	0.13
Paper birch	16	10.6	5.10	2,072	765	2.4	1.17	2.8	1.07
Red maple	5	2.7	1.63	619	302	0.5	0.38	0.6	0.38
Red pine	78	60.8	22.02	12,518	4,481	12.9	3.44	12.9	3.25
Swamp	89	168.6	50.11	24,295	7,607	29.0	7.52	22.9	5.75
Tamarack	8	6.6	4.69	1,238	780	0.6	0.34	0.6	0.38
Trembling aspen	166	190.7	62.93	37,546	11,846	29.5	7.31	30.4	6.12
N. white cedar	25	24.5	8.87	6,603	2,375	3.5	0.97	4.5	1.25
White oak	0	0.0	0.00	0	0	0.0	0.00	0.0	0.00
White pine	5	1.6	0.72	486	199	0.5	0.28	0.7	0.37
White spruce	0	0.0	0.00	0	0	0.0	0.00	0.0	0.00
Cover type group[a]									

Dense conifer	58	38.4	14.47	9,588	3,482	6.1	1.33	8.2	1.77
Forage	63	50.3	16.36	12,134	3,978	11.3	3.27	12.1	2.85
Hardwood	161	179.1	59.51	34,532	11,292	30.0	5.96	30.8	4.88
Mixed hardwood	32	29.7	10.03	6,879	2,267	5.2	1.67	6.7	2.05
Moderate conifer	65	46.1	18.04	9,760	3,789	12.9	3.88	12.6	3.01
Open conifer	23	17.2	7.91	3,684	1,381	2.7	0.82	3.4	0.97
Other	4	8.9	6.25	815	436	0.1	0.07	0.1	0.06
Wetland	89	168.6	50.11	24,295	7,607	29.0	7.52	22.9	5.75

[a] Grouped cover types are based on dominate species of cover type classes and percent canopy cover for conifer stands. Open, moderate, and dense conifer represent the 3 canopy closure classes used for conifer stands; open = 0−39%, moderate = 40−69%, and dense = 70−100%. Mixed hardwood stands have hardwood as the dominant species and conifer as the co-dominant.

Table 8. Mean (± SE) of average percent use of cover types and cover type groups by global positioning system (GPS)-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018.

Study site	Cover type	Number of GPS location-fixes	Number of deer	Mean % use[b]	SE
EL					
	Agriculture	0	0	0.0	0.00
	Black ash	23	6	0.4	0.21
	Balsam fir	133	3	2.6	1.69
	Black spruce	5	1	0.1	0.09
	Forage	660	9	12.7	4.02
	Jack pine	18	1	0.3	0.30
	Paper birch	315	6	5.7	2.61
	Red maple	0	0	0.0	0.00
	Red pine	166	4	3.1	2.60
	Swamp	41	7	0.8	0.31
	Tamarack	0	0	0.0	0.00
	Trembling aspen	2,588	10	48.1	7.67
	N. White cedar	520	2	10.6	6.73
	White oak	62	2	1.4	1.13
	White pine	715	6	13.6	4.17
	White spruce	32	1	0.6	0.54

	Cover type group[c]				
	Dense conifer	1,144	8	22.6	7.88
	Forage	660	9	12.7	4.02
	Hardwood	1,648	10	30.7	7.89
	Mixed hardwood	1,340	9	24.9	7.70
	Moderate Conifer	307	6	5.7	3.06
	Open conifer	138	3	2.6	1.45
	Other	0	0	0.0	0.00
	Wetland	41	7	0.8	0.31
IN					
	Agriculture	3	1	0.1	0.06
	Black ash	2	1	0.1	0.06
	Balsam fir	96	3	6.2	2.30
	Black spruce	128	5	3.1	1.39
	Forage	1,094	8	22.8	6.40
	Jack pine	0	0	0.0	0.00
	Paper birch	149	5	2.9	2.36
	Red maple	1	1	0.0	0.02
	Red pine	523	9	10.6	2.97
	Swamp	509	8	11.0	2.21
	Tamarack	170	2	3.9	3.66
	Trembling aspen	1,815	8	40.3	8.01
	N. White cedar	99	4	2.1	1.35

White oak	0	0	0.0	0.00
White pine	52	3	1.1	0.84
White spruce	0	0	0.0	0.00
Cover type group				
Dense conifer	427	9	8.9	3.10
Forage	1,094	8	22.8	6.40
Hardwood	1,797	9	39.4	7.34
Mixed hardwood	170	7	3.9	1.57
Moderate conifer	430	9	9.0	3.30
Open conifer	211	4	4.7	3.61
Other	3	1	0.1	0.06
Wetland	509	8	11.0	2.21

[a] Average mean percent of individual deer GPS locations within each cover type on respective study sites.

[c] Grouped cover types are based on dominate species of cover type classes and percent canopy cover for conifer stands. 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.

Table 9. Mean (± SE) stand-level characteristics (size, edge, and edge:area ratio) of cover type groups used by global positioning system (GPS)-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018.

Study site	Cover type group[a]	Number of GPS locations	Mean size (ha)	SE	Mean edge (m)	SE	Mean edge:area (m/ha)	SE
EL								
	Open conifer	138	18.3	1.04	2,952	119	184	2.88
	Moderate conifer	307	4.5	0.09	1,098	17	252	2.99
	Dense conifer	1,144	17.0	0.47	2,497	59	228	3.37
	Hardwood	1,648	31.5	0.65	3,880	59	158	1.64
	Mixed hardwood	1,340	14.7	0.30	2,168	35	200	3.63
	Forage	660	7.6	0.17	1,850	25	288	3.89
	Wetland	41	24.6	1.74	5,343	309	241	9.46
IN								
	Open conifer	211	7.8	0.10	1,915	20	260	6.36

Moderate conifer	430	12.4	0.46	2,374	83	224	4.08
Dense conifer	427	7.6	0.25	1,818	35	308	5.88
Hardwood	1,797	17.1	0.27	2,988	34	215	2.87
Mixed hardwood	170	4.4	0.27	1,107	64	251	3.45
Forage	1,094	14.4	0.27	2,973	45	255	3.67
Wetland	509	56.3	3.11	5,982	231	187	5.92

[a] Grouped cover types are based on dominate species of cover type classes and percent canopy cover for conifer stands. 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.

Table 10. Mean (± SE) fine-scale measurements of winter habitat use by global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018. Distance (m) was measured from location-fix to the nearest forage opening, dense conifer and moderately dense conifer stand (when not in use), and to the nearest edge and center of the stand-level cover type being used.

		Distance to (m)[c]									
Cover type group[b]	*n*	Forage	SE	Dense conifer	SE	Moderate conifer	SE	Edge of stand	SE	Center of stand	SE
EL											
Open conifer	138	281	10.4	149	6.2	305	7.3	41	2.7	202	10.4
Moderate conifer	307	114	9.9	177	4.8	NA	NA	22	0.9	100	2.6
Dense conifer	1,144	241	5.6	NA	0.0	385	6.0	38	1.2	184	4.5
Hardwood	1,648	334	4.8	293	5.6	356	5.3	43	0.9	286	5.7
Mixed hardwood	1,340	239	3.7	227	3.8	404	4.1	38	0.9	182	3.8
Forage	660	NA	NA	177	7.4	209	6.7	23	0.8	145	3.1
Wetland	41	353	31.6	137	25.4	394	36.6	13	2.5	223	18.5

IN											
Open conifer	211	292	6.8	66	6.2	409	6.2	34	1.5	108	4.1
Moderate conifer	430	109	8.2	215	6.9	NA	NA	27	1.0	144	4.5
Dense conifer	427	147	8.0	NA	NA	221	7.9	21	0.9	135	4.6
Hardwoods	1,797	279	7.3	351	7.7	316	5.0	35	0.8	179	2.4
Mixed hardwood	170	340	25.7	559	27.1	148	7.7	28	1.4	84	5.7
Forage	1,094	NA	NA	195	4.4	204	4.4	37	1.0	160	2.9
Wetland	509	327	14.0	307	14.8	347	8.2	40	1.6	360	19.4

[a] Home ranges within which location-fixes occur were calculated using the 95% kernel density estimator.

[b] Cover type group indicates the stand being used based on GPS locations of female white-tailed deer . 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%.

[c] Distances were measured using the Near tool in ArcGIS Pro 2.2.2. Mean calculations are based on pooled winter (12 Mar−30 Apr 2018) locations of all GPS-collared deer using these cover type groups within the respective study sites.

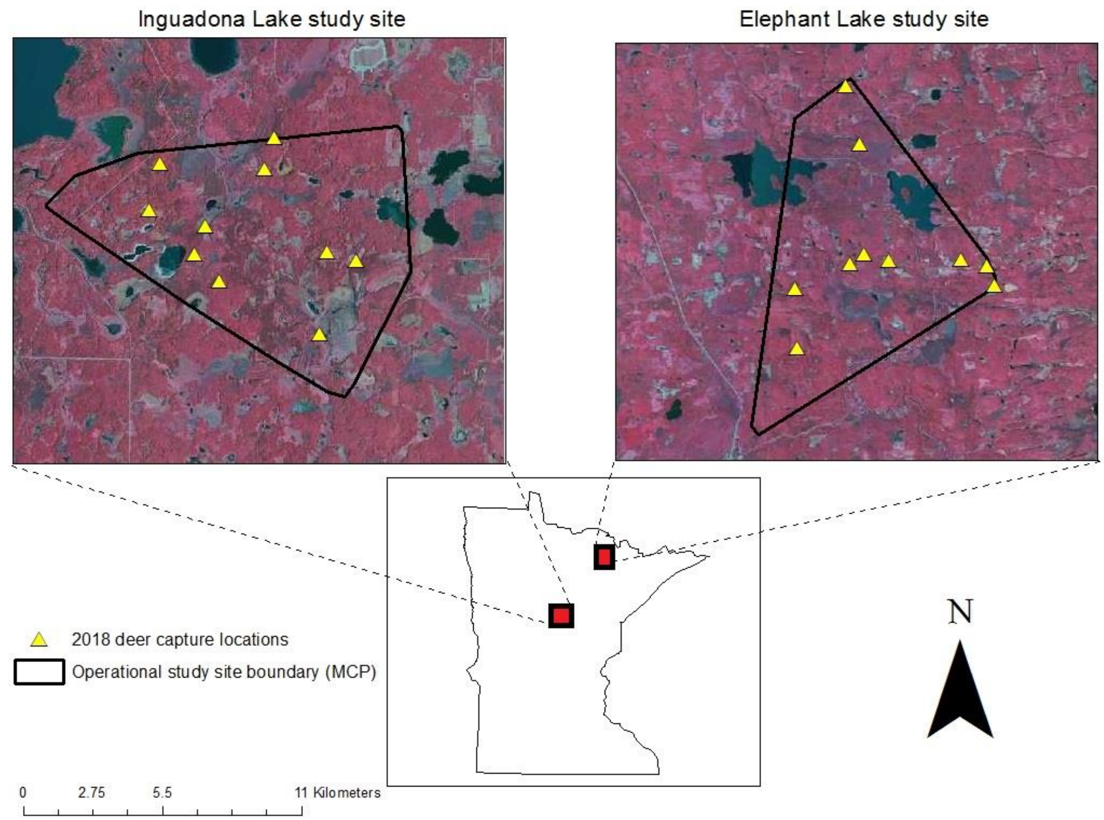

Figure 1. Operational study site boundaries delineated by 100% minimum convex polygon (MCP) home ranges of pooled global positioning system-locations of 20 (10/site) adult (≥1.5 yr), female white-tailed deer at the Inguadona Lake (30 km^2) and Elephant Lake (72 km^2) sites, northcentral and northeastern Minnesota, 10−11 March 2018. Helicopter net-gun capture locations are depicted as yellow triangles. One deer was captured via Clover trap at Inguadona Lake.

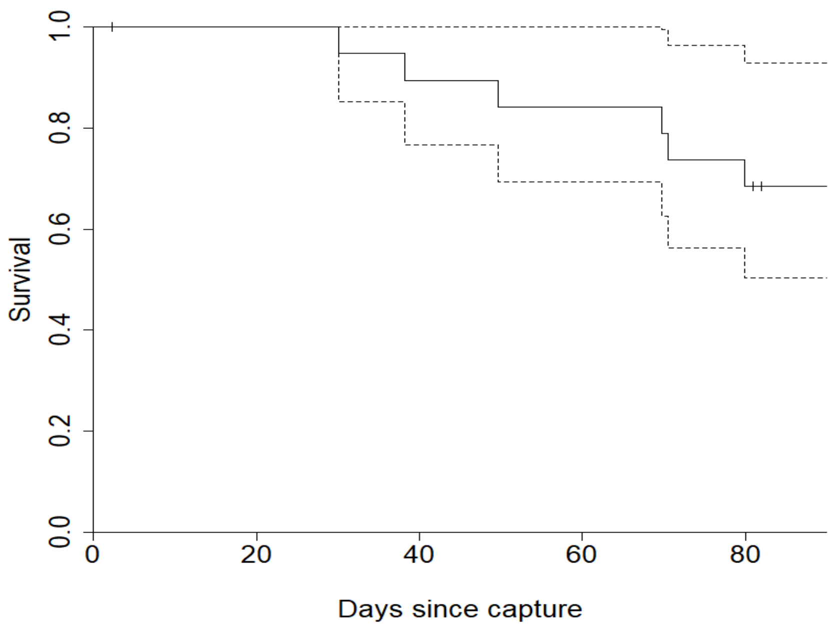

Figure 2. Kaplan-Meier estimated survival of all 20 global positioning system-collared, adult (≥1.5 yr), female white-tailed deer on the Inguadona Lake (northcentral) and Elephant Lake (northeastern) study sites, Minnesota, 11 March−31 May 2018. The early single tick-mark represents the deer censored due to capture-related mortality (died within 2 days of capture), and the double tick-mark represents the last day post-capture included in the analysis. Dotted lines represent 95% confidence intervals.

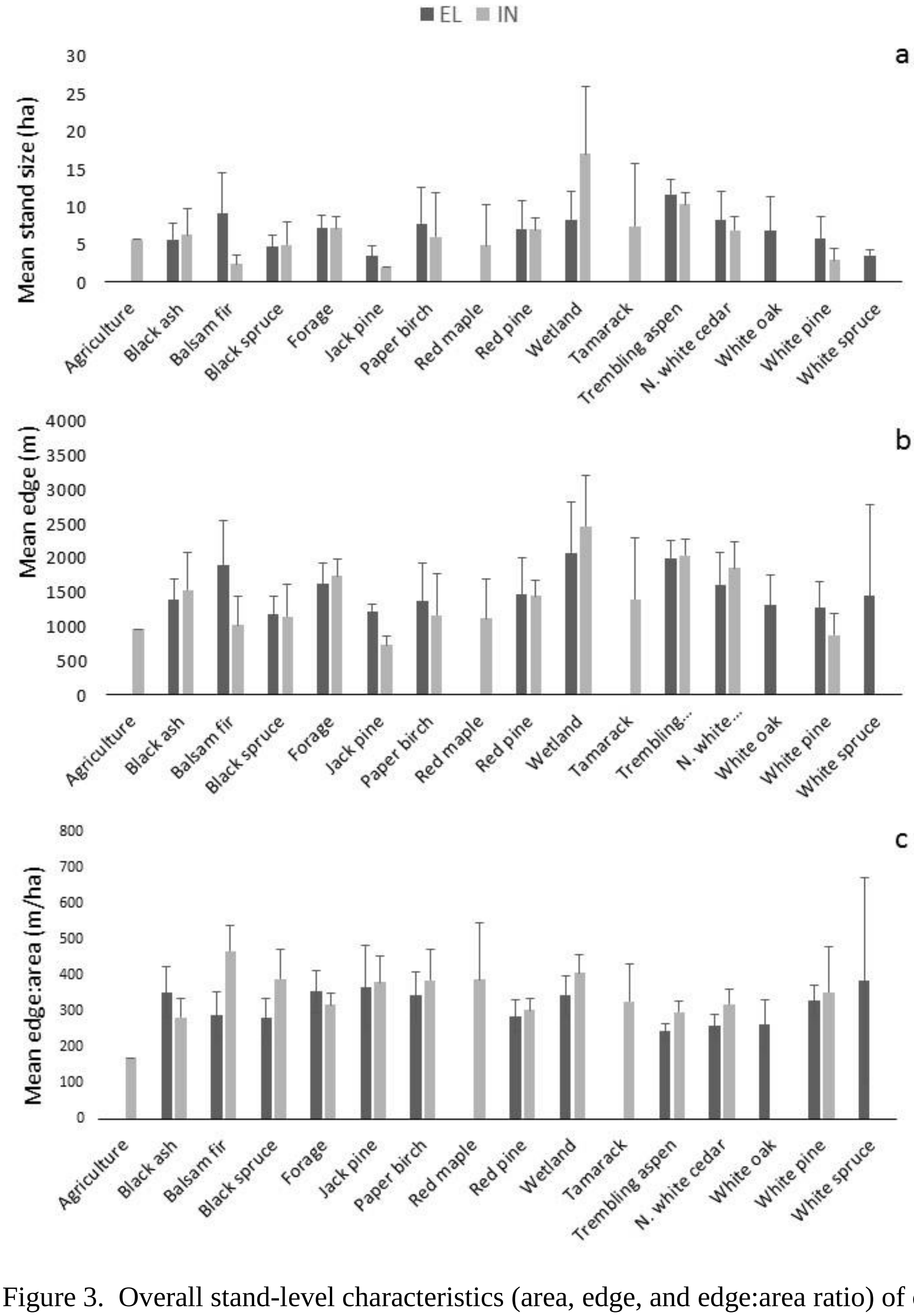

Figure 3. Overall stand-level characteristics (area, edge, and edge:area ratio) of cover types pooled over 95% kernel density estimated home ranges of individual, global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake

(EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018. Error bars represent upper 95% confidence intervals.

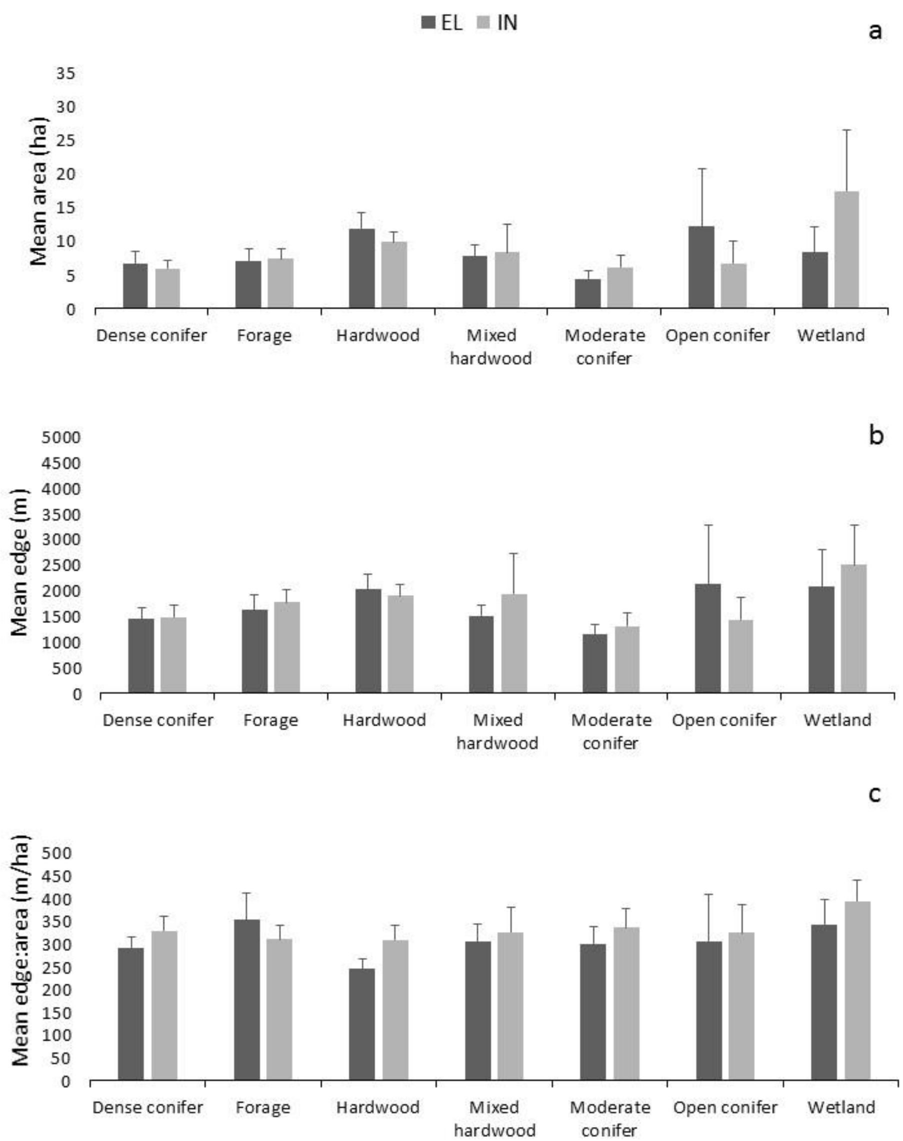

Figure 4. Overall stand-level characteristics (area, edge, and edge:area ratio) of cover type groups pooled over 95% kernel density estimated home ranges of individual global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake

(EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March–30 April 2018. Error bars represent upper 95% confidence intervals.

APPENDIX

Appendix A. Habitat classification system used for interpretation of color infrared aerial photographs from October 2010 and 2012 to inventory available winter habitat for global positioning system-collared adult (≥1.5yr), female white-tailed deer at the Elephant Lake and Inguadona Lake sites, northeastern and northcentral Minnesota, winter 2017−2018.

Cover Type	Class	Description	Code
Conifer			
	Northern white cedar (*Thuja occidentalis*)		WC
	Balsam fir (*Abies balsamea*)		BF
	Black spruce (*Picea mariana)*		BS
	Tamarack (Larix laricina)		T
	Red pine (*Pinus resinosa*)		RP
	Jack pine (*Pinus banksiana*)		JP
	White pine (*Pinus strobus*)		WP
	White spruce (*Picea Glauca*)		WS
	Mixture of 2 dominants		Symbol/Symbol

Hardwoods			
	Trembling aspen (*Populus tremuloides*)		TA
	Paper birch (*Betula papyrifera)*		PB
	Red maple (*Acer rubrum*)		RM
	Balck ash (*Fraxinus nigra)*		BA
	White oak (*Quercus alba*)		WO
Height (m)			
	1	≥2 and <6	1
	2	≥6 and <11	2
	3	≥11	3
	Mixed 1	<6 and 6 to <11	4
	Mixed 2	<6 and ≥11	5
	Mixed 3	≥6 and <11 and ≥11	6
Canopy closure (%)			

	Open	<40%	a
	Moderately dense	≥40% and <70%	b
	Dense	≥70%	c
Openings			
	Forage/opening		F
	Swamp/bog		SW
	Agriculture		AG
	Residential		Rr
Water			
	Pond	<5 hectares	P
	Lake	≥5 hectares	L

Appendix B. Cover type composition of individual 95% kernel density estimated home ranges of global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018.

Study site	Deer id	Cover type	Stand count	Total area (ha)	Total edge (m)	Percent area[a]	Percent edge
EL	697083A	Black ash	1	3.1	1,362	1.2	2.6
		Forage	6	50.1	11,308	18.8	21.7
		Paper birch	1	23.0	2,350	8.6	4.5
		Red pine	3	13.2	3,435	4.9	6.6
		Swamp	2	8.3	2,425	3.1	4.7
		Trembling aspen	8	80.8	14,059	30.2	27.0
		N. White cedar	2	3.5	1,341	1.3	2.6
		White oak	5	35.5	6,347	13.3	12.2
		White pine	6	49.6	9,377	18.6	18.0
		Grand total[b]	34	267.1	52,004	100.0	100.0
	697087A	Black ash	3	5.8	2,033	1.5	2.5
		Balsam fir	2	8.4	2,973	2.1	3.7
		Black spruce	3	18.5	3,957	4.7	4.9
		Forage	9	83.7	18,519	21.5	22.8
		Paper birch	4	10.5	3,519	2.7	4.3
		Swamp	3	33.8	8,506	8.7	10.5

	Trembling aspen	5	47.0	8,795	12.1	10.8
	N. White cedar	14	152.0	28,132	39.0	34.6
	White pine	2	30.5	4,842	7.8	6.0
	Grand total	45	390.0	81,275	100.0	100.0
697089A	Balsam fir	2	26.3	4,932	14.8	13.9
	Forage	3	6.6	2,354	3.7	6.7
	Paper birch	2	37.0	5,132	20.9	14.5
	Swamp	1	2.5	1,477	1.4	4.2
	Trembling aspen	12	95.5	18,127	53.9	51.2
	White pine	3	9.4	3,358	5.3	9.5
	Grand total	23	177.3	35,380	100.0	100.0
697090A	Black ash	1	10.0	1,961	2.4	2.2
	Balsam fir	3	31.3	6,401	7.3	7.3
	Forage	11	34.1	9,144	8.0	10.5
	Paper birch	3	41.3	6,030	9.7	6.9
	Swamp	6	28.9	8,167	6.8	9.3
	Trembling aspen	27	263.3	49,835	61.9	57.0
	White oak	2	9.4	2,653	2.2	3.0
	White pine	1	2.9	1,111	0.7	1.3
	White spruce	1	4.0	2,126	0.9	2.4
	Grand total	55	425.3	87,426	100.0	100.0
697091A	Black ash	1	9.1	2,290	7.1	8.5
	Forage	6	45.3	10,406	35.6	38.6

	Red pine	1	3.6	913	2.9	3.4
	Swamp	1	2.2	890	1.7	3.3
	Trembling aspen	4	57.3	9,554	45.0	35.5
	N. white cedar	1	2.6	921	2.0	3.4
	White pine	2	7.4	1,963	5.8	7.3
	Grand total	16	127.4	26,937	100.0	100.0
697093A	Forage	2	14.7	3,153	5.8	6.7
	Paper birch	1	0.8	461	0.3	1.0
	Swamp	1	25.4	5,536	10.1	11.7
	Trembling aspen	7	133.1	21,436	52.8	45.3
	N. white cedar	9	59.2	11,280	23.5	23.8
	White pine	4	15.4	4,722	6.1	10.0
	White spruce	1	3.2	767	1.3	1.6
	Grand total	25	251.8	47,354	100.0	100.0
697094A	Black ash	3	32.0	6,305	10.1	11.9
	Black spruce	1	4.5	954	1.4	1.8
	Forage	1	15.6	2,131	4.9	4.0
	Swamp	3	25.1	7,016	7.9	13.2
	Trembling aspen	14	238.8	36,546	75.6	69.0
	Grand total	22	316.0	52,951	100.0	100.0
697097A	Balsam fir	1	23.2	3,540	16.1	14.6
	Forage	1	1.4	776	0.9	3.2
	Paper birch	1	36.2	4,678	25.1	19.3

	Trembling aspen	9	80.7	14,143	55.9	58.3
	White pine	1	2.9	1,111	2.0	4.6
	Grand total	13	144.5	24,247	100.0	100.0
699965A	Black ash	10	65.4	14,875	7.5	8.7
	Balsam fir	3	11.3	3,018	1.3	1.8
	Black spruce	7	28.6	7,995	3.3	4.7
	Forage	5	61.0	11,895	7.0	6.9
	Jack pine	1	2.7	1,167	0.3	0.7
	Paper birch	12	37.0	10,675	4.3	6.2
	Red pine	17	134.8	27,041	15.5	15.7
	Swamp	5	29.6	6,679	3.4	3.9
	Trembling aspen	36	414.0	71,914	47.6	41.8
	N. white cedar	2	15.6	3,421	1.8	2.0
	White oak	1	9.9	1,516	1.1	0.9
	White pine	10	59.9	11,713	6.9	6.8
	Grand total	109	869.9	171,908	100.0	100.0
699967A	Black ash	4	5.9	3,021	2.3	5.7
	Forage	5	36.9	10,013	14.2	18.9
	Jack pine	1	4.2	1,273	1.6	2.4
	Red pine	1	4.6	1,137	1.8	2.2
	Swamp	1	35.7	7,030	13.7	13.3
	Trembling aspen	12	146.0	23,662	56.1	44.8
	White pine	6	26.8	6,703	10.3	12.7

		Grand total	30	260.1	52,838	100.0	100.0
IN							
	697084A	Forage	3	24.8	5,717	6.4	5.8
		Red pine	4	38.1	5,527	9.8	5.6
		Swamp	1	39.1	5,065	10.0	5.1
		Trembling aspen	5	53.3	9,964	13.6	10.1
		Grand total	13	155.4	26,274	39.8	26.6
	697085A	Black spruce	4	7.4	3,595	1.9	3.6
		Forage	8	31.4	9,721	8.0	9.9
		Lake	1	61.3	4,274		
		Red maple	1	3.9	1,277	1.0	1.3
		Red pine	5	14.1	4,804	3.6	4.9
		Swamp	11	39.6	13,506	10.1	13.7
		Tamarack	1	0.6	320	0.2	0.3
		Trembling aspen	41	280.7	62,049	71.8	62.9
		N. white cedar	1	12.2	2,876	3.1	2.9
		White pine	1	0.8	456	0.2	0.5
		Grand total	74	452.0	102,878	100.0	100.0
	697086A	Black ash	6	39.6	9,502	2.4	2.9
		Balsam fir	3	5.6	2,476	0.3	0.7
		Black spruce	6	42.4	8,155	2.6	2.4
		Forage	25	175.5	42,746	10.6	12.8
		Pond	1	6.7	1,050		

	Paper birch	8	21.7	6,647	1.3	2.0
	Red maple	3	4.8	2,144	0.3	0.6
	Red pine	31	236.2	48,188	14.2	14.5
	Swamp	39	486.8	81,433	29.3	24.5
	Tamarack	4	44.2	6,895	2.7	2.1
	Trembling aspen	50	520.8	103,317	31.4	31.0
	N. White cedar	13	81.5	21,417	4.9	6.4
	Grand total	189	1665.7	333,972	100.0	100.0
697088A	White pine	1	4.6	1,252	0.7	1.1
	Balsam fir	1	1.2	557	0.2	0.5
	Forage	7	61.2	13,832	9.2	11.7
	Jack pine	2	3.9	1,465	0.6	1.2
	Pond	1	6.7	1,050		
	Paper birch	2	7.1	2,374	1.1	2.0
	Red pine	12	83.6	17,105	12.6	14.5
	Swamp	11	250.6	29,493	37.9	25.0
	Tamarack	3	14.9	3,925	2.3	3.3
	Trembling aspen	16	220.3	43,848	33.3	37.2
	N. white cedar	2	14.0	4,031	2.1	3.4
	Grand total	58	668.0	118,931	100.0	100.0
697095A	Black ash	1	4.6	1,238	1.2	2.6
	Balsam fir	2	4.8	1,638	1.3	3.5
	Black spruce	3	23.2	4,474	6.1	9.4

	Paper birch	1	10.9	1,394	2.9	2.9
	Red pine	1	0.8	523	0.2	1.1
	Swamp	3	286.2	28,732	75.7	60.6
	Trembling aspen	4	47.8	9,419	12.6	19.9
	Grand total	15	378.3	47,417	100.0	100.0
697096A	Balsam fir	2	7.9	3,468	4.5	8.8
	Forage	5	40.2	9,294	22.9	23.6
	Paper birch	1	0.5	304	0.3	0.8
	Red pine	8	60.5	13,344	34.4	33.8
	Swamp	2	47.8	7,701	27.2	19.5
	N. white cedar	2	14.2	3,895	8.1	9.9
	White pine	2	4.7	1,415	2.7	3.6
	Grand total	22	175.9	39,421	100.0	100.0
697098A	Black spruce	1	13.7	2,635	12.5	10.5
	Forage	2	36.6	7,279	33.3	28.9
	Paper birch	2	4.9	1,935	4.4	7.7
	Red pine	6	28.5	5,886	25.9	23.3
	Trembling aspen	5	26.3	7,474	24.0	29.6
	Grand total	16	110.0	25,210	100.0	100.0
699964A	Agriculture	1	5.6	961	0.7	0.6
	Black spruce	5	7.8	2,826	1.0	1.8
	Forage	10	72.5	17,703	9.0	11.0
	Paper birch	1	1.2	507	0.1	0.3

	Red pine	7	42.2	10,333	5.2	6.4
	Swamp	16	135.2	29,139	16.8	18.1
	Trembling aspen	41	487.1	83,914	60.4	52.2
	N. white cedar	7	49.7	14,001	6.2	8.7
	White pine	1	4.6	1,252	0.6	0.8
	Grand total	89	805.9	160,637	100.0	100.0
699966A	Forage	3	10.7	2,911	2.5	4.9
	Paper birch	1	49.6	5,491	11.5	9.3
	Red maple	1	15.6	2,146	3.6	3.6
	Red pine	4	43.1	6,949	10.0	11.8
	Swamp	6	232.2	23,581	53.9	40.0
	Trembling aspen	4	79.7	17,925	18.5	30.4
	Grand total	19	430.9	59,003	100.0	100.0

[a] Open water (lakes and ponds) were excluded from the denominator of the percent area and percent edge calculations.

[b] Grand total for "Total area (ha)" is calculated by summing the total area of all complete cover types within each individual home range. Cover type polygon boundaries that extend beyond the home range boundary were retained intact to preserve biological integrity of the stand.

Appendix C. Cover type group composition of individual 95% kernel density estimated home ranges of global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018.

Study Site	Deer id	Cover type group[a]	Stand count	Total area (ha)	Total edge (m)	Percent area[b]	Percent edge
EL	697083A	Dense conifer	7	16.4	5,667	6.2	10.9
		Forage	6	50.1	11,308	18.8	21.7
		Hardwood	10	118.5	17,583	44.4	33.8
		Mixed hardwood	5	23.8	6,535	8.9	12.6
		Moderate conifer	2	16.1	3,179	6.0	6.1
		Open conifer	2	33.8	5,307	12.6	10.2
		Wetland	2	8.3	2,425	3.1	4.7
		Grand total[c]	34	267.1	52,004	100.0	100.0
	697087A	Dense conifer	17	189.4	35,267	48.6	43.4
		Forage	9	83.7	18,519	21.5	22.8
		Hardwood	7	38.8	8,872	9.9	10.9
		Mixed hardwood	5	24.5	5,475	6.3	6.7
		Moderate conifer	4	19.8	4,636	5.1	5.7
		Wetland	3	33.8	8,506	8.7	10.5
		Grand total	45	390.0	81,275	100.0	100.0
	697089A	Dense conifer	4	32.4	7,412	18.3	20.9

	Forage	3	6.6	2,354	3.7	6.7
	Hardwood	3	27.9	5,584	15.7	15.8
	Mixed hardwood	11	104.6	17,675	59.0	50.0
	Moderate conifer	1	3.3	878	1.9	2.5
	Wetland	1	2.5	1,477	1.4	4.2
	Grand total	23	177.3	35,380	100.0	100.0
697090A	Dense conifer	3	30.1	6,777	7.1	7.8
	Forage	11	34.1	9,144	8.0	10.5
	Hardwood	20	200.7	39,426	47.2	45.1
	Mixed hardwood	13	123.4	21,052	29.0	24.1
	Moderate conifer	2	8.0	2,861	1.9	3.3
	Wetland	6	28.9	8,167	6.8	9.3
	Grand total	55	425.3	87,426	100.0	100.0
697091A	Dense conifer	3	9.0	2,767	7.1	10.3
	Forage	6	45.3	10,406	35.6	38.6
	Hardwood	4	63.1	10,386	49.5	38.6
	Mixed hardwood	1	3.3	1,458	2.6	5.4
	Moderate conifer	1	4.6	1,030	3.6	3.8
	Wetland	1	2.2	890	1.7	3.3
	Grand total	16	127.4	26,937	100.0	100.0
697093A	Dense conifer	14	77.8	16,769	30.9	35.4
	Forage	2	14.7	3,153	5.8	6.7
	Hardwood	7	126.9	20,467	50.4	43.2

	Mixed hardwood	1	7.0	1,429	2.8	3.0
	Wetland	1	25.4	5,536	10.1	11.7
	Grand total	25	251.8	47,354	100.0	100.0
697094A	Forage	1	15.6	2,131	4.9	4.0
	Hardwood	11	208.9	29,509	66.1	55.7
	Mixed hardwood	6	61.9	13,341	19.6	25.2
	Moderate conifer	1	4.5	954	1.4	1.8
	Wetland	3	25.1	7,016	7.9	13.2
	Grand total	22	316.0	52,951	100.0	100.0
697097A	Dense conifer	2	26.1	4,651	18.1	19.2
	Forage	1	1.4	776	0.9	3.2
	Hardwood	2	23.3	3,943	16.1	16.3
	Mixed hardwood	8	93.7	14,877	64.8	61.4
	Grand total	13	144.5	24,247	100.0	100.0
699965A	Dense conifer	21	115.3	25,555	13.3	14.9
	Forage	5	61.0	11,895	7.0	6.9
	Hardwood	36	382.2	67,369	43.9	39.2
	Mixed hardwood	23	144.1	31,611	16.6	18.4
	Moderate conifer	11	42.5	11,767	4.9	6.8
	Open conifer	8	95.1	17,033	10.9	9.9
	Wetland	5	29.6	6,679	3.4	3.9
	Grand total	109	869.9	171,908	100.0	100.0
699967A	Dense conifer	5	15.7	4,894	6.0	9.3

		Forage	5	36.9	10,013	14.2	18.9
		Hardwood	11	129.5	22,291	49.8	42.2
		Mixed hardwood	5	22.3	4,391	8.6	8.3
		Moderate conifer	1	2.7	998	1.0	1.9
		Open conifer	2	17.1	3,222	6.6	6.1
		Wetland	1	35.7	7,030	13.7	13.3
		Grand total	30	260.1	52,838	100.0	100.0
IN							
	697084A	Dense conifer	1	0.9	437	0.6	1.7
		Forage	3	24.8	5,717	16.0	21.8
		Hardwood	5	53.3	9,964	34.3	37.9
		Moderate conifer	3	37.2	5,090	24.0	19.4
		Wetland	1	39.1	5,065	25.2	19.3
		Grand total	13	155.4	26,274	100.0	100.0
	697085A	Dense conifer	5	26.1	7,386	6.7	7.5
		Forage	8	31.4	9,721	8.0	9.9
		Hardwood	33	227.1	51,241	58.1	52.0
		Mixed hardwood	9	57.5	12,085	14.7	12.3
		Moderate conifer	5	7.0	3,406	1.8	3.5
		Open conifer	2	2.0	1,258	0.5	1.3
		Other	1	61.3	4,274	15.7	4.3
		Wetland	11	39.6	13,506	10.1	13.7
		Grand total	74	452.0	102,878	115.7	104.3

697086A	Dense conifer	24	143.2	34,785	8.6	10.4
	Forage	25	175.5	42,746	10.6	12.8
	Hardwood	54	499.5	100,433	30.0	30.1
	Mixed hardwood	12	86.4	20,858	5.2	6.2
	Moderate conifer	29	195.0	41,229	11.7	12.3
	Open conifer	6	78.6	13,402	4.7	4.0
	Other	1	6.7	1,050		
	Wetland	39	486.8	81,433	29.3	24.5
	Grand total	190	1,670.3	335,224	100.0	100.0
697088A	Dense conifer	9	71.6	15,250	10.9	13.1
	Forage	7	61.2	13,832	9.3	11.9
	Hardwood	15	178.5	36,202	27.2	31.0
	Mixed hardwood	3	48.8	10,019	7.4	8.6
	Moderate conifer	6	16.9	4,592	2.6	3.9
	Open conifer	5	29.1	7,242	4.4	6.2
	Other	1	6.7	1,050		
	Wetland	11	250.6	29,493	38.2	25.3
	Grand total	57	663.4	117,680	100.0	100.0
697095A	Dense conifer	2	4.8	1,638	1.3	3.5
	Hardwood	5	57.6	10,374	15.2	21.9
	Mixed hardwood	1	5.7	1,676	1.5	3.5
	Moderate conifer	4	24.1	4,997	6.4	10.5
	Wetland	3	286.2	28,732	75.7	60.6

	Grand total	15	378.3	47,417	100.0	100.0
697096A	Dense conifer	5	22.5	7,669	12.8	19.5
	Forage	5	40.2	9,294	22.9	23.6
	Hardwood	1	0.5	304	0.3	0.8
	Moderate conifer	5	51.1	10,647	29.1	27.0
	Open conifer	4	13.8	3,805	7.8	9.7
	Wetland	2	47.8	7,701	27.2	19.5
	Grand total	22	175.9	39,421	100.0	100.0
697098A	Dense conifer	2	3.2	1,212	2.9	4.8
	Forage	2	36.6	7,279	33.3	28.9
	Hardwood	5	26.3	7,474	24.0	29.6
	Mixed hardwood	2	4.9	1,935	4.4	7.7
	Moderate conifer	4	35.6	6,382	32.3	25.3
	Open conifer	1	3.4	926	3.1	3.7
	Grand total	16	110.0	25,210	100.0	100.0
699964A	Dense conifer	9	55.0	15,615	6.8	9.7
	Forage	10	72.5	17,703	9.0	11.0
	Hardwood	39	476.7	81,172	59.2	50.5
	Mixed hardwood	3	11.7	3,399	1.4	2.1
	Moderate conifer	7	27.8	7,744	3.5	4.8
	Open conifer	4	21.4	5,053	2.7	3.1
	Other	1	5.6	961	0.7	0.6
	Wetland	16	135.2	29,139	16.8	18.1

	Grand total	89	805.9	160,637	100.0	100.0
699966A	Dense conifer	1	18.0	2,296	4.2	3.9
	Forage	3	10.7	2,911	2.5	4.9
	Hardwood	4	92.6	13,622	21.5	23.1
	Mixed hardwood	2	52.3	11,940	12.1	20.2
	Moderate conifer	2	18.7	3,186	4.3	5.4
	Open conifer	1	6.4	1,467	1.5	2.5
	Wetland	6	232.2	23,581	53.9	40.0
	Grand total	19	430.9	59,003	100.0	100.0

[a] Grouped cover types are based on dominate species of cover type classes and percent canopy cover for conifer stands. Open, moderate, and dense conifer represent the 3 canopy closure classes used for conifer stands; 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.

[b] Open water (lakes and ponds) were subtracted from the denominator of the percent area and percent edge calculations.

[c] Grand total for "Total area (ha)" is calculated by summing the total area of all complete cover types within each individual home range. Cover type polygon boundaries that extend beyond the home range boundary were retained to preserve biological integrity of the cover type stand.

Appendix D. Mean stand-level characteristics (size, edge, and edge:area ratio) and 95% confidence interval (CI) of cover types within individual 95% kernel density estimated home ranges of global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018.

Study site	Deer id	Cover type	Stand count	Mean size (ha)	Lower CI	Upper CI	Mean edge (m)	Lower CI	Upper CI	Mean edge:area (m/ha)	Lower CI	Upper CI
EL	697083A	Black ash	1	3.1	3.08	3.08	1,362	1,362	1,362	442	442	442
		Forage	6	8.4	3.93	12.78	1,885	1,277	2,492	270	201	340
		Paper birch	1	23.0	22.98	22.98	2,350	2,350	2,350	102	102	102
		Red pine	3	4.4	2.88	5.92	1,145	880	1,410	275	165	385
		Swamp	2	4.2	0.23	8.07	1,212	581	1,843	332	170	493
		Trembling aspen	8	10.1	2.64	17.56	1,757	922	2,593	234	161	307
		N. white cedar	2	1.8	0.16	3.35	671	180	1,161	403	317	489
		White oak	5	7.1	0.09	14.12	1,269	708	1,831	262	166	358

	White pine	6	8.3	0.03	16.50	1,563	438	2,687	276	193	358
	Total	34									
697087A	Black ash	3	1.9	0.47	3.37	678	449	906	408	256	560
	Balsam fir	2	4.2	1.44	6.92	1,486	730	2,243	366	307	425
	Black spruce	3	6.2	1.88	10.44	1,319	705	1,933	232	174	290
	Forage	9	9.3	6.61	11.98	2,058	1,292	2,823	236	183	290
	Paper birch	4	2.6	1.06	4.19	880	535	1,224	361	282	440
	Swamp	3	11.3	1.55	20.99	2,835	307	5,364	299	170	428
	Trembling aspen	5	9.4	0.67	18.14	1,759	470	3,047	284	135	433
	N. white cedar	14	10.9	4.50	17.20	2,009	1,144	2,875	236	188	284
	White pine	2	15.2	-12.02	42.47	2,421	-992	5,834	327	-34	688
	Total	45									
697089A	Balsam fir	2	13.1	-6.63	32.90	2,466	360	4,572	304	7	602
	Forage	3	2.2	-0.90	5.30	785	27	1,542	573	210	937

	Paper birch	2	18.5	-16.33	53.30	2,566	-1,572	6,705	379	-111	869
	Swamp	1	2.5	2.48	2.48	1,477	1,477	1,477	597	597	597
	Trembling aspen	12	8.0	5.07	10.85	1,511	1,109	1,912	280	170	391
	White pine	3	3.1	2.90	3.39	1,119	842	1,397	357	264	451
	Total	23									
697090A	Black ash	1	10.0	10.01	10.01	1,961	1,961	1,961	196	196	196
	Balsam fir	3	10.4	-2.13	22.96	2,134	724	3,543	286	147	425
	Forage	11	3.1	0.67	5.54	831	409	1,253	535	362	708
	Paper birch	3	13.8	-8.33	35.90	2,010	-616	4,636	321	16	626
	Swamp	6	4.8	1.76	7.89	1,361	808	1,914	354	257	451
	Trembling aspen	27	9.8	6.83	12.68	1,846	1,377	2,315	244	191	297
	White oak	2	4.7	-1.24	10.62	1,326	-83	2,736	315	217	412
	White pine	1	2.9	2.90	2.90	1,111	1,111	1,111	382	382	382
	White spruce	1	4.0	4.00	4.00	2,126	2,126	2,126	531	531	531

	Total	55									
697091A	Black ash	1	9.1	9.06	9.06	2,290	2,290	2,290	253	253	253
	Forage	6	7.6	3.57	11.53	1,734	1,156	2,312	270	199	340
	Red pine	1	3.6	3.63	3.63	913	913	913	251	251	251
	Swamp	1	2.2	2.15	2.15	890	890	890	414	414	414
	Trembling aspen	4	14.3	0.16	28.50	2,388	935	3,842	243	105	381
	N. white cedar	1	2.6	2.57	2.57	921	921	921	359	359	359
	White pine	2	3.7	2.00	5.38	981	886	1,077	278	176	380
	Total	16									
697093A	Forage	2	7.3	-5.80	20.46	1,576	-856	4,009	365	43	687
	Paper birch	1	0.8	0.85	0.85	461	461	461	545	545	545
	Swamp	1	25.4	25.43	25.43	5,536	5,536	5,536	218	218	218
	Trembling aspen	7	19.0	3.41	34.61	3,062	1,160	4,964	200	156	245
	N. white cedar	9	6.6	1.40	11.75	1,253	836	1,671	258	214	302

	White pine	4	3.9	0.23	7.49	1,181	80	2,281	313	278	349
	White spruce	1	3.2	3.19	3.19	767	767	767	240	240	240
	Total	25									
697094A	Black ash	3	10.7	-0.67	21.98	2,102	788	3,415	277	56	497
	Black spruce	1	4.5	4.47	4.47	954	954	954	213	213	213
	Forage	1	15.6	15.62	15.62	2,131	2,131	2,131	136	136	136
	Swamp	3	8.4	4.54	12.18	2,339	1,273	3,404	282	240	324
	Trembling aspen	14	17.1	5.74	28.38	2,610	1,555	3,666	218	172	264
	Total	22									
697097A	Balsam fir	1	23.2	23.22	23.22	3,540	3,540	3,540	152	152	152
	Forage	1	1.4	1.37	1.37	776	776	776	567	567	567
	Paper birch	1	36.2	36.25	36.25	4,678	4,678	4,678	129	129	129
	Trembling aspen	9	9.0	6.25	11.69	1,571	1,205	1,938	223	134	311
	White pine	1	2.9	2.90	2.90	1,111	1,111	1,111	382	382	382

	Total	13									
699965A	Black ash	10	6.5	3.79	9.28	1,487	1,131	1,844	281	216	346
	Balsam fir	3	3.8	1.91	5.65	1,006	707	1,305	280	207	354
	Black spruce	7	4.1	2.22	5.94	1,142	786	1,498	314	245	383
	Forage	5	12.2	1.76	22.64	2,379	923	3,835	290	176	405
	Jack pine	1	2.7	2.74	2.74	1,167	1,167	1,167	426	426	426
	Paper birch	12	3.1	1.57	4.61	890	594	1,185	356	287	425
	Red pine	17	7.9	3.06	12.81	1,591	916	2,265	293	238	349
	Swamp	5	5.9	-2.31	14.14	1,336	-10	2,682	389	226	552
	Trembling aspen	36	11.5	8.10	14.90	1,998	1,543	2,452	234	202	266
	N. white cedar	2	7.8	4.63	10.98	1,711	1,137	2,284	221	205	237
	White oak	1	9.9	9.87	9.87	1,516	1,516	1,516	153	153	153
	White pine	10	6.0	-1.19	13.17	1,171	256	2,086	374	265	482
	Total	109									

699967A	Black ash	4	1.5	0.51	2.43	755	426	1,084	592	421	762
	Forage	5	7.4	3.48	11.29	2,003	1,322	2,683	298	233	363
	Jack pine	1	4.2	4.16	4.16	1,273	1,273	1,273	306	306	306
	Red pine	1	4.6	4.58	4.58	1,137	1,137	1,137	248	248	248
	Swamp	1	35.7	35.74	35.74	7,030	7,030	7,030	197	197	197
	Trembling aspen	12	12.2	5.74	18.59	1,972	1,168	2,775	293	172	413
	White pine	6	4.5	1.91	7.02	1,117	776	1,458	308	215	402
	Total	30									
IN											
697084A	Forage	3	8.3	3.49	13.06	1,906	930	2,881	237	212	262
	Red pine	4	9.5	1.61	17.44	1,382	610	2,154	235	61	409
	Swamp	1	39.1	39.12	39.12	5,065	5,065	5,065	129	129	129
	Trembling aspen	5	10.7	5.76	15.57	1,993	1,249	2,736	198	159	236
	Total	13									

697085A	Black spruce	4	1.8	0.16	3.53	899	247	1,551	541	374	707
	Forage	8	3.9	2.46	5.40	1,215	1,051	1,380	390	256	524
	Lake	1	61.3	61.34	61.34	4,274	4,274	4,274	70	70	70
	Red maple	1	3.9	3.93	3.93	1,277	1,277	1,277	325	325	325
	Red pine	5	2.8	-0.24	5.88	961	178	1,744	485	291	679
	Swamp	11	3.6	1.21	5.98	1,228	464	1,992	536	376	697
	Tamarack	1	0.6	0.64	0.64	320	320	320	498	498	498
	Trembling aspen	41	6.8	4.79	8.90	1,513	1,176	1,851	353	273	433
	N. white cedar	1	12.2	12.24	12.24	2,876	2,876	2,876	235	235	235
	White pine	1	0.8	0.76	0.76	456	456	456	602	602	602
	Total	74									
697086A	Black ash	6	6.6	2.67	10.55	1,584	955	2,213	285	223	347
	Balsam fir	3	1.9	0.35	3.37	825	279	1,372	472	401	544
	Black spruce	6	7.1	0.78	13.37	1,359	408	2,310	337	178	497

	Forage	25	7.0	4.85	9.19	1,710	1,363	2,057	308	269	348
	Pond	1	6.7	6.69	6.69	1,050	1,050	1,050	157	157	157
	Paper birch	8	2.7	1.28	4.13	831	589	1,072	393	285	501
	Red maple	3	1.6	0.50	2.71	715	398	1,031	492	352	632
	Red pine	31	7.6	4.97	10.27	1,554	1,135	1,974	292	244	341
	Swamp	39	12.5	1.93	23.04	2,088	1,158	3,018	372	314	430
	Tamarack	4	11.1	-5.59	27.70	1,724	10	3,437	321	131	511
	Trembling aspen	50	10.4	7.59	13.24	2,066	1,597	2,535	303	257	349
	N. white cedar	13	6.3	3.70	8.83	1,647	1,108	2,187	326	259	392
	White pine	1	4.6	4.63	4.63	1,252	1,252	1,252	270	270	270
	Total	190									
697088A	Balsam fir	1	1.2	1.17	1.17	557	557	557	476	476	476
	Forage	7	8.7	3.99	13.48	1,976	1,212	2,741	278	210	346
	Jack pine	2	1.9	1.90	1.97	733	603	862	379	306	453

	Pond	1	6.7	6.69	6.69	1,050	1,050	1,050	157	157	157
	Paper birch	2	3.5	1.01	6.04	1,187	953	1,421	374	173	575
	Red pine	12	7.0	3.91	10.03	1,425	992	1,859	257	205	309
	Swamp	11	22.8	-13.11	58.68	2,681	-93	5,455	344	242	447
	Tamarack	3	5.0	1.60	8.34	1,308	579	2,038	279	203	355
	Trembling aspen	16	13.8	7.56	19.98	2,740	1,582	3,898	264	205	324
	N. white cedar	2	7.0	2.91	11.14	2,016	1,276	2,755	298	229	367
	Total	57									
697095A	Black ash	1	4.6	4.60	4.60	1,238	1,238	1,238	269	269	269
	Balsam fir	2	2.4	-1.26	6.02	819	-111	1,749	483	135	831
	Black spruce	3	7.7	-4.55	20.04	1,491	-450	3,432	292	152	431
	Paper birch	1	10.9	10.87	10.87	1,394	1,394	1,394	128	128	128
	Red pine	1	0.8	0.82	0.82	523	523	523	634	634	634

	Swamp	3	95.4	-12.78	203.60	9,577	2,598	16,556	128	80	175
	Total	11									
697096A	Trembling aspen	4	11.9	5.73	18.16	2,355	1,479	3,231	217	159	276
	Balsam fir	2	3.9	2.88	4.98	1,734	1,045	2,423	437	379	496
	Forage	5	8.0	0.50	15.59	1,859	554	3,164	354	211	498
	Paper birch	1	0.5	0.49	0.49	304	304	304	625	625	625
	Red pine	8	7.6	0.56	14.58	1,668	434	2,902	362	223	500
	Swamp	2	23.9	12.08	35.72	3,850	3,846	3,855	172	87	257
	N. white cedar	2	7.1	3.18	11.05	1,947	1,074	2,821	278	247	310
	White pine	2	2.4	1.40	3.35	708	644	772	309	209	408
	Total	26									
697098A	Black spruce	1	13.7	13.71	13.71	2,635	2,635	2,635	192	192	192
	Forage	2	18.3	6.86	29.72	3,640	1,945	5,334	205	169	240

	Paper birch	2	2.4	-0.86	5.75	968	-10	1,945	487	228	746
	Red pine	6	4.7	2.06	7.43	981	670	1,292	267	168	366
	Trembling aspen	5	5.3	1.78	8.76	1,495	648	2,342	320	252	388
	Total	16									
699964A	Agriculture	1	5.6	5.65	5.65	961	961	961	170	170	170
	Black spruce	5	1.6	0.71	2.40	565	312	818	428	287	569
	Forage	10	7.2	3.27	11.23	1,770	1,077	2,464	347	239	455
	Paper birch	1	1.2	1.17	1.17	507	507	507	434	434	434
	Red pine	7	6.0	2.68	9.37	1,476	950	2,003	307	206	407
	Swamp	16	8.5	0.73	16.18	1,821	636	3,006	512	381	643
	Trembling aspen	41	11.9	8.71	15.05	2,047	1,638	2,455	269	215	323
	N. white cedar	7	7.1	3.15	11.05	2,000	1,113	2,887	339	254	423
	White pine	1	4.6	4.63	4.63	1,252	1,252	1,252	270	270	270
	Total	89									

699966A	Forage	3	3.6	2.86	4.26	970	785	1,155	273	269	276
	Paper birch	1	49.6	49.58	49.58	5,491	5,491	5,491	111	111	111
	Red maple	1	15.6	15.58	15.58	2,146	2,146	2,146	138	138	138
	Red pine	4	10.8	4.36	17.18	1,737	1,205	2,270	191	126	255
	Swamp	6	38.7	-26.86	104.26	3,930	-1,133	8,994	398	144	652
	Trembling aspen	4	19.9	4.43	35.44	4,481	1,722	7,240	250	166	334
	Total	19									

Appendix E. Mean stand level characteristics (size, edge, and edge:area ratio) and 95% confidence interval (CI) of cover type groups within individual 95% kernel density estimated home ranges of global positioning system-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018.

Study site	Deer id	Cover type group[a]	Stand count	Mean size (ha)	Lower CI	Upper CI	Mean edge (m)	Lower CI	Upper CI	Mean edge:area (m/ha)	Lower CI	Upper CI
EL	697083A	Dense conifer	7	2.3	1.54	3.16	810	562	1,057	362	315	408
		Forage	6	8.4	3.93	12.78	1,885	1,277	2,492	270	201	340
		Hardwood	10	11.9	4.98	18.72	1,758	1,032	2,484	199	155	243
		Mixed hardwood	5	4.8	1.73	7.81	1,307	1,136	1,478	346	231	462
		Moderate conifer	2	8.0	1.21	14.87	1,590	493	2,686	206	167	245
		Open conifer	2	16.9	-4.54	38.30	2,653	-312	5,619	171	130	212
		Wetland	2	4.2	0.23	8.07	1,212	581	1,843	332	170	493
		Total	34									

697087A	Dense conifer	17	11.1	5.40	16.89	2,075	1,314	2,835	246	200	292
	Forage	9	9.3	6.61	11.98	2,058	1,292	2,823	236	183	290
	Hardwood	7	5.5	-0.46	11.54	1,267	413	2,121	342	249	435
	Mixed hardwood	5	4.9	-0.66	10.46	1,095	238	1,952	338	195	482
	Moderate conifer	4	4.9	1.11	8.79	1,159	624	1,694	302	159	445
	Wetland	3	11.3	1.55	20.99	2,835	307	5,364	299	170	428
	Total	45									
697089A	Dense conifer	4	8.1	-1.78	17.98	1,853	744	2,962	354	219	489
	Forage	3	2.2	-0.90	5.30	785	27	1,542	573	210	937
	Hardwood	3	9.3	3.17	15.41	1,861	937	2,785	217	167	266
	Mixed hardwood	11	9.5	3.46	15.57	1,607	886	2,328	316	179	452
	Moderate conifer	1	3.3	3.31	3.31	878	878	878	265	265	265
	Wetland	1	2.5	2.48	2.48	1,477	1,477	1,477	597	597	597
	Total	23									

697090A	Dense conifer	3	10.0	-2.89	22.97	2,259	878	3,640	355	139	571
	Forage	11	3.1	0.67	5.54	831	409	1,253	535	362	708
	Hardwood	20	10.0	6.29	13.78	1,971	1,363	2,579	227	197	257
	Mixed hardwood	13	9.5	4.40	14.58	1,619	1,011	2,228	295	176	413
	Moderate conifer	2	4.0	3.49	4.55	1,430	921	1,940	353	273	433
	Wetland	6	4.8	1.76	7.89	1,361	808	1,914	354	257	451
	Total	55									
697091A	Dense conifer	3	3.0	2.38	3.64	922	911	934	313	250	377
	Forage	6	7.6	3.57	11.53	1,734	1,156	2,312	270	199	340
	Hardwood	4	15.8	2.80	28.73	2,596	1,261	3,932	196	136	256
	Mixed hardwood	1	3.3	3.31	3.31	1,458	1,458	1,458	441	441	441
	Moderate conifer	1	4.6	4.55	4.55	1,030	1,030	1,030	226	226	226
	Wetland	1	2.2	2.15	2.15	890	890	890	414	414	414
	Total	16									

697093A	Dense conifer	14	5.6	2.09	9.02	1,198	806	1,589	273	240	305
	Forage	2	7.3	-5.80	20.46	1,576	-856	4,009	365	43	687
	Hardwood	7	18.1	2.00	34.25	2,924	929	4,919	249	142	356
	Mixed hardwood	1	7.0	7.04	7.04	1,429	1,429	1,429	203	203	203
	Wetland	1	25.4	25.43	25.43	5,536	5,536	5,536	218	218	218
	Total	25									
697094A	Forage	1	15.6	15.62	15.62	2,131	2,131	2,131	136	136	136
	Hardwood	11	19.0	4.71	33.27	2,683	1,336	4,029	205	155	256
	Mixed hardwood	6	10.3	4.79	15.85	2,224	1,562	2,885	270	159	382
	Moderate conifer	1	4.5	4.47	4.47	954	954	954	213	213	213
	Wetland	3	8.4	4.54	12.18	2,339	1,273	3,404	282	240	324
	Total	22									
697097A	Dense conifer	2	13.1	-6.85	32.97	2,325	-56	4,706	267	42	493
	Forage	1	1.4	1.37	1.37	776	776	776	567	567	567

	Hardwood	2	11.7	6.70	16.61	1,972	1,722	2,222	175	122	228
	Mixed hardwood	8	11.7	4.32	19.10	1,860	985	2,734	223	122	324
	Total	13									
699965A	Dense conifer	21	5.5	3.65	7.33	1,217	968	1,466	292	244	340
	Forage	5	12.2	1.76	22.64	2,379	923	3,835	290	176	405
	Hardwood	36	10.6	7.10	14.13	1,871	1,401	2,342	257	220	293
	Mixed hardwood	23	6.3	4.43	8.10	1,374	1,109	1,640	280	232	327
	Moderate conifer	11	3.9	2.23	5.50	1,070	738	1,401	320	269	372
	Open conifer	8	11.9	-0.61	24.40	2,129	477	3,781	372	238	506
	Wetland	5	5.9	-2.31	14.14	1,336	-10	2,682	389	226	552
	Total	109									
699967A	Dense conifer	5	3.1	2.11	4.18	979	772	1,186	331	250	413
	Forage	5	7.4	3.48	11.29	2,003	1,322	2,683	298	233	363
	Hardwood	11	11.8	4.95	18.60	2,026	1,184	2,869	297	172	422

		Mixed hardwood	5	4.5	-2.40	11.34	878	242	1,515	522	309	735
		Moderate conifer	1	2.7	2.68	2.68	998	998	998	373	373	373
		Open conifer	2	8.6	8.21	8.93	1,611	1,148	2,074	188	141	234
		Wetland	1	35.7	35.74	35.74	7,030	7,030	7,030	197	197	197
		Total	30									
IN												
	697084A	Dense conifer	1	0.9	0.88	0.88	437	437	437	499	499	499
		Forage	3	8.3	3.49	13.06	1,906	930	2,881	237	212	262
		Hardwood	5	10.7	5.76	15.57	1,993	1,249	2,736	198	159	236
		Moderate conifer	3	12.4	4.58	20.25	1,697	1,041	2,352	147	115	180
		Wetland	1	39.1	39.12	39.12	5,065	5,065	5,065	129	129	129
		Total	13									
	697085A	Dense conifer	5	5.2	0.79	9.65	1,477	489	2,466	355	267	442
		Forage	8	3.9	2.46	5.40	1,215	1,051	1,380	390	256	524

	Hardwood	33	6.9	4.60	9.16	1,553	1,162	1,944	370	273	466
	Mixed hardwood	9	6.4	1.86	10.91	1,343	758	1,928	288	208	368
	Moderate conifer	5	1.4	-0.08	2.89	681	101	1,261	580	437	722
	Open conifer	2	1.0	0.87	1.10	629	235	1,023	626	301	951
	Other	1	61.3	61.34	61.34	4,274	4,274	4,274	70	70	70
	Wetland	11	3.6	1.21	5.98	1,228	464	1,992	536	376	697
	Total	74									
697086A	Dense conifer	24	6.0	3.95	7.98	1,449	1,093	1,806	314	271	358
	Forage	25	7.0	4.85	9.19	1,710	1,363	2,057	308	269	348
	Hardwood	54	9.1	6.71	11.45	1,826	1,457	2,195	328	279	376
	Mixed hardwood	12	7.2	0.58	13.81	1,738	474	3,002	335	241	430
	Moderate conifer	29	6.5	3.76	9.25	1,374	941	1,808	342	281	403
	Open conifer	6	13.1	2.74	23.45	2,234	1,072	3,395	233	165	301
	Other	1	6.7	6.69	6.69	1,050	1,050	1,050	157	157	157

	Wetland	39	12.5	1.93	23.04	2,088	1,158	3,018	372	314	430
	Total	190									
697088A	Dense conifer	9	8.0	4.88	11.03	1,694	1,325	2,064	242	198	285
	Forage	7	8.7	3.99	13.48	1,976	1,212	2,741	278	210	346
	Hardwood	15	11.9	6.75	17.05	2,413	1,511	3,316	284	216	352
	Mixed hardwood	3	16.3	-10.25	42.81	3,340	-1,808	8,488	240	197	283
	Moderate conifer	6	2.8	1.49	4.13	765	583	947	323	236	411
	Open conifer	5	5.8	0.74	10.91	1,448	577	2,320	327	237	417
	Other	1	6.7	6.69	6.69	1,050	1,050	1,050	157	157	157
	Wetland	11	22.8	-13.11	58.68	2,681	-93	5,455	344	242	447
	Total	57									
697095A	Dense conifer	2	2.4	-1.26	6.02	819	-111	1,749	483	135	831
	Hardwood	5	11.5	6.41	16.62	2,075	1,230	2,920	194	145	244
	Mixed hardwood	1	5.7	5.69	5.69	1,676	1,676	1,676	295	295	295

	Moderate conifer	4	6.0	-3.32	15.35	1,249	-203	2,702	377	183	572
	Wetland	3	95.4	-12.78	203.60	9,577	2,598	16,556	128	80	175
	Total	15									
697096A	Dense conifer	5	4.5	1.75	7.26	1,534	831	2,237	428	272	584
	Forage	5	8.0	0.50	15.59	1,859	554	3,164	354	211	498
	Hardwood	1	0.5	0.49	0.49	304	304	304	625	625	625
	Moderate conifer	5	8.7	-0.47	17.88	1,868	249	3,488	302	209	396
	Open conifer	4	3.4	0.40	6.48	951	497	1,405	372	195	549
	Wetland	2	23.9	12.08	35.72	3,850	3,846	3,855	172	87	257
	Total	22									
697098A	Dense conifer	2	1.6	0.85	2.34	606	583	629	401	228	573
	Forage	2	18.3	6.86	29.72	3,640	1,945	5,334	205	169	240
	Hardwood	5	5.3	1.78	8.76	1,495	648	2,342	320	252	388
	Mixed hardwood	2	2.4	-0.86	5.75	968	-10	1,945	487	228	746

	Moderate conifer	4	8.9	5.06	12.73	1,596	859	2,332	180	162	198
	Open conifer	1	3.4	3.40	3.40	926	926	926	272	272	272
	Total	16									
699964A	Dense conifer	9	6.1	2.78	9.44	1,735	962	2,508	346	274	419
	Forage	10	7.2	3.27	11.23	1,770	1,077	2,464	347	239	455
	Hardwood	39	12.2	8.65	15.18	2,029	1,603	2,456	279	219	339
	Mixed hardwood	3	3.9	0.18	7.60	1,133	401	1,865	424	53	795
	Moderate conifer	7	4.0	1.94	6.01	1,106	742	1,470	373	240	506
	Open conifer	4	5.4	-0.89	11.60	1,263	176	2,351	301	192	410
	Other	1	5.6	5.65	5.65	961	961	961	170	170	170
	Wetland	16	8.5	0.73	16.18	1,821	636	3,006	512	381	643
	Total	89									
699966A	Dense conifer	1	18.0	18.04	18.04	2,296	2,296	2,296	127	127	127
	Forage	3	3.6	2.86	4.26	970	785	1,155	273	269	276

Hardwood	4	23.1	5.80	40.49	3,405	1,863	4,948	170	112	227
Mixed hardwood	2	26.2	-7.51	59.85	5,970	829	11,111	285	114	456
Moderate conifer	2	9.3	-0.65	19.33	1,593	655	2,531	203	86	320
Open conifer	1	6.4	6.36	6.36	1,467	1,467	1,467	231	231	231
Wetland	6	38.7	-26.86	104.26	3,930	-1,133	8,994	398	144	652
Total	19									

[a] Grouped cover types are based on dominate species of cover type classes and % canopy cover for conifer stands. Open, moderate, and dense conifer represent the 3 canopy closure classes used for conifer stands; open = 0−39%, moderate = 40−69%, and dense = 70−100%. Mixed hardwood stands have hardwood as the dominant species and conifer as the co-dominant.

Appendix F. Mean stand level characteristics (size, edge, and edge:area ratio) and 95% confidence intervals (CI) and percent use of cover types used by individual global positioning system (GPS)-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018.

Study site	Deer id	Cover type	Number of GPS-fixes	Percent use[a]	Mean size (ha)	Lower CI	Upper CI	Mean edge (m)	Lower CI	Upper CI	Mean edge: area (m/ha)	Lower CI	Upper CI
EL	697083A	Black ash	1	0.2	3.08	NA	NA	1,362	NA	NA	442	NA	NA
		Forage	67	15.7	6.51	6.15	6.88	1,854	1,803	1,906	291	284	298
		Paper birch	1	0.2	22.98	NA	NA	2,350	NA	NA	102	NA	NA
		Red pine	8	1.9	3.63	3.63	3.63	913	913	913	251	251	251
		Swamp	1	0.2	6.15	NA	NA	1,534	NA	NA	249	NA	NA
		Trembling aspen	172	40.4	30.58	29.03	32.13	4,049	3,872	4,227	149	138	159

	White oak	51	12.0	15.45	13.09	17.81	1,912	1,748	2,076	195	158	232
	White pine	125	29.3	9.09	7.15	11.02	1,593	1,323	1,864	276	260	292
	Grand total	426	100.0									
697087A	Black ash	1	0.2	1.23	NA	NA	648	NA	NA	529	NA	NA
	Balsam fir	8	1.9	5.58	5.58	5.58	1,872	1,872	1,872	336	336	336
	Forage	79	19.0	6.56	5.78	7.33	1,288	1,183	1,392	243	222	264
	Paper birch	7	1.7	3.19	1.93	4.46	1,021	767	1,275	353	289	418
	Swamp	7	1.7	17.42	17.42	17.42	5,078	5,078	5,078	291	291	291
	Trembling aspen	96	23.1	11.48	10.29	12.67	2,104	1,917	2,291	198	192	204
	N. white cedar	217	52.3	35.15	32.61	37.69	5,323	4,975	5,671	164	160	168
	Grand total	415	100.0									
697089A	Balsam fir	90	17.6	23.22	23.22	23.22	3,540	3,540	3,540	152	152	152
	Forage	48	9.4	3.94	3.34	4.54	1,204	1,055	1,354	367	331	403
	Paper birch	29	5.7	0.72	0.72	0.72	455	455	455	629	629	629

	Trembling aspen	254	49.8	8.98	8.56	9.40	1,652	1,590	1,715	233	214	252
	White pine	89	17.5	2.98	2.94	3.01	1,069	1,050	1,088	361	352	371
	Grand total	510	100.0									
697090A	Balsam fir	35	6.2	10.78	7.76	13.80	2,325	2,030	2,620	311	273	350
	Forage	116	20.5	8.13	7.24	9.02	1,641	1,507	1,774	245	225	264
	Paper birch	120	21.2	33.86	32.35	35.37	4,394	4,215	4,573	135	131	138
	Swamp	3	0.5	2.78	0.30	5.26	921	334	1,509	378	276	480
	Trembling aspen	282	49.7	14.27	13.27	15.28	2,779	2,595	2,964	199	195	204
	White oak	11	1.9	7.71	7.71	7.71	2,046	2,046	2,046	265	265	265
	Grand total	567	100.0									
697091A	Black ash	2	0.4	9.06	9.06	9.06	2,290	2,290	2,290	253	253	253
	Forage	230	41.5	9.62	9.06	10.19	2,225	2,154	2,296	263	253	272
	Red pine	4	0.7	3.63	3.63	3.63	913	913	913	251	251	251
	Trembling aspen	111	20.0	6.76	6.09	7.42	1,622	1,587	1,657	297	275	320

	White pine	207	37.4	4.34	4.27	4.42	1,018	1,014	1,023	239	234	243
	Grand total	554	100.0									
697093A	Forage	1	0.2	14.03	NA	NA	2,817	NA	NA	201	NA	NA
	Swamp	13	2.3	25.43	25.43	25.43	5,536	5,536	5,536	218	218	218
	Trembling aspen	99	17.7	26.88	24.55	29.22	4,939	4,601	5,277	199	191	207
	N. white cedar	303	54.1	24.62	23.80	25.44	2,346	2,293	2,399	113	106	120
	White pine	112	20.0	6.91	6.28	7.54	2,099	1,904	2,295	303	300	307
	White spruce	32	5.7	3.19	3.19	3.19	767	767	767	240	240	240
	Grand total	560	100.0									
697094A	Black ash	4	0.7	12.83	2.33	23.32	1,605	723	2,487	170	100	241
	Forage	4	0.7	15.62	15.62	15.62	2,131	2,131	2,131	136	136	136
	Swamp	1	0.2	4.53	NA	NA	1,276	NA	NA	281	NA	NA
	Trembling aspen	561	98.4	53.45	50.77	56.12	5,554	5,318	5,790	120	117	123
	Grand total	570	100.0									

697097A	Paper birch	124	22.0	36.25	36.25	36.25	4,678	4,678	4,678	129	129	129
	Trembling aspen	439	78.0	9.25	9.06	9.45	1,556	1,529	1,584	171	169	173
	Grand total	563	100.0									
699965A	Black ash	2	0.4	7.88	7.88	7.88	2,053	2,053	2,053	261	261	261
	Black spruce	5	0.9	1.47	1.47	1.47	583	583	583	396	396	396
	Forage	2	0.4	1.13	1.13	1.13	488	488	488	434	434	434
	Paper birch	34	6.3	6.65	5.64	7.66	1,561	1,365	1,758	243	237	249
	Red pine	149	27.7	3.39	3.30	3.48	1,117	1,063	1,172	326	318	333
	Swamp	1	0.2	1.44	NA	NA	542	NA	NA	375	NA	NA
	Trembling aspen	299	55.7	23.35	22.16	24.54	2,700	2,589	2,811	147	137	157
	White pine	45	8.4	22.92	17.81	28.04	3,279	2,656	3,902	192	171	212
	Grand total	537	100.0									
699967A	Black ash	13	2.3	2.68	2.44	2.91	1,104	1,027	1,181	417	401	434
	Forage	113	19.6	5.60	5.05	6.15	1,971	1,901	2,041	385	372	397

		Jack pine	18	3.1	4.16	4.16	4.16	1,273	1,273	1,273	306	306	306
		Red pine	5	0.9	4.58	4.58	4.58	1,137	1,137	1,137	248	248	248
		Swamp	15	2.6	35.74	35.74	35.74	7,030	7,030	7,030	197	197	197
		Trembling aspen	275	47.7	16.58	15.82	17.35	2,139	2,052	2,225	173	156	191
		White pine	137	23.8	6.11	5.56	6.66	1,447	1,363	1,531	293	273	313
		Grand total	576	100.0									
IN													
	697084A	Forage	118	16.5	6.03	5.64	6.43	1,443	1,367	1,518	246	242	249
		Red pine	99	13.8	7.72	6.73	8.71	1,208	1,113	1,304	208	184	231
		Swamp	119	16.6	39.12	39.12	39.12	5,065	5,065	5,065	129	129	129
		Trembling aspen	380	53.1	12.03	11.67	12.38	2,055	1,996	2,114	173	170	175
		Grand total	716	100.0									
	697085A	Black spruce	19	3.8	1.00	0.98	1.01	588	513	664	586	522	651
		Forage	158	31.3	3.78	3.43	4.13	1,203	1,163	1,243	434	401	468

	Red maple	1	0.2	3.93	NA	NA	1,277	NA	NA	325	NA	NA
	Red pine	57	11.3	6.15	5.26	7.03	1,821	1,598	2,044	324	311	338
	Swamp	46	9.1	4.00	3.62	4.38	1,042	973	1,110	301	261	342
	Tamarack	1	0.2	0.64	NA	NA	320	NA	NA	498	NA	NA
	Trembling aspen	219	43.4	6.08	5.51	6.65	1,432	1,320	1,544	341	308	375
	N. white cedar	1	0.2	12.24	NA	NA	2,876	NA	NA	235	NA	NA
	White pine	3	0.6	0.76	0.76	0.76	456	456	456	602	602	602
	Grand total	505	100.0									
697086A	Balsam fir	1	0.2	1.17	NA	NA	557	NA	NA	476	NA	NA
	Black spruce	39	9.1	6.25	6.25	6.25	1,640	1,640	1,640	262	262	262
	Forage	39	9.1	3.10	2.53	3.68	1,037	895	1,179	353	340	366
	Paper birch	1	0.2	2.24	NA	NA	1,067	NA	NA	476	NA	NA
	Red pine	10	2.3	10.25	9.49	11.01	1,537	1,355	1,718	155	125	184
	Swamp	31	7.3	10.08	8.69	11.46	1,967	1,773	2,160	244	191	296

	Trembling aspen	295	69.1	17.27	16.57	17.97	3,970	3,840	4,100	243	238	248
	N. white cedar	11	2.6	11.24	9.26	13.21	1,765	1,640	1,889	180	130	230
	Grand total	427	100.0									
697088A	Forage	55	11.4	17.50	16.58	18.41	2,991	2,854	3,127	176	167	185
	Red pine	117	24.2	9.01	8.17	9.85	1,700	1,608	1,791	214	204	224
				145.2	120.9		12,02		13,89	187	138	236
	Swamp	57	11.8	4	8	169.50	5	10,153	7			
	Tamarack	169	34.9	8.35	8.35	8.35	2,051	2,051	2,051	246	246	246
	Trembling aspen	86	17.8	14.43	12.82	16.05	3,194	2,827	3,560	256	234	278
	Grand total	484	100.0									
697095A	Black ash	2	0.6	4.60	4.60	4.60	1,238	1,238	1,238	269	269	269
	Balsam fir	8	2.4	3.77	2.86	4.68	1,175	942	1,407	350	263	437
	Black spruce	11	3.4	5.07	0.62	9.52	1,041	330	1,751	277	239	316
	Red pine	5	1.5	0.82	0.82	0.82	523	523	523	634	634	634

	Swamp	70	21.3	76.96	59.76	94.17	8,362	7,249	9,475	141	133	149
	Trembling aspen	232	70.7	15.57	15.11	16.04	2,582	2,521	2,644	175	169	181
	Grand total	328	100.0									
697096A	Balsam fir	87	15.8	4.47	4.47	4.47	2,085	2,085	2,085	467	467	467
	Forage	180	32.7	19.53	18.77	20.29	4,102	3,984	4,221	229	219	240
	Paper birch	1	0.2	0.49	NA	NA	304	NA	NA	625	NA	NA
	Red pine	140	25.5	22.43	20.95	23.91	4,267	3,995	4,539	192	191	192
	Swamp	25	4.5	29.45	28.50	30.39	3,848	3,848	3,849	132	125	139
	N. white cedar	72	13.1	5.10	5.10	5.10	1,502	1,502	1,502	294	294	294
	White pine	45	8.2	1.88	1.88	1.88	675	675	675	360	360	360
	Grand total	550	100.0									
697098A	Black spruce	58	11.7	13.71	13.71	13.71	2,635	2,635	2,635	192	192	192
	Forage	346	69.6	23.75	23.54	23.97	4,449	4,417	4,481	188	187	189
	Paper birch	1	0.2	4.13	NA	NA	1,467	NA	NA	355	NA	NA

	Red pine	14	2.8	3.18	2.43	3.94	763	672	854	264	234	295
	Trembling aspen	78	15.7	3.04	2.72	3.36	1,001	932	1,071	357	344	370
	Grand total	497	100.0									
699964A	Agriculture	3	0.5	5.65	5.65	5.65	961	961	961	170	170	170
	Black spruce	1	0.2	2.36	NA	NA	1,033	NA	NA	438	NA	NA
	Forage	118	20.8	11.23	10.49	11.96	2,727	2,595	2,860	254	248	260
	Paper birch	17	3.0	1.17	1.17	1.17	507	507	507	434	434	434
	Red pine	9	1.6	4.54	4.54	4.54	1,246	1,246	1,246	275	275	275
	Swamp	51	9.0	32.95	28.55	37.35	4,825	4,282	5,367	205	159	250
	Trembling aspen	349	61.6	17.72	16.63	18.81	2,731	2,559	2,903	168	163	173
	N. white cedar	15	2.6	16.32	16.32	16.32	3,985	3,985	3,985	244	244	244
	White pine	4	0.7	4.63	4.63	4.63	1,252	1,252	1,252	270	270	270
	Grand total	567	100.0									
699966A	Forage	80	14.1	4.04	3.98	4.10	1,100	1,083	1,116	272	272	272

Paper birch	129	22.8	49.58	49.58	49.58	5,491	5,491	5,491	111	111	111
Red pine	72	12.7	12.26	10.92	13.60	1,887	1,791	1,982	178	166	190
Swamp	110	19.4	67.28	50.63	83.92	6,548	5,322	7,774	218	189	247
Trembling aspen	176	31.0	15.26	14.90	15.62	3,766	3,711	3,821	249	246	253
Grand total	567	100.0									

[a] Percent use is the number of GPS-fixes in each cover type divided by the total number of GPS-fixes for each individual deer.

Appendix G. Mean stand-level characteristics (size, edge, and edge:area ratio) and 95% confidence intervals (CI) and percent use of cover type groups used by individual global positioning system (GPS)-collared adult (≥1.5 yr), female white-tailed deer at the Elephant Lake (EL) and Inguadona Lake (IN) sites, northeastern and northcentral Minnesota, 12 March−30 April 2018.

Study site	Deer id	Cover type group[a]	Number of GPS-fixes	Percent use[b]	Mean size (ha)	Lower CI	Upper CI	Mean edge (m)	Lower CI	Upper CI	Mean edge: area ratio (m/ha)	Lower CI	Upper CI
EL	697083A	Dense conifer	80	18.8	1.6	1.44	1.76	526	491	562	342	334	349
		Forage	67	15.7	6.5	6.15	6.88	1,854	1,803	1,906	291	284	298
		Hardwood	183	43.0	31.7	30.74	32.76	4,058	3,912	4,204	129	126	131
		Mixed hardwood	42	9.9	6.3	5.06	7.50	1,309	1,243	1,375	298	254	342
		Moderate conifer	23	5.4	8.8	7.37	10.22	1,711	1,483	1,939	202	194	210

	Open conifer	30	7.0	27.8	27.81	27.81	4,166	4,166	4,166	150	150	150
	Wetland	1	0.2	6.2	NA	NA	1,534	NA	NA	249	NA	NA
	Total	426	100.0									
697087A	Dense conifer	225	54.2	34.1	31.55	36.65	5,200	4,854	5,546	170	164	176
	Forage	79	19.0	6.6	5.78	7.33	1,288	1,183	1,392	243	222	264
	Hardwood	8	1.9	2.9	1.75	4.14	975	736	1,213	375	305	446
	Mixed hardwood	96	23.1	11.5	10.29	12.67	2,104	1,917	2,291	198	192	204
	Wetland	7	1.7	17.4	17.42	17.42	5,078	5,078	5,078	291	291	291
	Total	415	100.0									
697089A	Dense conifer	163	32.0	14.1	12.56	15.67	2,452	2,266	2,638	255	238	273
	Forage	48	9.4	3.9	3.34	4.54	1,204	1,055	1,354	367	331	403
	Hardwood	95	18.6	9.3	9.10	9.50	1,871	1,841	1,900	201	201	202
	Mixed hardwood	188	36.9	7.5	6.85	8.24	1,357	1,262	1,453	310	279	342
	Moderate conifer	16	3.1	3.3	3.31	3.31	878	878	878	265	265	265

	Total	510	100.0									
697090A	Dense conifer	12	2.1	23.2	23.22	23.22	3,540	3,540	3,540	152	152	152
	Forage	116	20.5	8.1	7.24	9.02	1,641	1,507	1,774	245	225	264
	Hardwood	224	39.5	15.1	13.89	16.37	3,083	2,867	3,298	215	210	220
	Mixed hardwood	189	33.3	25.3	23.44	27.18	3,402	3,183	3,621	143	140	145
	Moderate conifer	23	4.1	4.3	4.29	4.29	1,690	1,690	1,690	394	394	394
	Wetland	3	0.5	2.8	0.30	5.26	921	334	1,509	378	276	480
	Total	567	100.0									
697091A	Dense conifer	29	5.2	2.9	2.83	3.04	930	928	933	319	309	329
	Forage	230	41.5	9.6	9.06	10.19	2,225	2,154	2,296	263	253	272
	Hardwood	70	12.6	8.9	8.27	9.61	1,742	1,696	1,788	208	198	218
	Mixed hardwood	43	7.8	3.3	3.31	3.31	1,458	1,458	1,458	441	441	441
	Moderate conifer	182	32.9	4.6	4.55	4.55	1,030	1,030	1,030	226	226	226
	Total	554	100.0									

697093A	Dense conifer	447	79.8	18.6	17.65	19.64	2,171	2,100	2,243	170	161	179
	Forage	1	0.2	14.0	NA	NA	2,817	NA	NA	201	NA	NA
	Hardwood	99	17.7	26.9	24.55	29.22	4,939	4,601	5,277	199	191	207
	Wetland	13	2.3	25.4	25.43	25.43	5,536	5,536	5,536	218	218	218
	Total	560	100.0									
697094A	Forage	4	0.7	15.6	15.62	15.62	2,131	2,131	2,131	136	136	136
	Hardwood	503	88.2	58.1	55.44	60.83	5,921	5,678	6,164	112	109	115
	Mixed hardwood	62	10.9	12.8	12.19	13.38	2,323	2,223	2,423	186	177	194
	Wetland	1	0.2	4.5	NA	NA	1,276	NA	NA	281	NA	NA
	Total	570	100.0									
697097A	Hardwood	70	12.4	11.3	10.70	11.88	1,953	1,924	1,983	179	173	185
	Mixed hardwood	493	87.6	15.8	14.69	16.81	2,285	2,161	2,409	159	157	161
	Total	563	100.0									
699965A	Dense conifer	113	21.0	3.4	3.30	3.55	1,174	1,105	1,243	339	329	348

	Forage	2	0.4	1.1	1.13	1.13	488	488	488	434	434	434
	Hardwood	304	56.6	23.2	22.06	24.40	2,711	2,603	2,819	147	138	157
	Mixed hardwood	31	5.8	5.2	4.64	5.80	1,299	1,222	1,376	257	244	271
	Moderate conifer	61	11.4	3.2	3.07	3.36	905	878	931	287	278	296
	Open conifer	25	4.7	38.4	38.40	38.40	5,164	5,164	5,164	134	134	134
	Wetland	1	0.2	1.4	NA	NA	542	NA	NA	375	NA	NA
	Total	537	100.0									
699967A	Dense conifer	75	13.0	2.7	2.47	2.95	954	906	1,003	381	359	404
	Forage	113	19.6	5.6	5.05	6.15	1,971	1,901	2,041	385	372	397
	Hardwood	92	16.0	14.7	12.80	16.54	2,451	2,245	2,656	204	186	223
	Mixed hardwood	196	34.0	16.6	15.78	17.33	1,923	1,851	1,996	175	150	200
	Moderate conifer	2	0.3	2.7	2.68	2.68	998	998	998	373	373	373
	Open conifer	83	14.4	8.7	8.75	8.75	1,847	1,847	1,847	211	211	211
	Wetland	15	2.6	35.7	35.74	35.74	7,030	7,030	7,030	197	197	197

		Total	576	100.0								
IN												
	697084A	Dense conifer	14	0.02	0.9	0.88	0.88	437	437	437	499	499	499
		Forage	118	16.5	6.0	5.64	6.43	1,443	1,367	1,518	246	242	249
		Hardwood	380	53.1	12.0	11.67	12.38	2,055	1,996	2,114	173	170	175
		Moderate conifer	85	11.9	8.8	7.89	9.80	1,336	1,251	1,420	160	156	164
		Wetland	119	16.6	39.1	39.12	39.12	5,065	5,065	5,065	129	129	129
		Total	716	100.0								
	697085A	Dense conifer	71	14.1	5.3	4.41	6.16	1,590	1,371	1,809	354	335	373
		Forage	158	31.3	3.8	3.43	4.13	1,203	1,163	1,243	434	401	468
		Hardwood	188	37.2	6.2	5.53	6.85	1,465	1,336	1,595	359	321	398
		Mixed hardwood	32	6.3	5.4	5.06	5.70	1,233	1,209	1,258	234	224	244
		Moderate conifer	4	0.8	0.7	0.67	0.78	422	355	489	576	525	627
		Open conifer	6	1.2	1.0	1.05	1.05	830	830	830	792	792	792

	Wetland	46	9.1	4.0	3.62	4.38	1,042	973	1,110	301	261	342
	Total	505	100.0									
697086A	Dense conifer	13	3.0	10.9	9.18	12.61	1,812	1,690	1,934	188	144	231
	Forage	39	9.1	3.1	2.53	3.68	1,037	895	1,179	353	340	366
	Hardwood	281	65.8	18.0	17.44	18.65	4,142	4,042	4,243	240	235	245
	Mixed hardwood	15	3.5	1.7	1.74	1.74	556	556	556	320	320	320
	Moderate conifer	48	11.2	6.9	6.33	7.39	1,578	1,527	1,628	246	229	263
	Wetland	31	7.3	10.1	8.69	11.46	1,967	1,773	2,160	244	191	296
	Total	427	100.0									
697088A	Dense conifer	95	19.6	10.3	9.44	11.13	1,880	1,804	1,955	203	192	214
	Forage	55	11.4	17.5	16.58	18.41	2,991	2,854	3,127	176	167	185
	Hardwood	81	16.7	15.2	13.59	16.75	3,349	2,986	3,712	255	232	278
	Mixed hardwood	5	1.0	2.5	2.52	2.52	684	684	684	271	271	271
	Moderate conifer	22	4.5	3.5	3.51	3.51	922	922	922	263	263	263

	Open conifer	169	34.9	8.3	8.35	8.35	2,051	2,051	2,051	246	246	246
					120.9		12,02		13,89	187	138	236
	Wetland	57	11.8	145.2	8	169.50	5	10,153	7			
	Total	484	100.0									
697095A	Dense conifer	8	2.4	3.8	2.86	4.68	1,175	942	1,407	350	263	437
	Hardwood	208	63.4	16.7	16.50	16.90	2,683	2,628	2,737	161	158	164
	Mixed hardwood	26	7.9	5.7	5.69	5.69	1,676	1,676	1,676	295	295	295
	Moderate conifer	16	4.9	3.7	0.57	6.91	879	383	1,375	389	301	476
	Wetland	70	21.3	77.0	59.76	94.17	8,362	7,249	9,475	141	133	149
	Total	328	100.0									
697096A	Dense conifer	159	28.9	4.8	4.70	4.80	1,821	1,776	1,866	389	375	402
	Forage	180	32.7	19.5	18.77	20.29	4,102	3,984	4,221	229	219	240
	Hardwood	1	0.2	0.5	NA	NA	304	NA	NA	625	NA	NA
	Moderate conifer	185	33.6	17.4	15.73	19.12	3,393	3,090	3,696	233	222	243

	Wetland	25	4.5	29.4	28.50	30.39	3,848	3,848	3,849	132	125	139
	Total	550	100.0									
697098A	Dense conifer	8	1.6	2.0	1.98	1.98	618	618	618	313	313	313
	Forage	346	69.6	23.8	23.54	23.97	4,449	4,417	4,481	188	187	189
	Hardwood	78	15.7	3.0	2.72	3.36	1,001	932	1,071	357	344	370
	Mixed hardwood	1	0.2	4.1	NA	NA	1,467	NA	NA	355	NA	NA
	Moderate conifer	64	12.9	12.9	12.23	13.51	2,478	2,357	2,599	193	192	193
	Total	497	100.0									
699964A	Dense conifer	24	4.2	11.9	9.57	14.23	2,958	2,416	3,500	256	250	262
	Forage	118	20.8	11.2	10.49	11.96	2,727	2,595	2,860	254	248	260
	Hardwood	282	49.7	21.0	19.97	22.03	3,186	3,012	3,360	168	159	177
	Mixed hardwood	84	14.8	3.4	3.19	3.58	753	699	807	221	219	222
	Moderate conifer	4	0.7	4.6	4.63	4.63	1,252	1,252	1,252	270	270	270
	Open conifer	1	0.2	2.4	NA	NA	1,033	NA	NA	438	NA	NA

	Other	3	0.5	5.6	5.65	5.65	961	961	961	170	170	170
	Wetland	51	9.0	32.9	28.55	37.35	4,825	4,282	5,367	205	159	250
	Total	567	100.0									
699966A	Dense conifer	35	6.2	18.0	18.04	18.04	2,296	2,296	2,296	127	127	127
	Forage	80	14.1	4.0	3.98	4.10	1,100	1,083	1,116	272	272	272
	Hardwood	298	52.6	30.1	28.22	32.08	4,505	4,407	4,603	187	179	194
	Mixed hardwood	7	1.2	13.9	4.27	23.52	4,097	2,628	5,565	348	299	397
	Moderate conifer	2	0.4	14.4	14.44	14.44	2,071	2,071	2,071	143	143	143
	Open conifer	35	6.2	6.4	6.36	6.36	1,467	1,467	1,467	231	231	231
	Wetland	110	19.4	67.3	50.63	83.92	6,548	5,322	7,774	218	189	247
	Total	567	100.0									

[a] Grouped cover types are based on dominate species of cover type classes and % canopy cover for conifer stands. Open, moderate, and dense conifer represent the 3 canopy closure classes used for conifer stands; open = 0−39%, moderate = 40−69%, and dense = 70−100%. Mixed hardwood stands have hardwood as the dominant species and conifer as the co-dominant.

[b] Percent use is the number of GPS-fixes in each cover type divided by the total number of GPS-fixes for each individual deer.