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Annual and Seasonal Measurements of Home Ranges and Habitat Use by Female Elk (Cervus elaphus) in Northwestern Minnesota

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Annual and seasonal measurements of home ranges and habitat use by female elk (*Cervus elaphus*) in northwestern Minnesota

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Thesis Abstract

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Master of Science (M.S.) in Biological Sciences

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Elk were present historically in Minnesota's prairies and forest transition zone up until their extirpation from the state in the late 1800s (Hazard 1982, Minnesota Department of Natural Resources [MNDNR] 2017). Settlers moving into the region converted much of the land for agricultural purposes, significantly reducing the amount of habitat available for elk, and ultimately leading to their extirpation in the early 1900s. Elk returned to the state in the 1930s through a reintroduction effort, as well as through natural dispersal from North Dakota USA, and Manitoba Canada in the 1980s (MNDNR 2017). In 2016, the Minnesota Department of Natural Resources (MNDNR) began a study on Minnesota's free-ranging elk population. This population is found in a highly agricultural region in northwestern Minnesota, primarily in Kittson, Roseau, and Marshall counties. The purpose of this project was to collect baseline ecological data to provide a foundation for future research and management. Results from this study will help the MN DNR reduce elk conflicts with local landowners and inform management strategies to provide suitable habitat for this population. Our objectives for this project were to estimate the annual and seasonal home ranges of female elk, measure annual and seasonal home range fidelity, and describe annual and seasonal habitat use, for 2 full years. Current population estimates performed by the MNDNR in 2018, after a joint survey with Manitoba Conservation, the population is estimated to be about 220 elk (Franke 2018). While this population is still small, conflict with local landowners are a concern. More information is needed about the Minnesota elk population. Until 2016, there has been no multiscale study done on elk in northwestern Minnesota. The state of Minnesota would benefit from the collection of baseline ecological data, such as home ranges, seasonal movements, and habitat preferences. Our study will provide this baseline ecological data by combining home range information, landscape-level habitat use and selection of fine-scale habitat features by adult female elk in northwestern Minnesota.

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Chapter 1 : A brief history of Minnesota elk (*Cervus elaphus*), and introduction to studying elk home ranges and habitat use in northwestern Minnesota

Introduction

Elk (*Cervus elaphus*) were historically present throughout Minnesota's prairie and forest transition zone until their extirpation around 1932 (Fashingbauer 1965, Hazard 1982). The expansion of Europeans settlers into the elk range and the ensuing habitat conversion and unregulated hunting are considered the primary causes for the loss of elk in Minnesota. In 1913, the Minnesota Legislature appropriated $5,000 for the purpose of restoring elk to the state. In 1914-1915, 56 elk were brought from Jackson Hole, Wyoming and from the northernmost section of the Yellowstone National Park. Also in 1914, an additional 14 elk, descendants of elk captured in Wyoming, were obtained from the James J. Hill farm in Ramsey County, Minnesota. The 70 animals were released into an enclosure at Itasca State Park in Itasca County; however only 13 animals survived after one year due to harsh weather conditions. Subsequently, there were multiple unsuccessful attempts to establish a herd in northwestern Minnesota. The restoration effort was finally successful in 1935 when a herd was established in northwestern Beltrami County by releasing 27 of the remaining elk from Itasca State Park onto the Red Lake Game Preserve (Hazard 1982).

Elk population increases eventually caused conflicts with agricultural producers in the region (Hazard 1982). This conflict escalated with illegal elk harvest, which limited overall population growth (Minnesota Department of Natural Resources [MNDNR] 2017). Concurrently, declining public acceptance of the elk population prompted the Minnesota Legislature to require the MNDNR to write an elk management plan in 1987.

With the input of local landowners, the general public, and the local wildlife managers, the management plan was developed in 1988 and has been periodically updated as new information becomes available (MNDNR 2017).

Current Elk Knowledge

The Minnesotan elk population is currently restricted to the northwestern most counties in the state (MNDNR 2017). Although the range is limited, there are four spatially distinct population clusters. Remnants of the restored population currently occupy the northeastern-most area of Marshall County, between the Thief Lake Wildlife Management Area (WMA) and the city of Grygla (hereafter Grygla sub-group; MNDNR 2017). Three additional groups are located northwest of the city of Lancaster (hereafter Lancaster North group), southeast of the city of Lancaster (hereafter Lancaster South sub-group), and near the Caribou WMA (hereafter Caribou-Vita sub-group), were likely formed as individuals moved from Manitoba and North Dakota. The group near the Caribou WMA regularly crosses the USA-Canadian border, and ranges as far north as Vita, Manitoba (MNDNR 2017).

To estimate the population size of elk, the MNDNR annually conducts annual winter surveys using fixed-wing aircraft. Since Minnesota shares a herd with Canada (Caribou-Vita herd), MNDNR coordinates these surveys with the Manitoba Conservation agency when possible (Franke 2018). The most recent population estimate in 2018 identified 75 elk in the Lancaster North and South sub-groups combined and 15 elk in the Grygla herd. After a joint survey with Manitoba Conservation, the Caribou-Vita population was estimated at 133 elk (Franke 2018).

Despite the relatively small population size of elk in Minnesota, conflicts with local landowners are persistent. To address these conflicts, MNDNR created two elk working groups (Kittson County and Grygla), with members comprised of a mixture of landowners and staff who work together to continue to work on the elk management plan and address local issues. The most significant conflict between elk and agricultural producers continues to be the depredation of crops and the destruction of stored forage and fencing by elk. In 2016, the Minnesota legislature directed MNDNR to limit elk population growth within the established elk range. The statute does not allow any growth in the elk population unless evidence is presented that crop and fence damages have not increased in the previous two years

Gaining landowner acceptance for a viable elk population is challenging; however, the MNDNR works closely with the local agricultural producers to collaboratively resolve conflicts. Under the 2016 elk management plan, the MNDNR also provides fencing to producers to protect stored forage, fields, or pastures from elk damage. MNDNR staff plant food plots on public and private land in an attempt to attract elk away from agricultural fields. Habitat management, including brush land management and prescribed fire are often used to manipulate habitats to benefit elk. Finally, the Minnesota Department of Agriculture provides financial compensation to landowners for verified elk-related crop and fence damage.

To resolve conflicts and improve management strategies for elk in Minnesota, it is clear that more information is needed regarding how elk utilize resources at multiple spatial scales, primarily at the fine- and landscape-scales. Until now there has been no study of elk biology in northwestern Minnesota. Given the challenges of managing elk-human conflicts, baseline information is needed to help the MNDNR resolve these and improve management strategies. In my research, I addressed this need by developing a multi-scale habitat selection study of GPS collared elk in the 4 sub-groups of northwestern Minnesota. This study will provide these baseline ecological data by describing annual and seasonal home ranges, landscape-level habitat use and selection of fine-scale habitat features by adult female elk, hence providing information that will improve management of this small, yet important elk population and minimize elk human conflicts.

Research objectives

The overarching objective of my research is to improve the understanding of elk home ranges and habitat use at the landscape and fine-scale scales, in northwestern Minnesota. Specifically, my objectives are to:

1. Describe the size, locations, and site fidelity of annual and seasonal home ranges of adult female elk.

2. Characterize the habitat use of adult female elk within their home ranges.

    a. Describe seasonal habitat use at the landscape level.

    b. Describe fine-scale structural vegetation characteristics selected for by adult female elk during the growing season (i.e., May through July).

Home ranges

Description of the geographic space animals occupy are fundamental to studies on animal biology and are beneficial to answer pressing questions about a population (Fieberg and Börger 2012) such as knowing the specific location of individuals or the entire population, modeling an individual's movements, or comparing the sizes of utilization distributions (Anderson et al. 2005a, Jacques et al. 2009, Barbknecht et al. 2011). Several approaches have been used to estimate and map animals' home ranges. Estimators like Convex Hulls or Minimum Convex Polygons are simple ways to show the outer boundaries utilized by an animal (White and Garrott 1990, Lehman et al. 2016). Kernel density estimators (KDEs) and Brownian Bridge Movement Models (BBMMs) are often used to model an animal's utilization distribution, outlining areas that were most frequently used by the animal in a given time period (Seaman and Powell 1996, Horne et al. 2007).

Global Positioning System (GPS) and Very High Frequency (VHF) tracking collars are common means of collecting animal locational information. GPS technology uses the global satellite system and collects relatively precise locations that are stored on the collar and sometimes transmitted remotely. This technology collects a large amount of more accurate locations; however, they have a high cost which can limit the number of animals collared (Cagnacci et al. 2010, Hebblewhite and Haydon 2010). In contrast, VHF technology is less expensive; however, locations must be actively determined via direct study and locations must be triangulated. This requires more effort to locate the animals and the location errors are larger (White and Garrott 1990, Kochanny et al. 2009).

In this study, I used locations from GPS radio collars to create home ranges using BBMMs (Seaman and Powell 1990, Anderson et al. 2005b, Brough 2009, Jacques et al. 2009, Fieberg and Börger 2012, Spencer 2012). I was also interested in defining seasons that are biologically important for elk and measuring how home ranges changed between seasons (Ager et al. 2003, Jacques et al. 2009, Fieberg and Börger 2012). Through using seasonal home ranges for two consecutive years, I measured site fidelity and overlap of home ranges between different seasons (Van Dyke et al. 1998, Frair et al. 2008, Brough 2009).

Habitat Selection

Within their home range, animals use some resources disproportionally to their availability. The proportion of the different types of habitat used, when compared to the available habitat, can help determine what habitat is selected for by animals (Arthur et al. 1996, Boyce and McDonald 1999, Boyce et al. 2002, Manly et al. 2002, Lehman et al. 2016). A Resource Selection Function (RSF) is a method that can be used to measure the relative probability that an animal uses different resources compared to what is available in a given area (e.g., home range; Boyce and McDonald 1999, Boyce et al. 2002, Manly et al. 2002). The use of RSFs is a robust tool for learning about what habitats types or characteristics are selected for both at the scale of the landscape and at finer scales by elk in Minnesota.

For this study, I was interested in gaining a deeper understanding of the habitats used by elk, and what resources they prefer within the mixed landscape found in northwestern Minnesota across different seasons. In Minnesota, the landscape occupied by elk is dominated by agricultural land, but also contains large tracts of natural habitat including state-owned WMAs, private lands (e.g., lands owned and managed by The Nature Conservancy), and conservation reserve program (CRP) grasslands (Ditmer et al. 2015). Different management strategies (e.g., prescribed burning, brush removal, food plots) may also influence elk resource use within their home ranges. Knowledge about the way elk respond to different resources and management strategies will help with managing elk-human conflicts and creating habitat suitable for this population.

Vegetative cover is known to be an important resource for elk (Nudds 1977, Beck et al. 2001, Rumble and Gamo 2011, Beck et al. 2013). This type of measurement is best obtained using field techniques when remote imagery is not readily available for the sampling period of choice. I chose to measure vegetation at three different levels: canopy cover, visual cover, and ground cover (Anderson et al. 2005b, Barbknecht et al. 2011, Rumble and Gamo 2011, Lehman et al. 2016). Canopy cover can represent habitat that protects elk from environmental hazards (Beck, Jeffrey L. and Peek, James M. 2001, Anderson et al. 2005b, Barbknecht et al. 2011, Rumble and Gamo 2011, Lehman et al. 2016). Visual cover represents the ability of an elk to obscure themselves from predators (Nudds 1977, Barbknecht et al. 2011). Ground cover can represent both potential forage for elk, as well as bedding sites (Anderson et al. 2005b, Barbknecht et al. 2011, Rumble and Gamo 2011, Lehman et al. 2016). I measured the amount of structural vegetation in habitats used by elk as well as in habitats considered to be available to them. To estimate preferences for the 3 levels of habitat structure during the summer, I determined the probability of use versus availability for these 3 difference levels of vegetative cover (Boyce et al. 2002, Manly et al. 2002).

Estimating home ranges for elk, learning what habitats are most important for them will improve understanding of Minnesota elk. Through these objectives, this project will help wildlife managers make decisions that benefit long-term elk viability. Knowing what management strategies benefit elk will also help to reduce elk-human conflicts. This research will also provide a foundation for future studies on elk in Minnesota. Their importance to the environment, their economic benefits, and status as both a native and state listed sensitive species, make elk an important natural resource to the state of Minnesota. Thus, their continued presence and management will ultimately benefit the natural habitats and people of this state.

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Running Head: Freeman: Home ranges of female elk in Minnesota

Chapter 2 : Annual and seasonal home range size and site fidelity of female elk (*Cervus elaphus*) in northwestern Minnesota

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Abstract

Elk (*Cervus elaphus*) were successfully reintroduced to Minnesota in the 1930s, after their extirpation in the late 1800s as a result of overharvesting and conversion of the land to agriculture (Hazard 1982). Despite continued management of the population since that time, the basic ecology of Minnesota elk is not well understood. In February 2016, we placed Global Positioning System (GPS) collars on 20 free-ranging adult female elk in northwestern Minnesota to collect baseline ecological data that can be used for improving elk population management at multiple scales. We calculated the mean annual home range sizes for all collared elk with Brownian Bridge Movement Models (BBMM) by using locations taken at 4-hour intervals for 2 years. We calculated the average annual and seasonal home range sizes of elk in each of the four sub-groups of elk present in northwestern Minnesota (Caribou-Vita, Grygla, Lancaster North, Lancaster South). We estimated site fidelity between the two time periods as the proportional overlap of each annual home range, as well as the percent overlap within each season between the two time periods. The mean annual BBMM home range size of the collared cows from ranged from 71 km^2 ± 17.4 km^2 to 111.4 km^2 ± 1.5 km^2. The

mean seasonal home range sizes for elk were largest in the fall season (68.5 km^2 ± 6.8 SE) and smallest in the summer season (29.5 km^2 ± 1.9 SE). We found elk, overall, had greater than 50% site fidelity annually. Seasonally we found 43.7 km^2 ± 2.9 SE overlap in parturition, 29.5 km^2 ± 1.9 SE in summer, 68.5 km^2 ± 6.8 SE in fall, and 48.8 km^2 ± 1.9 SE in and winter. Through this project we hope to give local wildlife managers much needed information about this historic population.

Introduction

Elk (*Cervus elaphus*) form dynamic herds that move across broad areas of the landscape to meet their biological needs as environmental conditions change (Wisdom and Cook 2000). Through behaviors such as grazing, wallowing, and trampling vegetation, elk can substantially alter ecosystem processes and vegetation structure (Cox 2011). Compared to elk in western North America, eastern elk populations more commonly experience mortality due to interactions with humans, including vehicle collisions and nuisance culling (Keller et al. 2015). Reducing, elk-human conflicts are a major consideration in managing eastern elk populations (Walberg et al. 2018).

Careful monitoring of elk populations in human-influenced landscapes is critical to aid managers in reducing elk-human conflicts, mitigating the negative aspects of elk, and enhancing the ecological benefits of maintaining healthy elk populations (e.g., recreational hunting and viewing). Improving understanding of the way elk use landscapes aids in predicting distribution of populations and use of key habitats. Numerous studies have examined elk home ranges in North America (Unsworth, 1993; Anderson et al., 2005; Gingery et al., 2017; Rosatte, 2017). The spatial extent and location of an animal's home range is often measured after reintroductions to better understand how new populations utilize the landscape (Wichrowski et al., 2005; Rosatte, 2017). Home ranges are also measured to determine changes in the way an animal uses space across seasons, for example, to obtain resources in response to environmental phenological changes (Franklin et al. 1975, Unsworth 1993, Ager et al. 2003, Anderson et al. 2005a,b, Jacques et al. 2009, Skrobarczyk 2011, Beck et al. 2013, Seidel and Boyce 2016, Amor et al. 2019).

Measuring site fidelity on a seasonal or annual scale can show what areas provide the most benefit for elk survival (Edge et al. 1985, Van Dyke et al. 1998, Millspaugh et al. 2004, Stubblefield et al. 2006, Brough 2009). In the western USA there are some populations of elk that are migratory; they can travel long distances and traverse large elevation gradients every year throughout different seasons (Toweill and Thomas 2002, Ager et al. 2003, Anderson et al. 2005). These population have larger home ranges, and no overlap between winter and summer ranges (Toweill and Thomas, 2002; Jacques et al., 2009, Skrobarczyk 2011). Edge et al. 1985 estimated annual home ranges for elk cows between 44 km^2 and 45 km^2, while Skrobarczyk 2011 estimated annual home range sizes of 97 km^2 to 238 km^2. In contrast, eastern elk populations tend to be non-migratory (Toweill and Thomas, 2002; Wichrowski et al., 2005; Keller et al., 2015; Rosatte, 2017). Non-migratory populations of elk have often have smaller home ranges, and also develop small sub-groups within their population (Toweill and Thomas 2002, Millspaugh et al. 2004, Rosatte 2017). A recent study of cow elk in North Dakota, USA showed annual home ranges between 18 km^2 and 32 km^2 (Amor et al. 2019). In Southern Ontario, Canada elk cow annual home range sizes were between 27.9 km^2 and 93.4 km^2 (Rosatte 2017). However, no studies on elk home ranges have been conducted in the prairie or forest transition zones of northwestern Minnesota (USA) despite their ecological and economic importance.

In Minnesota, elk were once abundant across the prairie and forest transition zone habitats that covered most of the state (Hazard 1982, MNDNR 2017). Due to increased conversion of the land to agriculture, and hunting pressure from arriving settlers, elk were considered extirpated by the early 1900s (Hazard, 1982). In 1935, elk were successfully reintroduced, and by the 1980s another herd of elk had naturally recolonized near the border with Canada (Hazard 1982, MNDNR 2017). Prior to 2016 the only information collected on Minnesota elk were annual winter population surveys and roadside surveys done in each season and annually (MNDNR 2017).

Currently, the elk population that overlaps the US-Canada border in northwestern Minnesota and Manitoba, Canada is estimated to be over 200 individuals (Franke 2018). Due to the elk occupying an intensively-farmed landscape, conflicts with local agricultural producers are common. Minnesota Department of Agriculture compensate landowners for elk crop depredation and fencing damage (Minnesota Statue 3.7371) with payments totaling $47,947USD in 2016 and $39,405USD in 2017 (Vaubel 2017). Minimizing elk damage to agriculture is a management priority for MNDNR (MNDNR 2017). Current legislation (Minnesota Statutes 97B.515 and 97B.516) directs MNDNR to restrict the size of individual herds until there is no increase in crop depredation caused by elk for two years.

In an effort to better understand the spatio-temporal variability of elk space use in northwestern Minnesota, we collected yearly and seasonal location data for adult female elk in this region. We also examined herding behavior within sub-groups and attempted to detect any interaction between cows of different sub-groups. This information will assist wildlife managers to enhance public benefits of elk in this region and reduce conflicts with agricultural producers.

Methods

Study area

We conducted our study in northwestern Minnesota, USA, (49° 6' 0"N - 48° 12' 0"N, 97° 0’ 0” W- 95° 28' 12"W). The majority of elk reside in Kittson, Roseau, Marshall, and Beltrami counties (Figure 1). The average maximum and minimum temperatures were 10.0°C and -0.83°C during the study, and the mean precipitation was 69.6cm for the first year (beginning mid-April) and 45.9cm for the second year (NOAA 2018). Over 50% of the land is agricultural, including pasture lands, hay fields, and cultivated crops such as soybeans, corn, sunflower, wheat, hay, sugar beets, and a variety of cereal grains (Ditmer et al. 2015). The non-agricultural landscape is composed of state-managed Wildlife Management Areas, lands owned and managed by The Nature Conservancy, private Conservation Reserve Program grasslands, small private woodlots, and wetlands. Other land cover types include open water, developed land, and barren land (i.e., rocks, sand, clay). There is a small amount of urban land (0.2%) around the cities of Lancaster, Hallock, and Grygla, and an extensive road grid (Ditmer et al. 2015). The average elevation is approximately 330 m above sea level, with elevation gradients lacking as a result of glacial Lake Agassiz (Ojakangas and Matsch 1982).

Population structure

This study was conducted between February 2016 and April 2018. Elk cows in Minnesota segregate into four distinct sub-groups: Caribou-Vita (CV) ranging between the Caribou Wildlife Management Area (WMA) and the town of Vita (Canada), Grygla (GR) between the city of Grygla and Thief Lake WMA, Lancaster North (LN) found north of the city of Lancaster and ranging east toward Skull Lake WMA, and Lancaster South (LS) located south of Lancaster and ranging east onto the Percy WMA. Such grouping behavior has also been documented in South Dakota, and Ontario, Canada (Millspaugh et al. 2004, McIntosh et al. 2014, Rosatte 2017). Three of the 4 Minnesota sub-groups of elk remain in the US annually (Lancaster North, Lancaster South, and Grygla), while the Caribou-Vita sub-group regularly crosses the Canadian border into Manitoba. There is an estimated population size of 75 for Lancaster North and South combined, 15 elk for Grygla and 133 for Caribou-Vita according to the most recent survey (Franke 2018).

Capture and handling

We captured 20 adult female elk In February 2016 (Caribou-Vita, n = 3; Grygla, n = 3; Lancaster North, n = 9; Lancaster South, n = 5) and fitted them with Global Positioning System (GPS) collars (GPS PLUS Iridium Collars and GPS Vertex Iridium collars, VECTRONIC Aerospace GmBH, Berlin, Germany) and identifying ear tags (orange sheep and goat 2” X 7/8” ear tags, Destron Fearing™, Dallas, TX). The GPS collars were equipped with a mortality sensor, VHF beacon, and remote release mechanisms. We captured elk from a helicopter (Robinson R-44) using either net guns or tranquilizer darts loaded with Carfentanil (3.5 mg) and Xylazine (20 mg; Carfentanil and Xylazine, Wildlife Pharmaceuticals Inc. Windsor, Colorado). Carfentanil was reversed with 350 mg of Naltrexone and Xylazine was reversed with 600 mg of Tolazoline (Naltrexone and Tolazoline, Wildlife Pharmaceuticals Inc., Windsor, Colorado; Miller et al. 1996, Kreeger et al. 2010, 2011). Elk captured with immobilizing agents were blindfolded (n=12), and those captured via net gun were hobbled and blindfolded (n=8). Elk that were darted or those that had visible injuries were administered 10 mL Liquamycin LA-200 antibiotic subcutaneously (Zoetis, Parsippany, New Jersey). We monitored rectal temperatures throughout processing, and if temperatures exceeded 105°F, a collar was quickly fitted, and the animal was released without further data taken to minimize the chances capture myopathy. We collected hair samples to archive for future genetic studies and we collected 20mL of blood detection of diseases and to evaluate pregnancy status. Elk with progesterone levels >1.0 P4 ng/ml were considered pregnant (Huang et al. 2000). A wildlife veterinarian was present during all capture operations to prepare tranquilizer darts and to consult with the capture crew if an injury occurred.

We programmed the GPS collars to take locations every 4 hours throughout the year. We programmed the mortality sensor to override the schedule and send a mortality signal once a collar had been stationary for >12 hours. We tested the GPS collars prior to deployment to ensure the collars were properly communicating with the satellites, and to measure their locational error. We monitored collared elk for 2 weeks post-capture, using hourly locations to identify any signs of capture-related myopathy. These locations were censored from the analysis due to potential abnormal movements related to the capture event.

Home range delineation

We estimated annual and seasonal home ranges for each elk cow using Brownian Bridge Movement Models (BBMMs, Horne et al. 2007). We chose BBMMs becauses we wanted to account for the inherent autocorrelated nature of GPS location data (Horne et al., 2007; Gingery et al., 2017). We used 99% contours to estimate BBMM using methods adapted from the Manual of Spatial Ecology Online (Walter and Fischer 2016) in Program R (R Version x64 3.4.0, 2017, www.R-project.org, accessed 26 June 2017). We specified a location error of 25 m based on our collar testing (results not shown), and an output resolution of 30 m. Before delineating home ranges for the collared elk, we segmented the locations into two study years (year 1: 15 April 2016 to 14 April 2017, year 2: 15 April 2017 to 14 April 2018) and further partitioned into four seasons: 1) pre- to post-parturition (15 April-30 June) when cows may localize for parturition or to stay near a calf, 2) summer (1 July-31 August) as the growing season for the region (Tieszen et al. 1997, Ji and Peters 2003), 3) fall (1 September-31 December) which encompasses breeding, harvest of agricultural crops, and hunting for both elk and deer, and 4) winter (1 January-14 April 14) as the time period with the lowest availability of natural forages for elk in the region (Figure 2).

Comparison of seasonal home ranges

We estimated mean and sample standard error of home range sizes annually and by season for all individuals and within sub-groups. To understand whether elk use the same area from year to year, we calculated percent overlap of annual and seasonal home ranges for each sub-group (Brough et al. 2017; Figure 3). We also measured the spatial overlap between the four separate subgroups within each season for both years

(Figure 4). Three elk died during the study (1 in CV, 1 in GR, and 1 in LN), and were not included in the estimation of annual home ranges nor in the measurement of overlap of home ranges across years. However, elk that died during the study were included to estimate seasonal home ranges for seasons they had fully lived through, but were excluded from the season they died in.

Results

The elk population in northwestern Minnesota was known to have small spatially separated sub-groups; however, there was little knowledge on if these sub-groups interacted. We saw no interaction among the collared cows found in separate sub-groups (Figure 4). Conversely, elk cows within the same subgroups maintained close proximity. Across all collared elk in both time periods, the mean annual home range size was 77.5 km^2 ± 3.1 SE. Grygla elk had the largest annual home ranges across all sub-groups, on average, (90.2 km^2 ± 24.4 SE in year 1, and 111.4 km^2 ± 1.5 SE in year 2), while CV elk had the smallest home ranges (71.8 km^2 ± 17.4 SE in year 1 and 74.8 km^2 ± 0.7 SE in year 2; Figure 5, Supplementary Table 1a). There were no significant differences between individual home range sizes in different years, or between the annual home range sizes of elk in different sub-groups.

Elk in our study also showed site fidelity between the two years, with greater than 50% overlap for each of the four sub-groups. The mean annual home range overlaps for each sub-group were 52.4% ± 10.3 SE, 67.8% ± 0.2 SE, 81.2% ± 3.1 SE, and 65.4% ±1.8 SE for CV, GR, LN, and LS respectively. The greatest mean annual home range overlap occurred in LN (81.2% ± 3.1 SE) and the smallest mean annual home range overlap was in CV (52.4% ± 10.3 SE; Figure 6, Supplementary table 2a). Since elk in our study were also non-migratory, this high site fidelity indicates use of similar areas throughout the entire year.

The mean seasonal home range sizes for all elk were 43.7 km^2 ± 2.9 SE, 29.5 km^2 ± 1.9 SE, 68.5 km^2 ± 6.8 SE, and 48.8 km^2 ± 1.9 SE in parturition, summer, fall, and winter, respectively. Elk exhibited the largest individual seasonal home ranges during the fall season (range: 42.4k km^2 ± 1.0 SE to 125.9 km^2 ± 4.9 SE; Supplementary Table 1b). In comparison, the smallest individual seasonal home ranges overall occurred in summer with a range of 19.3 km^2 ± 2.0 SE to 41.8 km^2 ± 6.5 SE (Figure 8, Supplementary table 1b). The average home range sizes in fall were significantly larger than all the other seasons (part-fall p=0.003, sum-fall p=0.0002, wint-fall p=0.03, Figure 9). The GR sub-group exhibited the greatest difference between seasonal home range sizes for a given year with its smallest seasonal home range size in the summer of the second time period (21.6 km^2 ± 5.7 SE), and the largest overall seasonal home range size in the fall season of the second time period of this study (125.9 km^2 ± 4.9 SE; Figure 8, Supplementary table 1b). For CV there was a significant difference in average home range sizes between fall and parturition (p=0.04) and between fall and summer (p=0.04, Figure 7). For GR there were no significant differences between average home range sizes in any season in any year. For LN and LS there was no significant differences in average home range sizes between any season in any year.

The largest seasonal home range overlap for individual elk across all sub-groups occurred in fall and ranged from 52.9% ± 0.9 SE to 78.7% ± 0.1 SE (Figure 10, Supplementary Table 2c). Elk cows in winter had the lowest fidelity across all sub-groups with home range overlaps ranging from 20.1% ± 0.4 SE to 69.2% ± 6.7 SE

(Figure 10, Supplementary Table 2c). As a sub-group, LN consistently had the highest percent overlaps in every season (78.2% ± 4.1 SE in parturition, 68.5% ± 4.6 SE in summer, and 69.2% ± 6.7 SE in winter) when compared to the other 3 sub-groups, except for fall when GR had the largest overlap (78.7% ± 0.1 SE; Figure 10).

Discussion

Our study provides the first baseline estimates of space use by elk in Minnesota since reestablishment of the species in the state in the years 2016 to 2018. This information will aid wildlife managers in understanding how elk use the landscape for better directing resources for management and minimizing elk-human conflicts. Elk cows in Minnesota formed multiple, small, and independent sub-groups, similar to the distributions observed in other elk populations, specifically in South Dakota, USA and Southern Ontario, Canada (Millspaugh et al. 2004, Rosatte 2017). Since we did not collar bull elk for this study, we cannot speak to their movements or home range patterns. However, bull elk can disperse for long distances in search of resources (Toweill and Thomas 2002, Killeen et al. 2014), so it is likely that there is genetic exchange between these sub-groups through the dispersal movement of bulls.

Conspecific competition, and the abundance of nutritional and thermal resources, has been shown to restrict home range sizes in elk (Kjellander et al. 2004, Anderson et al. 2005, Goldingay 2015, Beest et al. 2015). The lower possibility of conspecific competition within the Grygla sub-group (15 individuals total) might allow for them to range further to look for higher quality resources throughout the year, resulting in larger home ranges and less overlap of their home ranges between the two years (except in the fall season). There might also be a difference in what thermal and nutritional resources are available to them compared to the other 3 sub-groups. Due to the proximity of the Agassiz National Wildlife Refuge to the Thief Lake WMA, there are less agricultural resources available to the GR sub-group, which could also lead to an increase in home range sizes as they would have to make larger movements to meet nutritional needs. The sub-groups Caribou-Vita, Lancaster North, and Lancaster South have more individuals than Grygla (50-100+ animals; Franke 2018), and conspecific competition, along with more agricultural resources, could contribute to the more condensed home range sizes. Despite the difference in the amount of agricultural resources between GR and the rest of the sub-groups, there is still a high amount of agriculture across the entire elk range. Due to this, it is not surprising that elk in all four sub-groups had greater than 50% overlap between the two years of annual home ranges, indicating relatively high site fidelity between the two study periods.

We found home range sizes for each of the sub-groups exhibited similar patterns across seasons. The parturition home ranges were, in general, larger than the summer home ranges but smaller than the fall and winter home ranges. Elk have the smallest home ranges in the summer, consistent with a higher availability of food resources in concentrated areas but could also be due to the elk cows confining their movements while rearing offspring (Anderson et al. 2005). In the fall season, collared elk occupied larger home ranges, possibly to avoid anthropogenic disturbances (i.e. hunting and farming activities) (Ager et al. 2003, Ranglack et al. 2017, Thurfjell et al. 2017, Amor et al. 2019). Winter home ranges were smaller than the fall season home ranges but larger than the parturition and summer home ranges. Due to less resources being available, elk may make more movements around the landscape to meet their resource needs (Anderson et al. 2005, Amor et al. 2019).

Elk tend to occupy fragmented landscapes in areas with large amounts of agricultural land (Stubblefield et al. 2006, Beck et al. 2013). As previously mentioned, the mixture of state-managed land and large amount of available crops found within the Minnesota elk range could be meeting the nutritional needs for three of the sub-groups, and therefore the need to move to new areas across seasons is minimal. Within seasons, elk space use had a high degree of overlap across years for elk in the LN, LS, and CV subgroups. The two collared elk in GR only showed greater than 50% overlap in the fall season, which was also when their home ranges were largest. The lowest percent overlap for GR was in winter, when there is the least food availability, and likely when they would have more need to explore for resources.

This study was the first documentation of the seasonal and annual home ranges of elk in Minnesota's prairie and forest transition zones. With knowledge on the seasonality of home range sizes and fidelity, wildlife managers will be able to focus their efforts and mitigate elk-human conflicts. Future research should focus on elk habitat use across seasons, particularly where managers can improve habitats important to sustaining elk populations in northwestern Minnesota.

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Figures

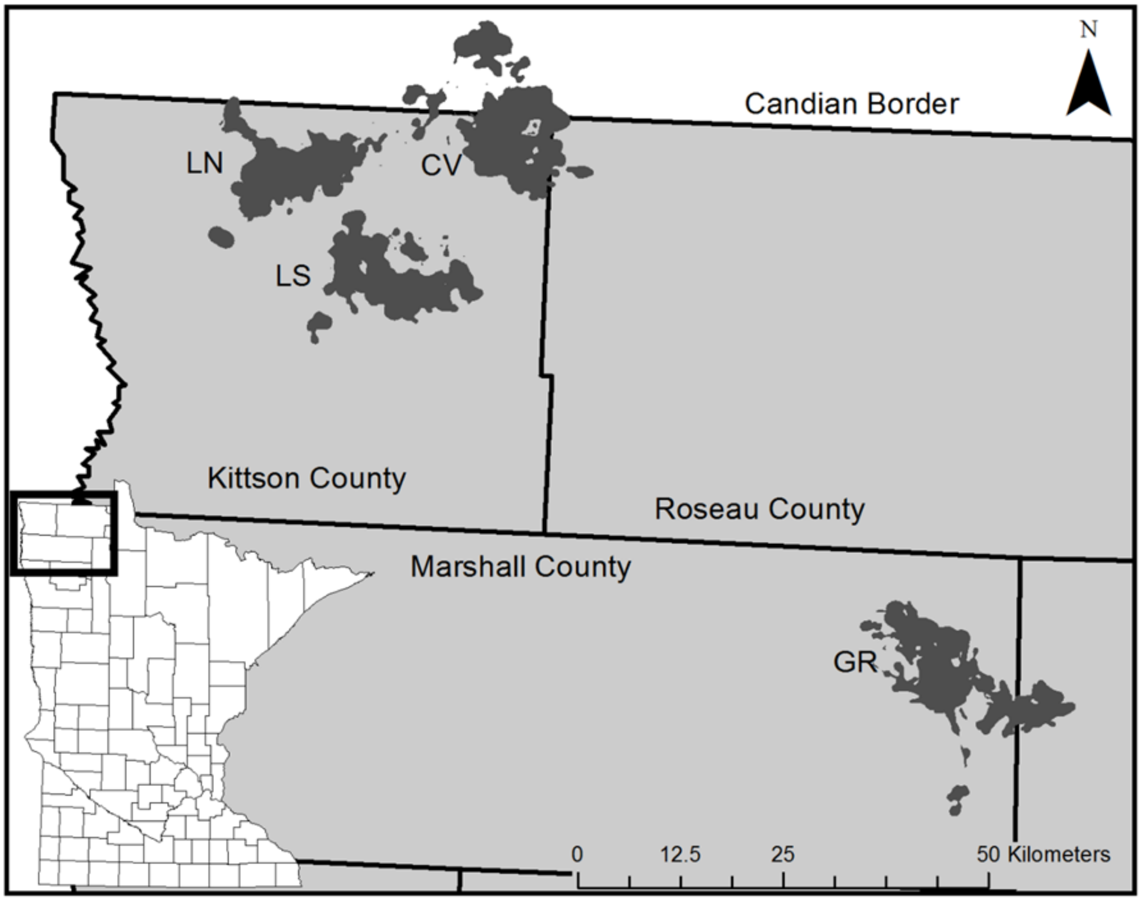

Figure 2-1 The study area is located in the northwestern corner of the state, primarily in Kittson, Roseau, and Marshall counties. This region is a patchwork of agriculture, private hunting lands, state owned lands, and federal wildlife reserves. The 4 sub-groups of elk (dark grey) are Caribou-Vita (CV), Grygla (GR), Lancaster North (LN), and Lancaster South (LS).

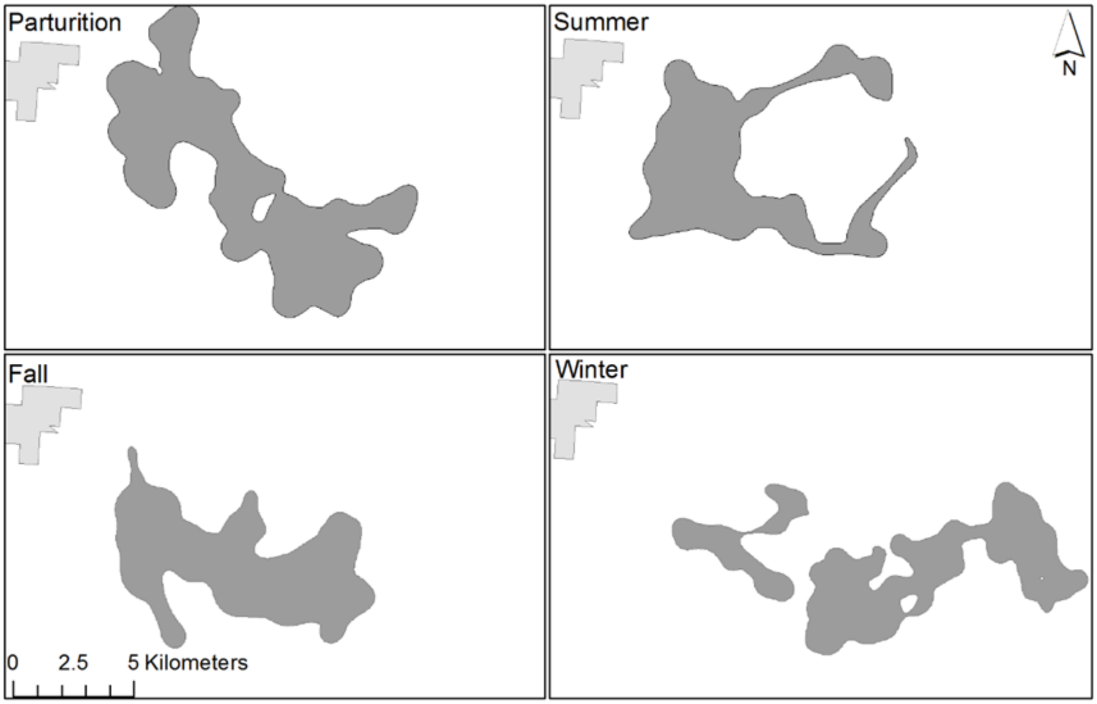

Figure 2-2 Four individual seasonal home ranges, from one collared elk in the Lancaster South sub-group in northwestern Minnesota, for the first study period ranging from 15 April 2017 to 14 April 2018. The city of Lancaster is shown in the top left corner of each seasonal box, and all boxes are the same scale. The seasonal home ranges were drawn using 99% Brownian Bridge Movement Models (BBMMs) using GPS location data collected every four hours for these seasons: pre- to post-parturition (15 April – 30 June), summer (1 July – 31 August), fall (1 September – 31 December), and winter (1 January – 14 April).

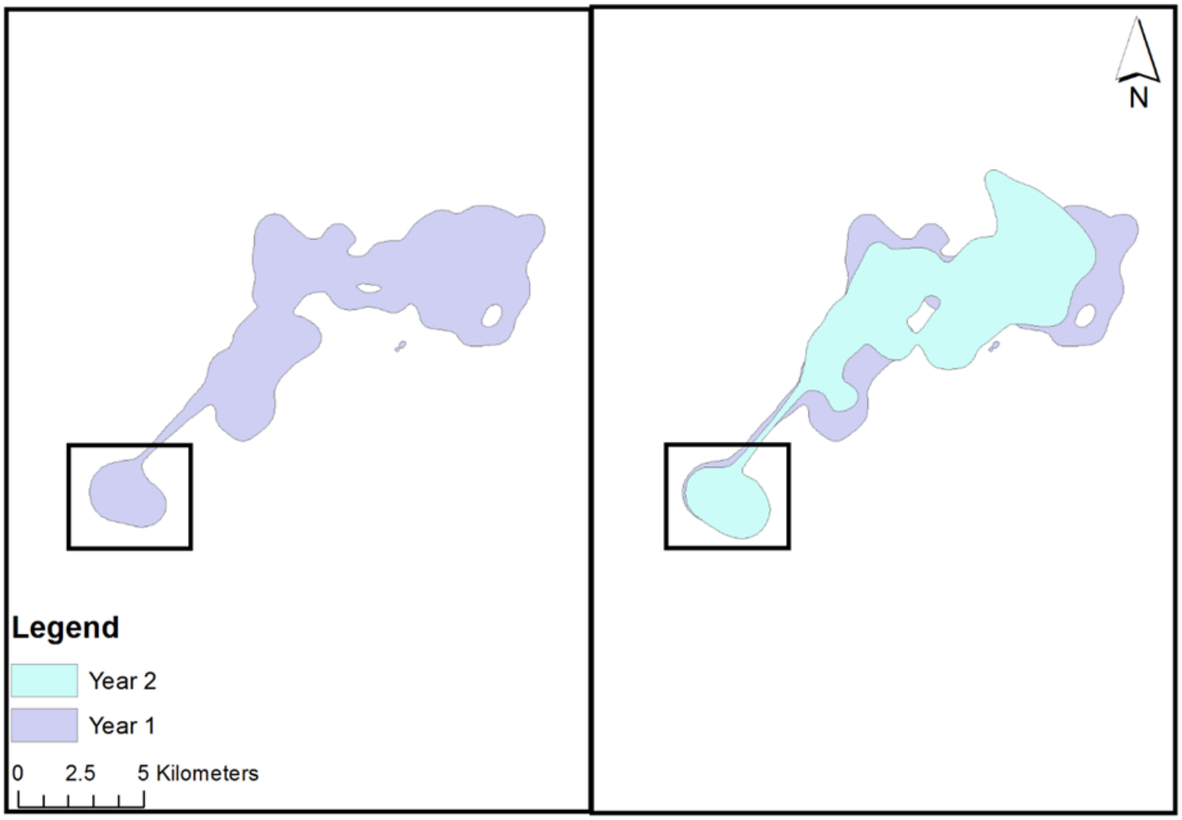

Figure 2-3 An example of the overlap of home ranges between 2 study periods. Shown is the home range BBMM of elk 20435 found in northwestern Minnesota during the parturition season (15 April – 30 June) in the years 2016 and 2017. Her specific calving location (black box) showed high annual fidelity. Local producers in the region confirmed that this elk returns to this location every year (R. Tebo, Personal Communication).

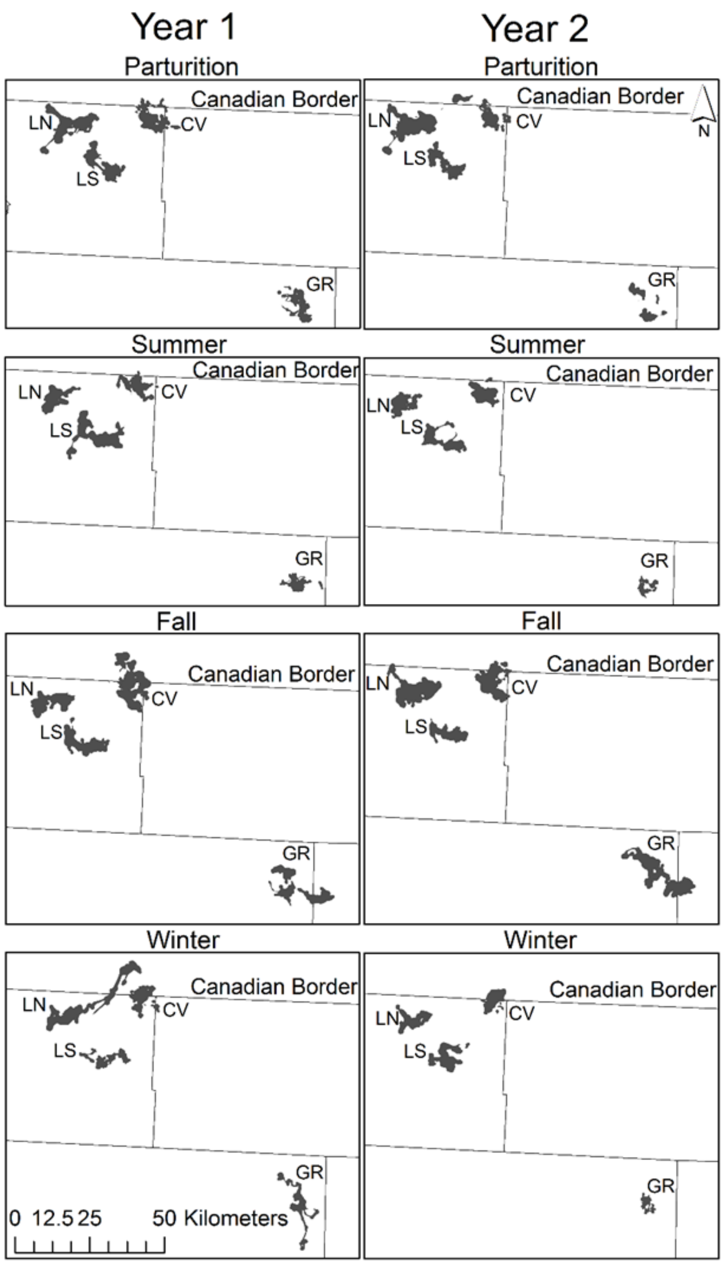

Figure 2-4 Seasonal home ranges of 4 elk sub-groups in northwestern Minnesota. Seasonal home range were created using 99% Browning Bridge Movement Models (BBMM). Season are parturition (15 April – 30 June), summer (1 July – 31 August), fall (1 September – 31 December), and winter (1 January – 14 April). These home ranges were estimated for each elk in 4 different sub-groups: Caribou-Vita (CV), Grygla (GR), Lancaster North (LN), and Lancaster South (LS).

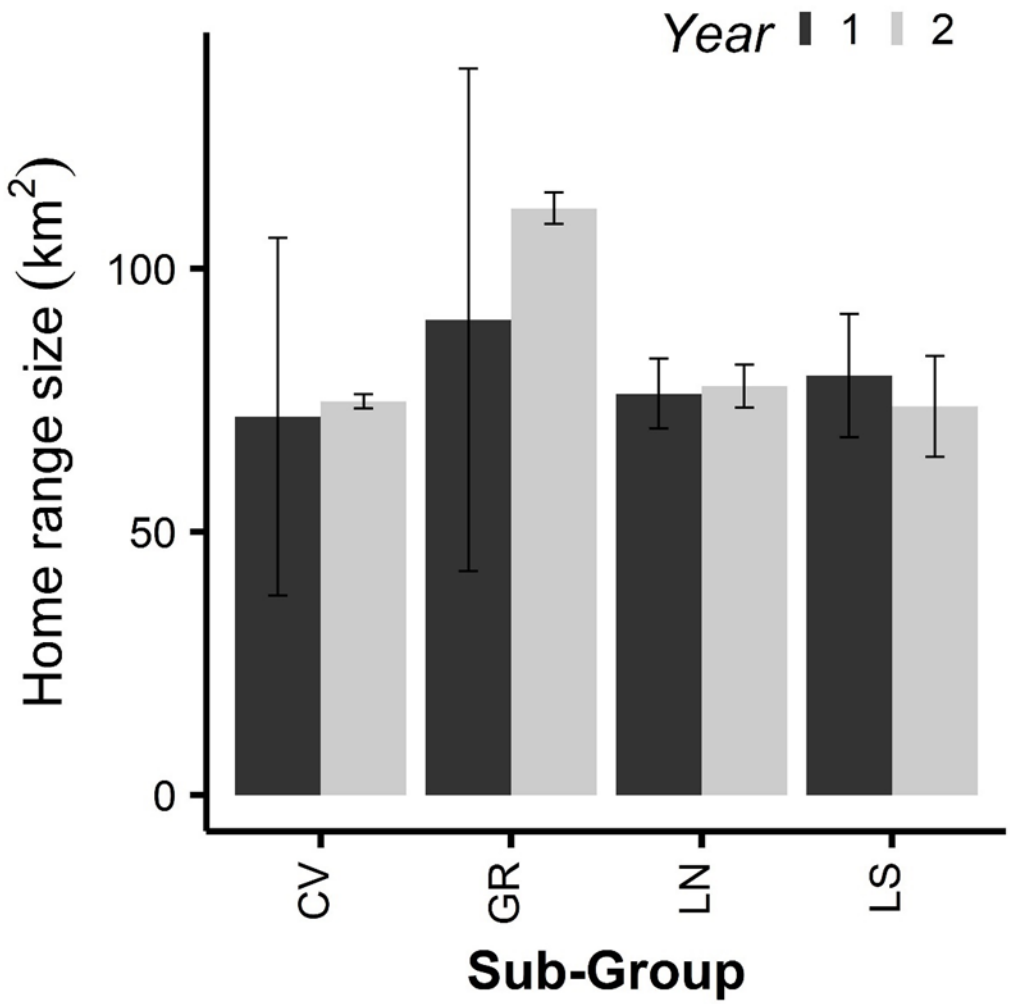

Figure 2-5 Mean annual home range sizes (±1 SE) of each sub-group for time period 1 (yr1) 15 April 2016 to 14 April 2017, and time period 2 (yr2) 15 April 2017 to 14 April 2018, of collared elk in Minnesota. Minnesota elk are found in 4 separate sub-groups; Caribou-Vita (CV, n=2), Grygla (GR, n=2), Lancaster North (LN, yr1 n=9, yr2 n=8), and Lancaster South (LS, n=5).

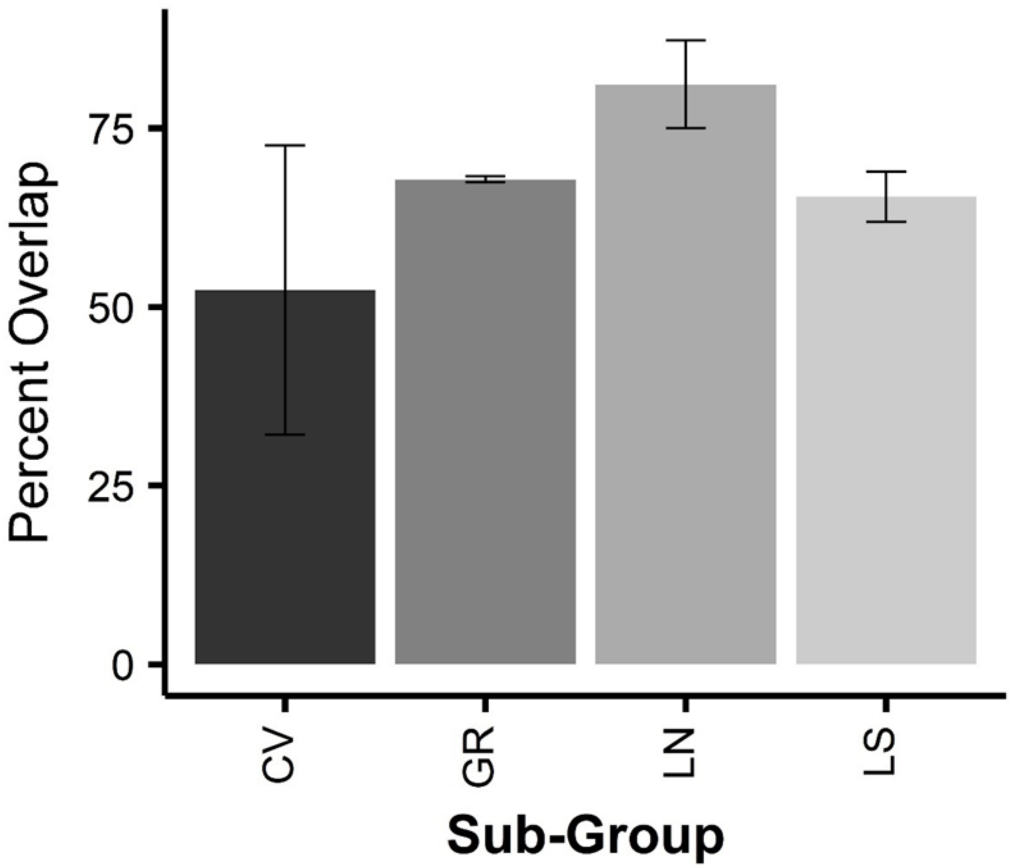

Figure 2-6 Average home range fidelity for elk in Minnesota calculated by measuring the percent, for each individual elk, of annual home ranges from year 2 that overlapped the home ranges from year 1. This was done for the four sub-groups: Caribou-Vita (CV, n = 2), Grygla (GR, n = 2), Lancaster North (LN, n = 8), and Lancaster South (LS, n = 5). Error bars indicate 1 SE.

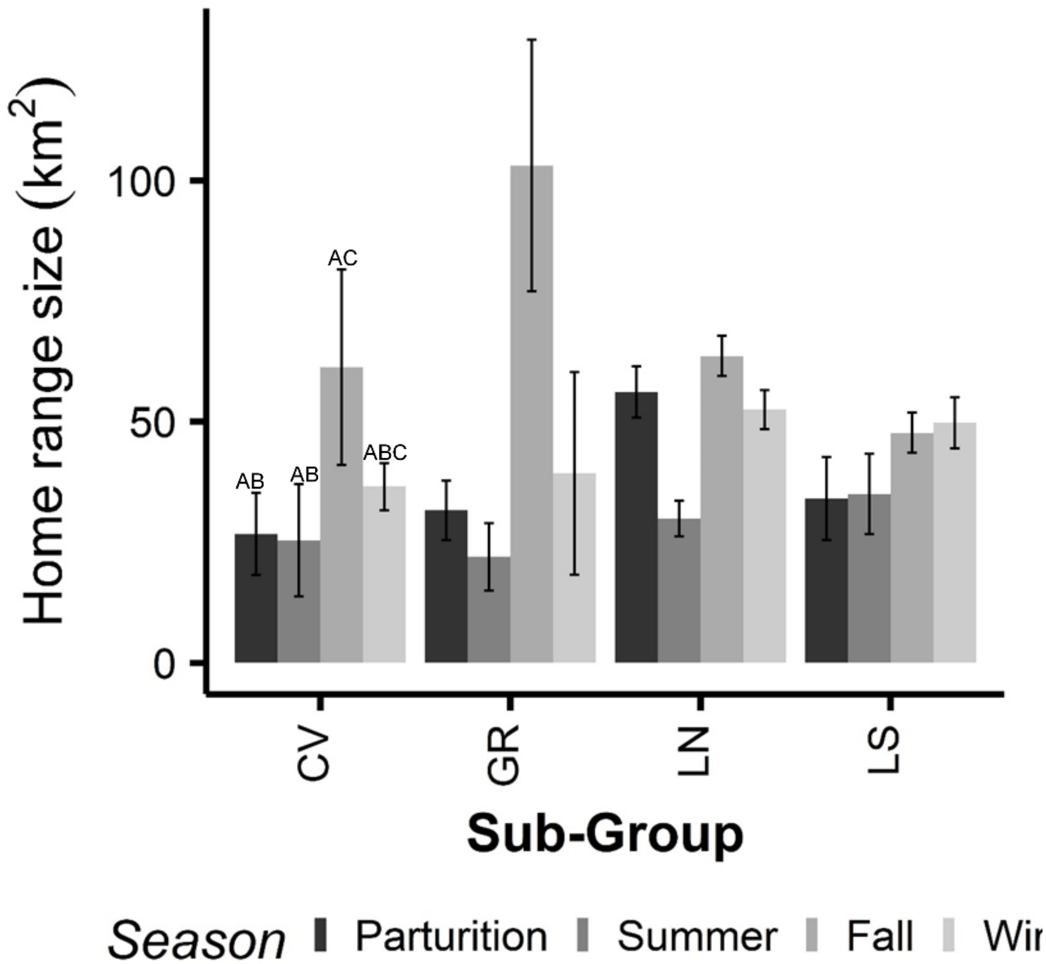

Figure 2-7 Average seasonal home range sizes for collared elk cows in northwestern Minnesota using Brownian Bridge Movement Models (BBMMs). Seasons were defined as: pre- to post-parturition (15 April – 30 June), summer (1 July – 31 August), fall (1 September – 31 December), and winter (1 January – 14 April). These home ranges were averaged by sub-group: Caribou-Vita (CV, n = 2), Grygla (GR, n = 2), Lancaster North (LN, n = 8), and Lancaster South (LS, n = 5).

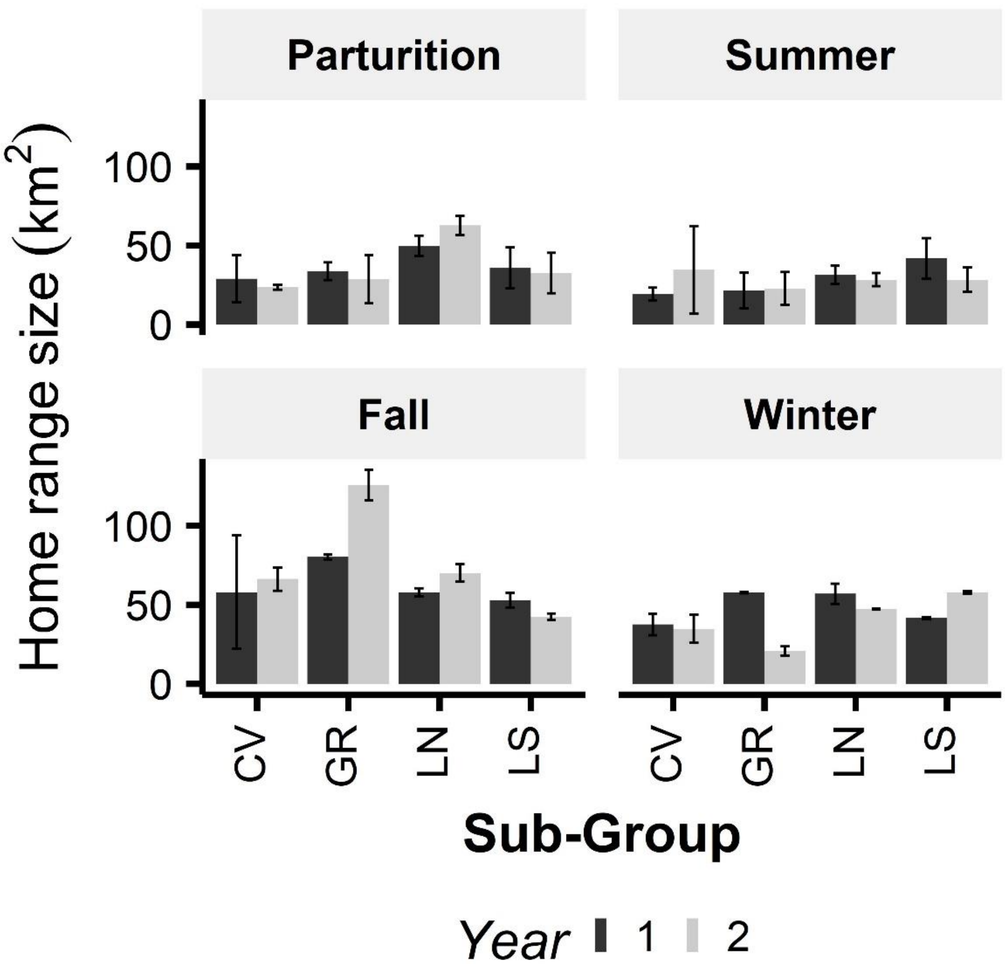

Figure 2-8 Mean seasonal home range size estimation by sub-group: Caribou-Vita (CV), Grygla (GR), Lancaster North (LN), and Lancaster South (LS). We defined seasons as: pre- to post-parturition (15 April – 30 June), summer (1 July – 31 August), fall (1 September – 31 December), and winter (1 January – 14 April). Within these seasons we estimated the homes ranges of collared elk cows using Brownian Bridge Movement Models (BBMMs). We measured differences in seasonal home range sizes by year and season using a 2-way ANOVA.

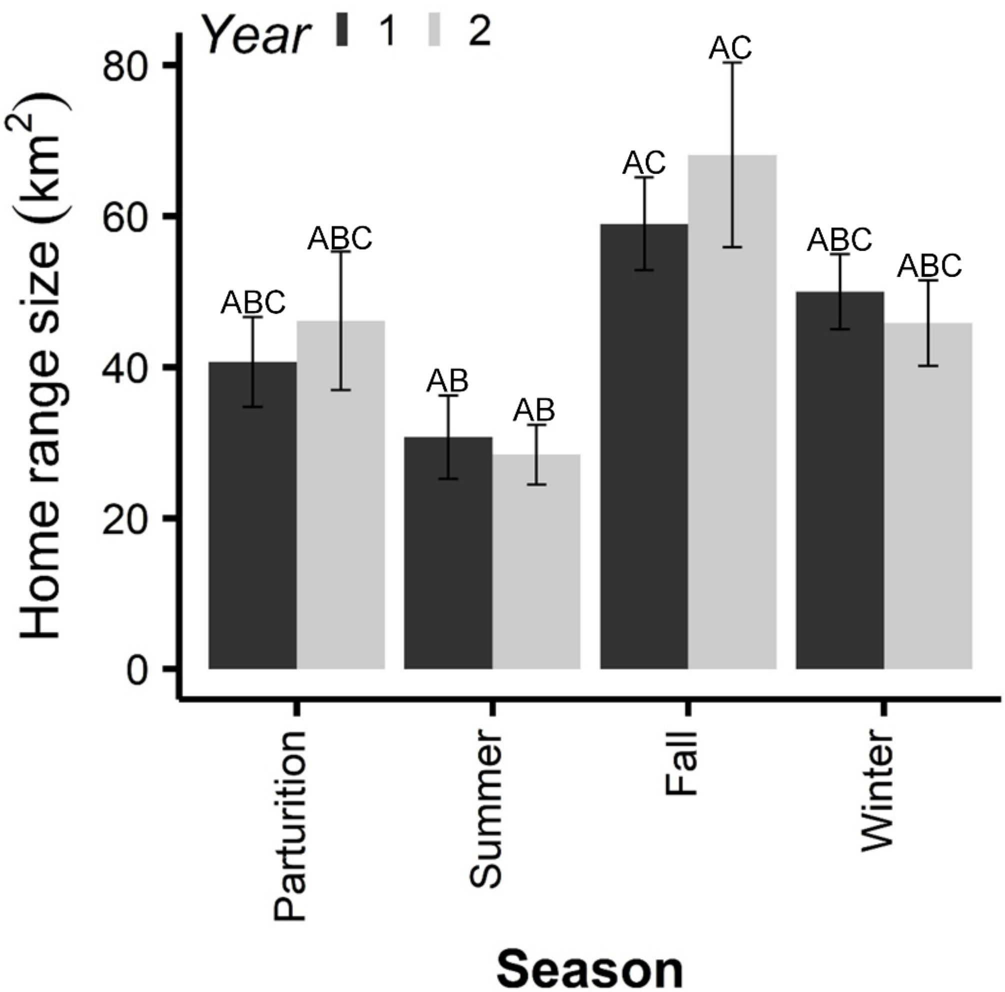

Figure 2-9 Mean seasonal home range sizes for all of the collared elk. We defined seasons as: pre- to post-parturition (15 April – 30 June), summer (1 July – 31 August), fall (1 September – 31 December), and winter (1 January – 14 April). Within these seasons we estimated the homes ranges of collared elk cows using Brownian Bridge Movement Models (BBMMs). The home range size during fall season for both years was significantly larger than summer home range sizes (p=0.01; 2-way ANOVA).

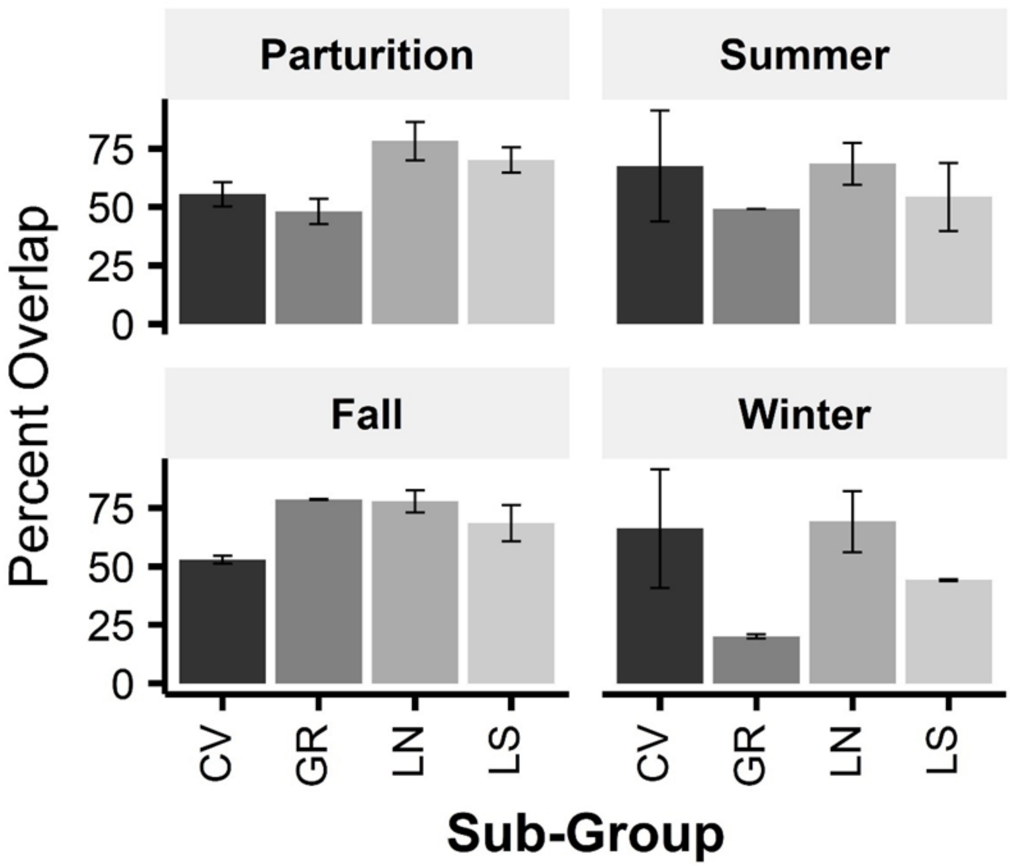

Figure 2-10   To calculate the seasonal home range fidelity for elk in northwestern Minnesota, we calculated the percent of a season from year 2 that overlapped the same season from year 1. These seasons were pre- to post-parturition (15 April – 30 June), summer (1 July – 31 August), fall (1 September – 31 December), and winter (1 January – 14 April). This was done for individual elk for each season, and the percentages were averaged within the 4 separate sub-groups of elk Caribou-Vita (CV, n= 2), Grygla (GR, n = 2), Lancaster North (LN, n = 8), and Lancaster South (LS, n = 5).

Appendix

Supplementary Tables 2.1a-2.1d

Supplementary Table 1a. Mean (±SE) annual home range sizes for four sub-groups of elk found in northwestern Minnesota for the two time periods: 15 April 2016 to 14 April 2017 and 15 April 2017 to 14 April 2018. The home ranges were calculated using Brownian Bridge Movement Models in the Program R (R Core Team 2017).

Sub-group ID	Year	Mean Home Range (km^2)		Mean Home Range (SE)	n
CV	1	71.8	±	17.4	3
	2	74.8	±	0.7	2
GR	1	90.2	±	24.4	3
	2	111.4	±	1.5	2
LN	1	76.3	±	3.4	9
	2	77.7	±	2.1	8
LS	1	79.7	±	5.9	5
	2	73.8	±	4.9	5

Supplementary Table 1b. Mean (±SE) home range size by seasons for four sub-groups of elk found in north western Minnesota for the two study periods (period 1: 15 April 2016 to 14 April 2017, period 2: 15 April 2017 to 14 April 20178). Seasons were defined as: pre-post parturition (part) 15 April to 30 June, summer (sum) 1 July to 31 August, fall (fall) 1 September to 31 December, and winter (wint) 1 January t0 14 April. The home ranges were calculated using Brownian Bridge Movement Models in the Program R (R Core Team 2017).

Sub-group ID	Year	Season	Mean Home Range Size (km^2)	SE (km^2)	n
CV	1	Parturition	28.8±	7.6	3
		Summer	19.3±	2.0	3
		Fall	58.0±	18.3	3
		Winter	37.6±	3.5	3
	2	Parturition	23.6±	0.8	2
		Summer	34.6±	14.2	2
		Fall	66.4±	3.7	2
		Winter	34.9±	4.6	2
GR	1	Parturition	33.7±	2.8	3
		Summer	21.6±	5.7	3
		Fall	80.3±	0.8	2
		Winter	57.8±	0.2	2
	2	Parturition	28.6±	7.8	2
		Summer	22.7±	5.3	2
		Fall	125.9±	4.9	2
		Winter	20.8±	1.5	2
LN	1	Parturition	49.7±	3.3	9

		Summer	31.4±	3.1	9
		Fall	57.9±	1.3	9
		Winter	57.0±	3.2	9
	2	Parturition	62.6±	3.1	9
		Summer	28.4±	2.2	9
		Fall	70.1±	2.8	8
		Winter	47.3±	0.2	8
LS	1	Parturition	35.7±	6.6	5
		Summer	41.8±	6.5	5
		Fall	53.0±	2.4	5
		Winter	41.6±	0.3	5
	2	Parturition	32.5±	6.5	5
		Summer	28.3±	3.9	5
		Fall	42.4±	1.0	5
		Winter	57.9±	0.4	5

Supplementary Table 1c. Mean (±SE) home range size by season for four sub-groups of elk found in north western Minnesota. Seasons were defined as: pre-post parturition (part) 15 April to 30 June, summer (sum) 1 July to 31 August, fall (fall) 1 September to 31 December, and winter (wint) 1 January t0 14 April. The home ranges were calculated using Brownian Bridge Movement Models in the Program R (R Core Team 2017).

Sub-group ID	Season	Mean Home Range Size (km^2)	SE (km^2)	n
CV	Parturition	26.7±	4.4	5
	Summer	25.4±	5.9	5
	Fall	61.3±	10.3	5

	Winter	36.5 ±	2.5	5
GR	Parturition	31.6 ±	3.2	5
	Summer	22.0 ±	3.6	5
	Fall	103.1 ±	13.3	4
	Winter	39.3 ±	10.7	4
LN	Parturition	56.2 ±	2.7	18
	Summer	29.9 ±	1.9	18
	Fall	63.6 ±	2.1	17
	Winter	52.5 ±	2.1	17
LS	Parturition	34.1 ±	4.4	10
	Summer	35.0 ±	4.2	10
	Fall	47.7 ±	2.1	10
	Winter	49.8 ±	2.7	10

Supplementary Table 1d. Mean (±SE) home range size by season for elk found in north western Minnesota. Seasons were defined as: pre-post parturition (part) 15 April to 30 June, summer (sum) 1 July to 31 August, fall (fall) 1 September to 31 December, and winter (wint) 1 January t0 14 April. The home ranges were calculated using Brownian Bridge Movement Models in the Program R (R Core Team 2017).

Year	Season	Mean Home Range Size (km^2)		SE (km^2)	n
1	Parturition	40.7	±	3.0	20
	Summer	30.7	±	2.8	20
	Fall	59.0	±	3.1	19
	Winter	50.0	±	2.5	19
2	Parturition	46.1	±	4.7	18

Summer	28.4	±	2.0	18
Fall	68.1	±	6.2	17
Winter	45.9	±	2.9	17

Supplementary Table 2.2a-2.2c

Supplementary Table 2a. Mean (±SE) annual home range overlap for four sub-groups of elk found in northwestern Minnesota for the two time periods: (year 1: 15 April 2016 to 14 April 2017; year 2:15 April 2017 to 14 April 2018). The home ranges were calculated using Brownian Bridge Movement Models in the Program R (R Core Team 2017). Percent overlap was calculated by determining the percent of the home range from time period 2 that overlapped with the home range from time period 1.

Sub-group ID	Mean Overlap (%)		SE (%)	n
CV	52.4	±	10.3	3
GR	67.8	±	0.2	2
LN	81.2	±	3.1	9
LS	65.4	±	1.8	5

Supplementary Table 2b. Mean (±SE) annual home range overlap for each collared elk in northwestern Minnesota for the two time periods: (year 1: 15 April 2016 to 14 April 2017; year 2:15 April 2017 to 14 April 2018). The home ranges were calculated using Brownian Bridge Movement Models in the Program R (R Core Team 2017). Percent overlap was calculated by determining the percent of the home range from time period 2 that overlapped with the home range from time period 1.

Sub-group ID	Collar ID	Overlap %
CV	20425	32.1
CV	20431	65.7
CV	20436	59.4
GR	15456	68.1
GR	20429	67.6
LN	15450	77.1
LN	15454	86.3
LN	16690	86.3
LN	16696	81.4
LN	17134	83.1
LN	17138	81.1
LN	20430	90.2
LN	20432	58.2
LN	20435	86.7
LS	15451	64.9
LS	17136	60.2
LS	19580	63.7
LS	20433	70.8
LS	20434	67.5

Supplementary Table 2c. Mean (±SE) home range overlap by season for elk found in north western Minnesota. Seasons were defined as: pre-post parturition (part) 15 April to 30 June, summer (sum) 1 July to 31 August, fall (fall) 1 September to 31 December, and winter (wint) 1 January t0 14 April. The home ranges were calculated using Brownian Bridge Movement Models in the Program R (R Core Team 2017). Percent overlap was calculated by determining the percent of the home range from time period 2 that overlapped with the home range from time period 1.

Sub-group ID	Season	Mean Overlap (%)	SE (%)	n
CV	Parturition	55.5 ±	2.6	2
	Summer	67.6 ±	12.1	2
	Fall	52.9 ±	0.9	2
	Winter	66.2 ±	12.9	2
GR	Parturition	48.1 ±	2.8	2
	Summer	49.3 ±	0.0	2
	Fall	78.7 ±	0.1	2
	Winter	20.1 ±	0.4	2
LN	Parturition	78.2 ±	4.1	9
	Summer	68.5 ±	4.6	9
	Fall	77.8 ±	2.4	8
	Winter	69.2 ±	6.7	8
LS	Parturition	70.2 ±	2.7	5
	Summer	54.4 ±	7.4	5
	Fall	68.5 ±	4.0	5
	Winter	44.1 ±	0.2	5

Chapter 3 : Seasonal Habitat Selection by Female Elk (*Cervus elaphus*) in Northwestern Minnesota

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Abstract

Since the reintroduction of elk (*Cervus elaphus*) into Minnesota in the 1930s, there have been no studies of their habitat selection in the state. We were interested in what habitat types and landscape features elk select, and whether they prefer particular areas. In February of 2016 we captured 20 adult elk cows and fitted them with Global Positioning System (GPS) collars. By collecting location data every 4 hour, we measured habitat selection of landscape-level habitat types across two time periods: 15 April 2016 to 14 April 2017 and 15 April 2017 to 14 April 2018. Using locations taken at 1-hour intervals during the summer of 2016 (1 May to 31 July), we examined elk selection of fine-scale vegetation structure. Elk primarily selected for woody cover types and food crops at the landscape level. At the fine-scale structural level, they selected for denser canopy cover and less horizontal visual cover. Although given our small sample size of collared elk and high variability of vegetation within cover types, we must interpret these results with caution. From this study, wildlife managers will have a better understanding of elk use of habitat types in northwestern Minnesota. This knowledge can be used to guide management decisions to enhance habitats suitable for elk, as well as aid in mitigating conflicts with agricultural producers.

KEY WORDS Resource Selection Functions, Elk, Minnesota, Habitat Selection.

Introduction

Elk (*Cervus elaphus*) were once found across the entire north American continent, however by the early 1900's they had been extirpated from much of that range. Numerous elk reintroductions have been done east of the Rocky Mountains since that time, however the landscape they now occupy is different due to European settlers converting the land to primarily agricultural or urban use. Elk now interact with a landscape mosaic comprised of agriculture, managed forests, small fragments of preserved prairies, and private hunting lands.

While many studies have been conducted to better understand how elk interact with different types of landscapes, there is a need to continue this type of research in areas where it has not yet been done. Landscape level studies involving elk are often done to better understand the way elk use different habitat types, and how they interact with different anthropogenic features. Elk are habitat generalists that occupy a large range of habitat types due to their ability to make wide-ranging movements (Irwin 2002, Frair et al. 2005, 2008, Cox 2011). Features such as road density, water availability, urban centers, management practices, food and vegetative cover are known to be important for influencing elk habitat selection (Ager et al. 2003, Anderson et al. 2005, Van Dyke and Darragh 2006, 2007, Frair et al. 2008, Baasch et al. 2010).

Elk biological and resource needs change seasonally (Toweill 2002, Ager et al. 2003, Larkin et al. 2003, Coe et al. 2011, Painter et al. 2015). For example, habitat used for raising calves differs from that preferred during parturition or during the breeding season (Toweill and Thomas 2002, Anderson et al. 2005, Brough 2009, Barbknecht et al. 2011, Pitman et al. 2014, Lehman et al. 2016). Changes in human activities such as hunting or crop harvesting, also affect how elk use the landscape (Ager et al. 2003, Van Dyke et al. 2012). In Minnesota, the amount of leafy structural cover decreases in winter which may also cause elk to shift locations and change the way they use different habitats to reduce the risk of predation and bioenergetics losses to thermoregulation (Nudds 1977, Baasch et al. 2010, Coe et al. 2011, Pitman et al. 2014).

Fine-scale structural habitat measurements can give more detailed information on elk habitat selection (Anderson et al. 2005, 2008, Frair et al. 2005, Barbknecht et al. 2011, Rumble and Gamo 2011, Pitman et al. 2014). Structural features are used by elk for shelter from climatic conditions, visual obscurity from predators, as well as forage or bedding (Nudds 1977, Rumble and Gamo 2011, Lendrum et al. 2012). Canopy cover is commonly measured due to its importance as thermal and visual protection (Anderson et al. 2005, Barbknecht et al. 2011, Rumble and Gamo 2011, Pitman et al. 2014, Lehman et al. 2016). Measuring visual cover and ground cover can disclose why elk choose certain areas for protection, bedding, or forage (Nudds 1977, Anderson et al. 2005, Barbknecht et al. 2011, Rumble and Gamo 2011, Pitman et al. 2014, Lehman et al. 2016). Seasonal changes in the amount and distribution of available structural cover, overlain on the annual cycle of energy requirements of elk, creates a complex cycle of habitat preferences and use (Thomas et al. 1988, Christianson and Creel 2007, Anderson et al. 2012).

Historically in Minnesota, elk were found in prairie and forest transition zone ecosystems and their presence had wide ranging effects that were important to maintaining the condition of those ecosystems (Hazard 1982, Cox 2011). A continued elk presence is, therefore, important to improving what is left of these ecosystems. The limited amount of information on the Minnesota elk population hinders the ability of managers to manipulate habitats to benefit elk. Currently, elk in Minnesota use a mixture of agricultural and managed lands, resulting in crop damage, which has led to conflicts with agricultural producers and a need to better understand elk habitat use. By tracking 20 adult elk cows fitted with Global Positioning System (GPS) collars in northwestern Minnesota, this project provides foundational ecological data for the only free-ranging population of elk in the state. We examined the landscape-level habitat use, and selection of fine-scale habitat features made by adult female elk in northwestern Minnesota.

Study area

The study area is in northwestern Minnesota, USA, a rural area that borders both North Dakota (USA) and Manitoba (Canada) (N49.10-N48.20, W97.00-W95.47) (Figure 1). Most of the land is agricultural; this includes large pastures, hay yards, and cultivated crops (Ditmer et al. 2015). The primary crops produced are soybeans, corn, sunflower, wheat, and hay. The rest of the land-use consists of lands managed by the Minnesota Department of Natural Resources (MNDNR) as wildlife management areas (WMAs), land owned and managed by The Nature Conservancy, Conservation Reserve Program grasslands, small private woodlots and wetlands (MNDNR 2017). Water, developed land, and barren land (i.e., rocks/sand/clay) make up the remaining land cover types found in the study area. There is an extensive road grid and a small amount of urban land (0.2%) around the cities of Lancaster, Hallock, and Grygla (Ditmer et al. 2015). Glacial Lake Agassiz covered the region 9000-11,700 years ago; as a result, the region lacks any significant topography, and sits approximately 330 m above sea level (Ojakangas and Matsch 1982). We recognize this elk population as divided into 4 sub-groups; Caribou-Vita (CV), Grygla (GR), Lancaster North (LN), and Lancaster South (LS) (Figure 1). Three of the 4 sub-groups of elk remain in the US annually (Lancaster North, Lancaster South, and Grygla), while the Caribou-Vita sub-group crosses the border with Manitoba throughout the year.

Methods

Elk location data

In February 2016, we captured 20 adult female elk (CV = 3, GR = 3, LN = 9, and LS = 5) and fitted them with GPS collars (GPS PLUS Iridium Collars and GPS Vertex Iridium collars, VECTRONIC Aerospace GmBH, Berlin, Germany) and identifying ear tags. Each GPS collar was equipped with a mortality sensor, VHF beacon, and remotely triggered and timed-release mechanisms. We established capture protocols designed to minimize handling effects on the elk during capture. We used helicopter-based capture techniques (in a Robinson R-44 helicopter) using both net guns and darts. We limited chase times by the helicopter to ≤ 5 minutes. Tranquilizer darts were loaded with Carfentanil (3.5 mg) and Xylazine (20 mg). Carfentanil was reversed with 350 mg of Naltrexone and Xylazine was reversed with 600 mg of Tolazoline (Stoskopf 2013). Elk captured via net gun were hobbled and blind-folded, whereas elk captured with immobilizing agents were only blindfolded. Rectal temperatures were monitored throughout the time the elk was being and if the temperature rose above 105°F, only a collar was fitted, and all other measurements were discontinued. A wildlife veterinarian was present during all capture operations to prepare tranquilizer darts and to consult the capture crew if an injury occurred. We administered an antibiotic (10 mL LA 200, Wildlife Pharmaceuticals Inc. Windsor, Colorado) to any elk that were darted as well as to those that had visible injuries to prevent infection. To watch for signs of capture myopathy, all elk were monitored for two weeks post-capture using hourly GPS locations.

Landscape-level data and analysis

We divided elk locations from 24 months of monitoring into two year-long time periods: 15 April 2016 to 14 April 2017 (period 1) and 15 April 2017 to 14 April 2018 (period 2). Because elk may use habitat seasonally, we segmented each time period into four seasons relevant both for elk biology (e.g., parturition) and of importance given the potential impact of some anthropogenic influences (e.g., hunting and crop harvest) on elk behavior: Pre- to post-parturition (April 15-June 30th), when elk are likely to be localizing for parturition or tending to a calf; summer (July 1st-August 31st), the time period with the most pronounced plant production for the region (Tieszen et al. 1997, Ji and Peters 2003); fall (September 1st-December 31st), which encompasses breeding, crop harvest, and hunting for both elk and white-tailed deer; and winter (January 1st-April 14th), a time period of lowest food availability for elk.

To compare use versus availability, and therefore preference, within seasonal home ranges, we created 95% Minimum Convex Polygons (MCPs) around the GPS locations for each individual elk within each season. We then generated random points at a density of 100/ km^2 within each MCP to characterize the habitat available to an individual elk within its seasonal home range (Figure 2). For each of the used (elk locations) and the available (random) points, we extracted land cover variables from the cropland data layer developed by the United States Geological Survey (USGS) for 2016 and 2017 (Han et al. 2014). Habitat variables therefore included forests, crops, grasslands, woody wetlands, herbaceous wetlands, open water, and developed land. Location points were assigned a binary value based on if they were from elk locations (1) or randomly generated “available” locations (0). We also calculated distances to roads, water, and urban centers by measuring the nearest Euclidean distance to each feature from shapefiles available at the Minnesota Geospatial Commons (Minnesota Geospatial Commons, 2017). Finally, to understand elk use of different habitat management strategies, we determined if the used and available locations were found within food plots, prescribed burns, or brush treatments. We used shapefiles that outlined the areas where these treatments had occurred in 2016 and 2017, obtained from area wildlife managers (K. Arola, K. and J. Wolin, unpublished data). We extracted locations from within all the food plots planted in 2016 and 2017. For the first time period we extracted just the burn and brush treatments for 2016. For the second time period we extracted locations from burn treatments and brush treatments from both 2016 and 2017 to see if elk continued utilizing management treatments that were done a year prior. For the management variable we also assigned binary values, with elk locations assigned a value of 1 and randomly generated available locations assigned a 0 value. All variables were extracted in Program R (R Version x64 3.4.0, 2017, www.R-project.org, accessed 26 June 2017).

We estimated third-order selection within a home range by an individual animal (Johnson 1980), using Resource Selection Functions (RSFs) to evaluate elk use of different land-cover types, management strategies, and other landscape features. Using a Resource Selection Function (RSF) that compares the proportion of use habitat vs. available habitat is advantageous for landscape level habitat analysis. Since used locations are found within areas known to be available to the animal, we decrease the chance of a getting a Type 1 error caused by incorrectly assuming an area, or resource, was unused (Boyce et al. 2002, Manly et al. 2002). We estimated RSF coefficients for each individual elk and each season and calculated the mean regression coefficients for each sub-group. We assessed the statistical significance of the regression coefficients based on 95% confidence intervals calculated around the mean (mean ± 1.96* SE). Due to the small sample sizes of collared elk in the CV and GR sub-groups (n = 3 and n = 3 respectively) and strong collinearity among animals, we focused our analysis and discussion on the two Lancaster subgroups (LN and LS) only. We combined these sub-groups (LANC, n = 14) for the landscape-level analysis based on similarities between the land covers and spatial proximity of the two sub-groups. We built two sets of models, each using different covariates. The first model included the coarse land cover classes (forests, crops, grasslands, woody wetlands, herbaceous wetlands, open water, and developed land) and proximity to landscape features such as roads, water, canopy cover, and urban center. The second model included the three different land management strategies: prescribed burns, brush thinning, and food plots.

In the first model we compared the use vs. availability of coarse cover habitat classifications (crops, grasslands, open water, developed, barren, forest, woody wetlands, and herbaceous wetlands) and measured distances to roads, water, urban centers, and woody cover (Table 1). The purpose of this first model was to test if elk were selecting crops over all other habitat types. We determined that forest and crop cover were the best reference levels to use in the RSF models since they are the two most important habitat types within the elk home ranges we examined. We included the continuous variables distance to roads, water, urban center, and forest cover to evaluate if elk remain near to, or avoid, areas closer to these features. All continuous variables were scaled by removing the mean and dividing by the standard deviation. Other studies have shown that elk often select for locations that are further from anthropogenic features and closer to canopy cover (Ager et al. 2003, Baasch et al. 2010, Barbknecht et al. 2011, Coe et al. 2011, Beck et al. 2013).

In the second model our goal was to evaluate if elk used areas within management treatments (prescribed burns, brush removal, and food plots) disproportionally to their availability within their home ranges. However, because on average 96% of the used, and 98% of the available locations occurred in areas that had not undergone any management treatments in the 2 years of study, we could not investigate this question further (Figure 8).

Fine-scale data and analysis

To evaluate the habitat available to elk, we delineated sampling areas using Minimum Complex Polygons (MCP; Arthur et al. 1996, Lehman et al. 2016) drawn around hourly locations of each subgroup collected between 1 May 2016 and 31 July 2016, and divided into 13 weeks. This approach resulted in four sampling areas per week (one for each sub-group), and 52 sampling areas total across the entire growing season (Figures 2, 3). We sampled the 4 sub-groups of elk separately since they were spatially segregated with no known interactions among the collared elk of different sub-groups during our study.

To evaluate fine-scale habitat selection during the growing season, we sampled structural habitat features at “used” locations (from the GPS collars) and “available” locations (randomly generated locations within the study areas). Sampling locations were constrained to natural habitat types (i.e., we excluded points located in cultivated crops based on the National Landcover Dataset; NLCD). We randomly selected 2 used locations for each elk from within all habitat types found in a given study area for that week. The 3 available locations were generated for each elk location within all habitat types inside the study area boundaries for each week (Anderson et al. 2005b, 2012, Baasch et al. 2010, Barbknecht et al. 2011, Rumble and Gamo 2011). Once we had generated all possible locations to choose from for each week, we randomly selected 2 used location and 6 random locations for each elk in that sub-group to visit and collect the structural vegetation data (CV: 6 used, 18 random; GR: 6 used, 18 random; LN: 18 used, 54 random; LS: 10 used, 30 random). Throughout the sampling season, we started sampling vegetation at the selected locations as soon as the points were selected, and for up to two weeks after, to better capture changes in plant phenology across the growing season.

To sample fine-scale vegetation characteristics, we centered two perpendicular 60-m transects on each sampling point (Figure 4). This resulted in four 30-m sub-transects per sampling point, each directed towards a cardinal direction (N, S, E, W). To determine percent ground cover, we sampled five 0.25-m2 quadrats along each 30-m sub-transect at 5-m intervals, starting at 5 meters, on alternating sides of the sub-transect (Anderson et al. 2005b, Barbknecht et al. 2011, Rumble and Gamo 2011, Pitman et al. 2014, Lehman et al. 2016). We used a densiometer at plot center and at points 15-m and 30-m along each sub-transect to estimate canopy cover (Barbknecht et al. 2011, Rumble and Gamo 2011, Pitman et al. 2014). We used cover poles placed at 15-m and 30-m distances in each of four cardinal directions to estimate lateral visual cover 1 meter above ground at each plot (Nudds 1977, Barbknecht 2008, Pitman et al. 2014, Lehman et al. 2016).

We sampled a total of 500 pts (230 used locations and 270 random points) from 15 May through 17 August 2016. The number of sampled locations were distributed among the four sub-groups, for a total of 55 used and 61 random locations in Caribou-Vita, 36 used and 53 random locations in Grygla, 90 used and 98 random locations in Lancaster North, and 49 used and 58 random locations in Lancaster South. Using a student's T-test, we compared means from used locations to random locations at the 3 levels of structural cover for all elk combined, as well as within each of the 4 sub-groups. All analyses were conducted in the Program R (R Version x64 3.4.0, 2017, www.R-project.org, accessed 26 June 2017).

Results

Landscape-level habitat selection by elk

In the LANC combined sub-group, crops represented, on average, 56.1% ±3.6%SE of available habitat within the home ranges. Forests and woody wetlands comprised the next largest amount of available land within the home ranges at 17.5% ± 2.1%SE and 4.5% ±0.5%SE respectively (Figure 5). The remaining area within the LANC elk home ranges were composed of herbaceous wetlands (9.2% ± 2.1%SE), grasslands (5.4% ± 0.9%SE), developed land (4.2% ± 0.3%SE), and open water (3.1% ± 0.4%SE; Figure 5). Elk locations were predominantly located in agricultural crops

(41% ± 2%), forests (29.6% ± 2.2%), and woody wetlands (15.2% ± 2.14). The rest of the elk locations were found in herbaceous wetlands (7.4% ± 1.8%), grasslands (2.5% ± 0.5%), open water (2.5% ± 0.4%), and developed land (1.9% ± 0.2%; Figure 5).

Results from the RSF models suggest that, on average, elk of the LANC subgroup select for forest and woody wetlands significantly more than what is available (Figure 7). Elk selected for crops; however the strength of that selection was not as strong as the selection for forest or woody wetlands. Grasslands, herbaceous wetlands, open water, and developed areas were selected for even less than crops when compared to what was available within their home ranges (Figure 7).

The collared elk cows were closer to woody cover during parturition of both years, winter of time period 1, and summer of time period 2 (Figure 6). Elk avoided roads in all seasons except for summer and winter of time period 2 during which we detected no significant relationship between elk locations and distances to roads (Figure 6). Elk were slightly more likely to be found in areas closer to open water in all seasons except for parturition of time period 2, when there was no significant relationship, and winter of time period 1, when they were more likely to be found further from open water. In fall of time period 1 elk were slightly more likely to be found in areas closer to urban centers, however in summer of time period 1, parturition of time period 2 and winter of both years, elk were more likely to be found in areas further from urban centers (Figure 6).

Fine-scale habitat

No difference was observed between elk and random points in CV, GR, or LS. Using a student's T-test we observed mean visual cover values to be significantly lower at used elk locations when compared with random locations for the LN sub-group ($p=0.00031$). We also observed mean canopy cover values to be significantly higher at used locations for elk in LN ($p < 0.001$) when compared with random locations. When we combined elk and random locations across all groups, no significant differences were observed in any of the fine-scale variables between elk and random locations (Figure 12).

Discussion

Elk inhabited the prairie and forest transition zones that spanned most of Minnesota before European settlers arrived (Hazard 1982, MNDNR 2017). Much of this prairie was converted into agriculture, removing a significant amount of the habitat that was available for elk (Hazard 1982, MNDNR 2017). Currently, the land use in northwestern Minnesota is approximately 50% agricultural (Ditmer et al. 2015). As it is in many agricultural regions with elk populations, crop depredation is a common concern (Baasch et al. 2010, Brook 2010). While the state of Minnesota provides repayments for crop depredation by elk, it is still an important issue for agricultural producers in this region (Minnesota Statute 3.7371). Therefore, our study of land use and habitat preferences of elk in Minnesota is important.

Crops cover most of the area within elk home ranges. While 41% of elk locations occurred within crops, more (56%) of elk home ranges consisted of crops. If elk were selecting for crops as a preferred habitat, we would have expected to see a higher percentage of elk locations found within this habitat type. It is likely that elk selected for crops primarily because they are so widely available, and easily accessible. However, this selection for crops is still important to consider due to conflicts with agricultural producers. Management activities currently used for elk have the goal of reducing these conflicts (MNDNR 2017). Unfortunately, few of the elk cows collared for our study were found within areas where management treatments occurred. Prescribed burns have been shown to attract elk (Van Dyke and Darragh 2006, 2007) and wildlife managers in northwestern Minnesota conduct very large prescribed burns every year. However, only three elk cows had locations found within the burn treatments conducted during the two years of this study. This could be due to the prescribed burn schedule for the region not perfectly aligning with the locations where elk were collared. More research is needed to measure the success of management treatments for attracting elk away from agricultural areas.

Collared elk showed a strong preference for forest. This was expected because elk often use forested woodland and shrubland canopy cover of as protective cover and do not move far from them within their home ranges (Boyce et al. 2003, Stubblefield et al. 2006, Baasch et al. 2010, Barbknecht et al. 2011, Rumble and Gamo 2011, Beck et al. 2013, Lehman et al. 2016). Elk selected for high canopy cover and low visual cover in the LN sub-group during the 2016 growing season. In the LANC combined-sub-group, selection for woody cover, especially woody wetlands, was strongest during the summer and fall when elk would need the cover for thermal protection (Rumble and Gamo 2011, Beck et al. 2013). The greatest proportion of locations found within woody cover types occurred in the fall when crops are harvested and during the elk and white-tailed deer (Odocoileus virginianus) hunting seasons. The two aforementioned anthropogenic activities may cause elk to seek shelter in less open areas (Ager et al. 2003, Brook 2010, Gingery et al. 2017, Ranglack et al. 2017, Thurfjell et al. 2017).

Besides crops and forest cover, we expected the large managed prairies and tracts of the Conservation Reserve Program grasslands to be another important resource for elk in the region (Minnesota Prairie Plan Working Group 2011). However, elk significantly selected for grasslands and herbaceous wetlands less than crops and woody cover when compared to what was available. This could be because the type, or amount, of prairie and CRP in the region do not fully meet the nutritional needs of the elk. The other possibility is that these grasslands are not located near sufficient forest cover, which is known to be an important factor in elk selection of habitats (Stubblefield et al. 2006).

Other studies have shown that proximity to woody cover and water or avoidance of roads and urban areas are important for elk habitat selection (Ager et al. 2003, Stubblefield et al. 2006, Baasch et al. 2010, Barbknecht et al. 2011, Coe et al. 2011, Beck et al. 2013). We found that the collared elk in our study were more likely to be found in areas closer to woody cover and in areas closer to sources of water. While elk in our study avoided roads, the strength of the selection for areas further from roads was very weak. This could be because the roads in this region are an extensive grid network that elk would be unable to disperse far from. The pattern with avoidance and selection for urban centers was not consistent across season or years. The cities found in this region are small and very dispersed and may not have much impact on elk selection of habitats.

Management implications

The elk we studied showed a preference for woody cover over crops; we therefore recommend that management strategies be focused on continuing to improve some land cover types within the forest transition zone, such as aspen woodlots, woody wetlands, and oak savanna, especially in areas of used elk locations. This could be done by continuing treatments to remove underbrush for reducing visual cover and encouraging new vegetative growth. These treatments could be targeted in areas that were known to have the collared elk cows from this study. Many large prescribed burns are done to manage habitat in northwestern Minnesota. Since elk are known to respond positively to habitat regeneration resulting from prescribed burns (Van Dyke and Darragh 2006, 2007), more prescribed burns could be focused in areas closer to the areas where elk are located. If wildlife managers wanted to measure elk use of management treatments, then it may be beneficial to focus any future study of elk habitat use in the Caribou-Vita region where there are more elk, and where their home ranges more often overlap with different types of habitat management strategies.

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Figures

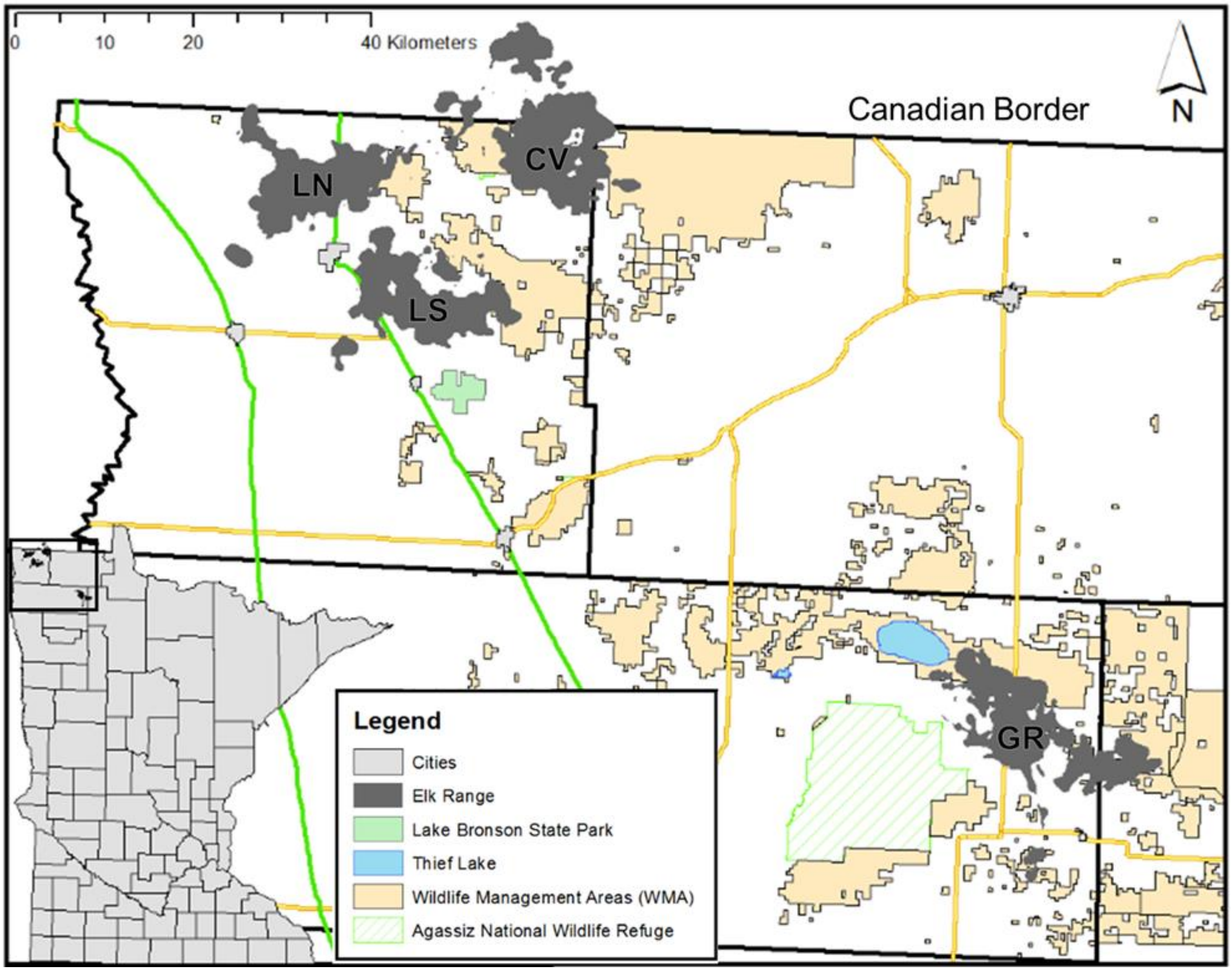

Figure 3-1 Study area in northwestern Minnesota. Elk (Cervus elaphus) are found in primarily Kittson, Roseau, and Marshall counties. The elk are found in 4 sub-groups that are labeled Caribou-Vita (CV), Grygla (GR), Lancaster North (LN), and Lancaster South (LS).

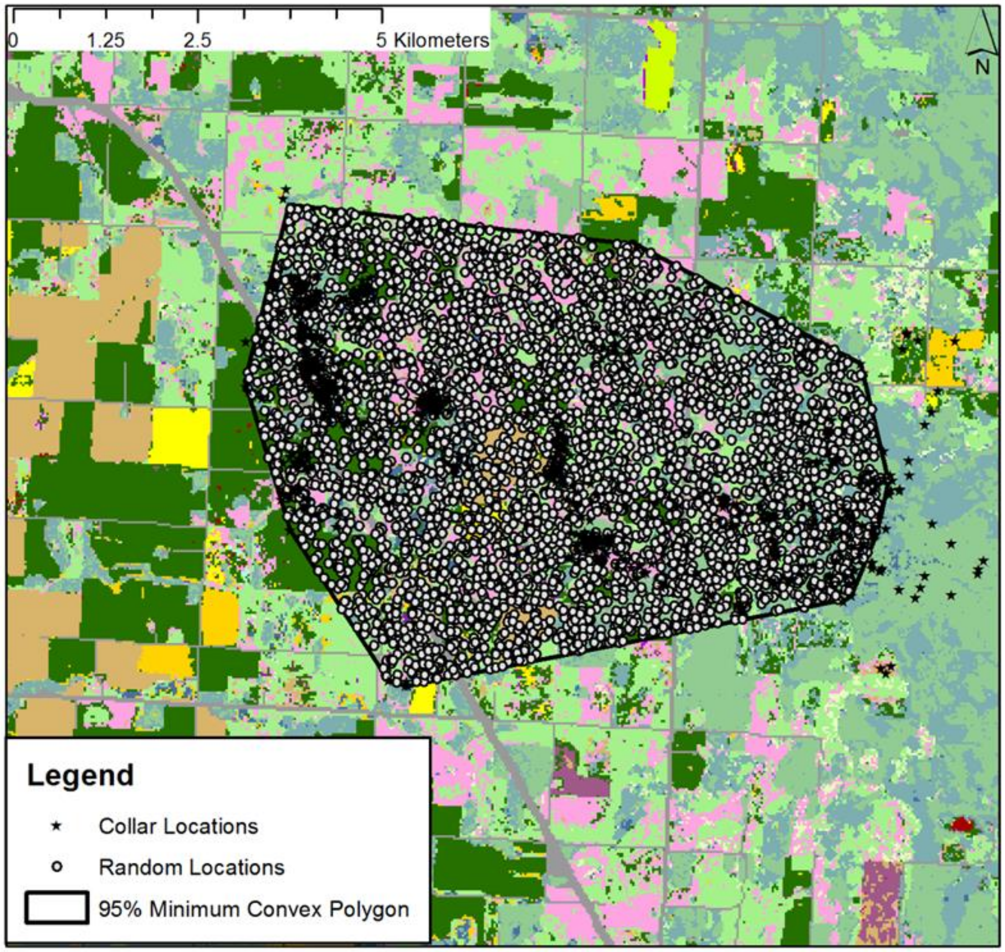

Figure 3-2 Example of an elk home range used to sample used (collar locations) and available (random locations) habitat overlaid on the 2016 and 2017USGS Cropland data layer

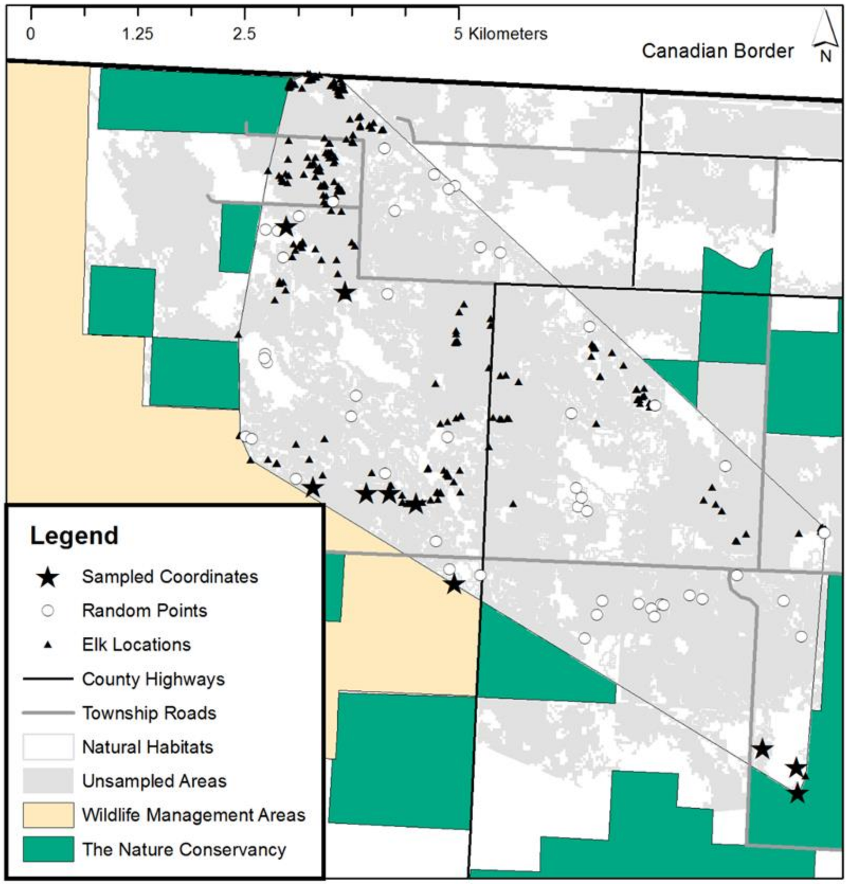

Figure 3-3 Example of the methods done to select used and random points for sampling fine-scale vegetation characteristics within MCP home ranges of elk in northwestern Minnesota.

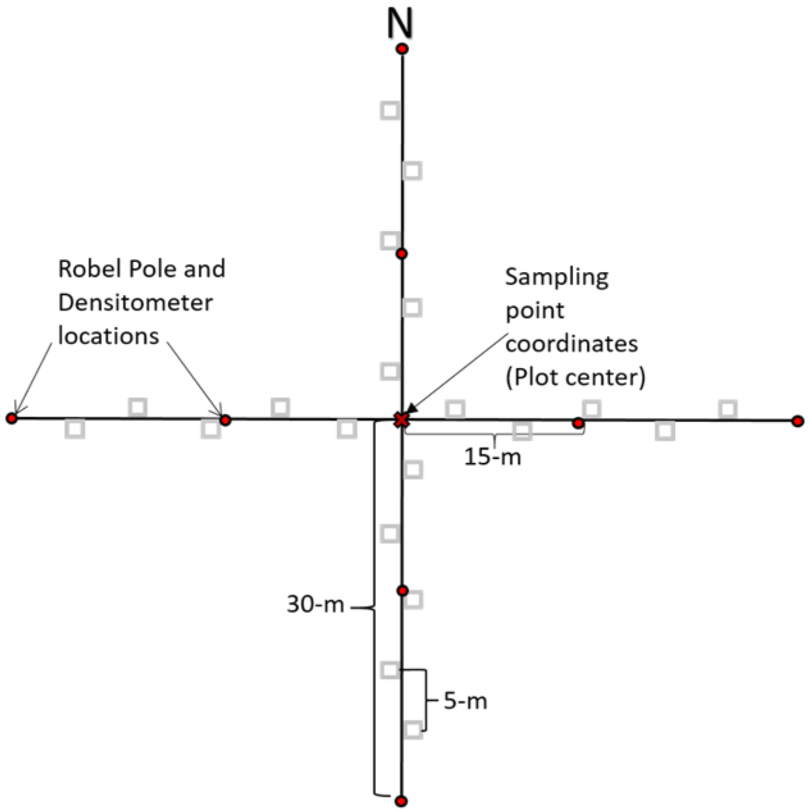

Figure 3-4 Diagram of the fine-scale sampling design used at 230 locations used by elk and 270 random locations.

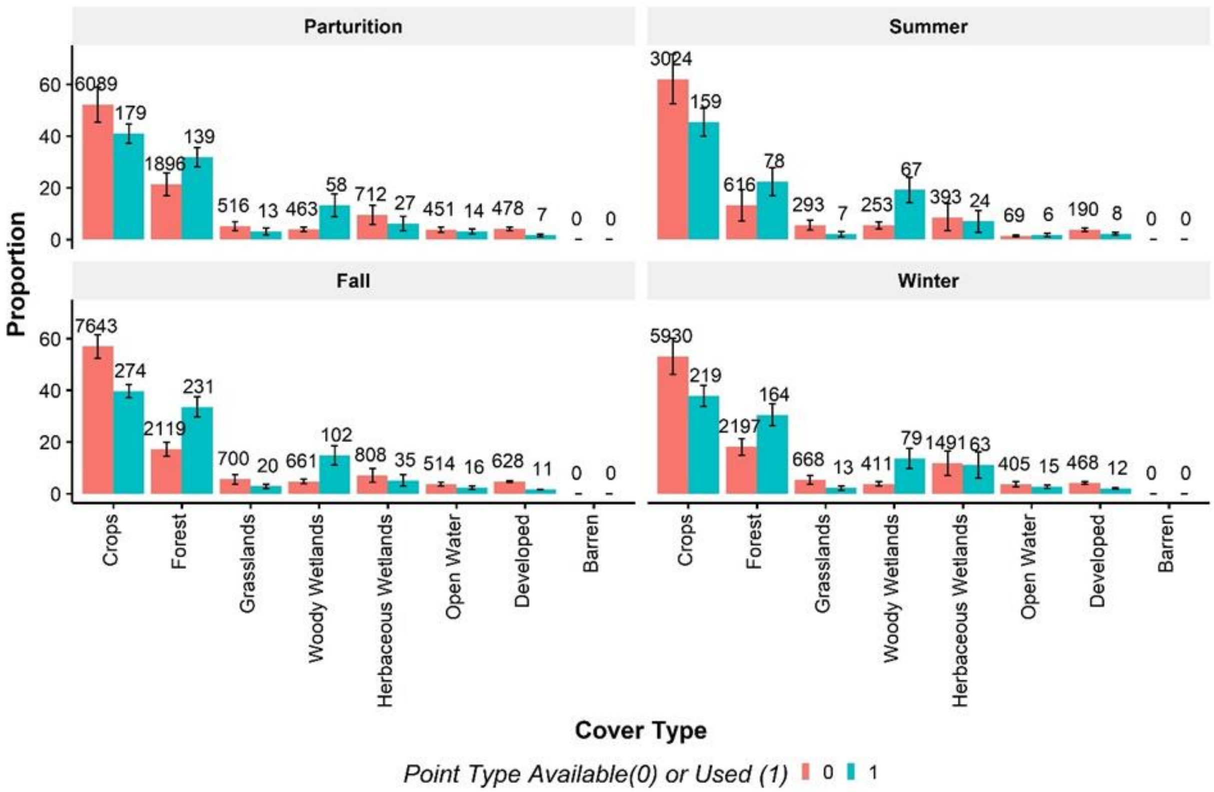

*Figure 3-5 Average proportion of used (red) and available (blue) locations (±1.96*SE) in different landcover types within elk home ranges across seasons across the two years for the LANC sub-group. The average number of elk locations in each cover type per elk and year is shown.*

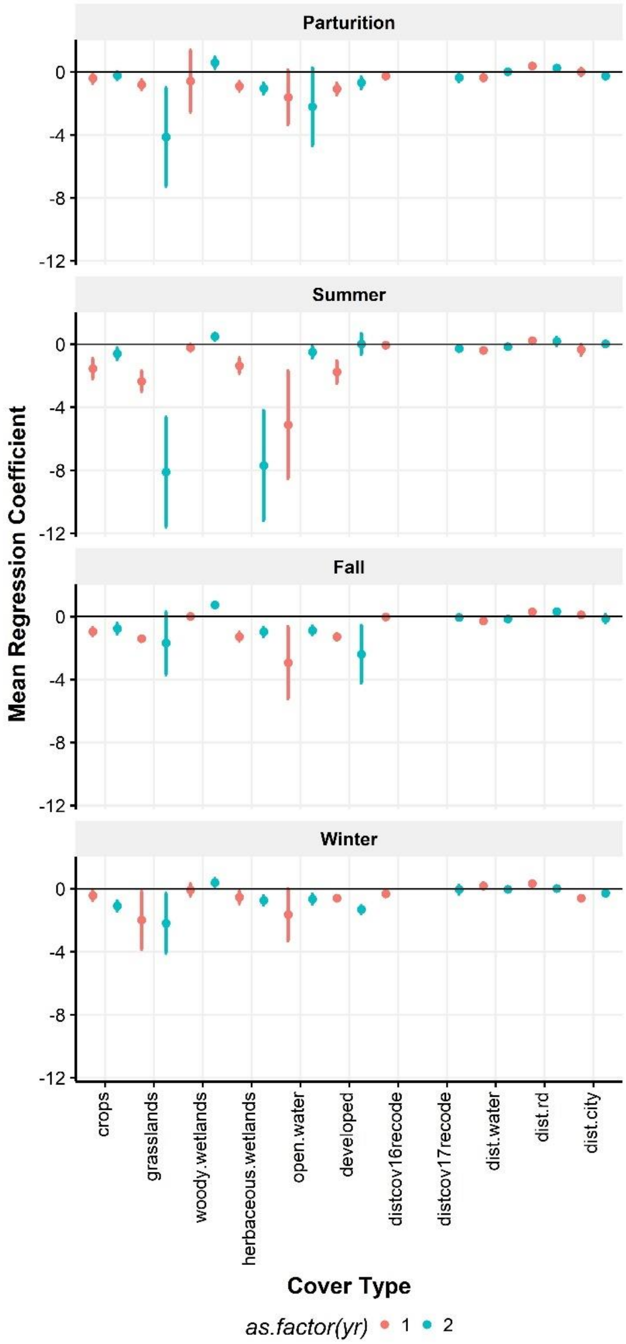

*Figure 3-6 Coarse Cover Resource Selection Function model comparing random locations (available) and elk locations (used) in coarse cover variables and measuring proximity probability to important landscape features for each season in northwestern Minnesota. We used forest as the reference level (represented by the zero line) for the habitat variables in this model. Selection is considered greater than that of forest when the regression coefficient is >0 and error bars (1.96*SE) do not overlap 0.*

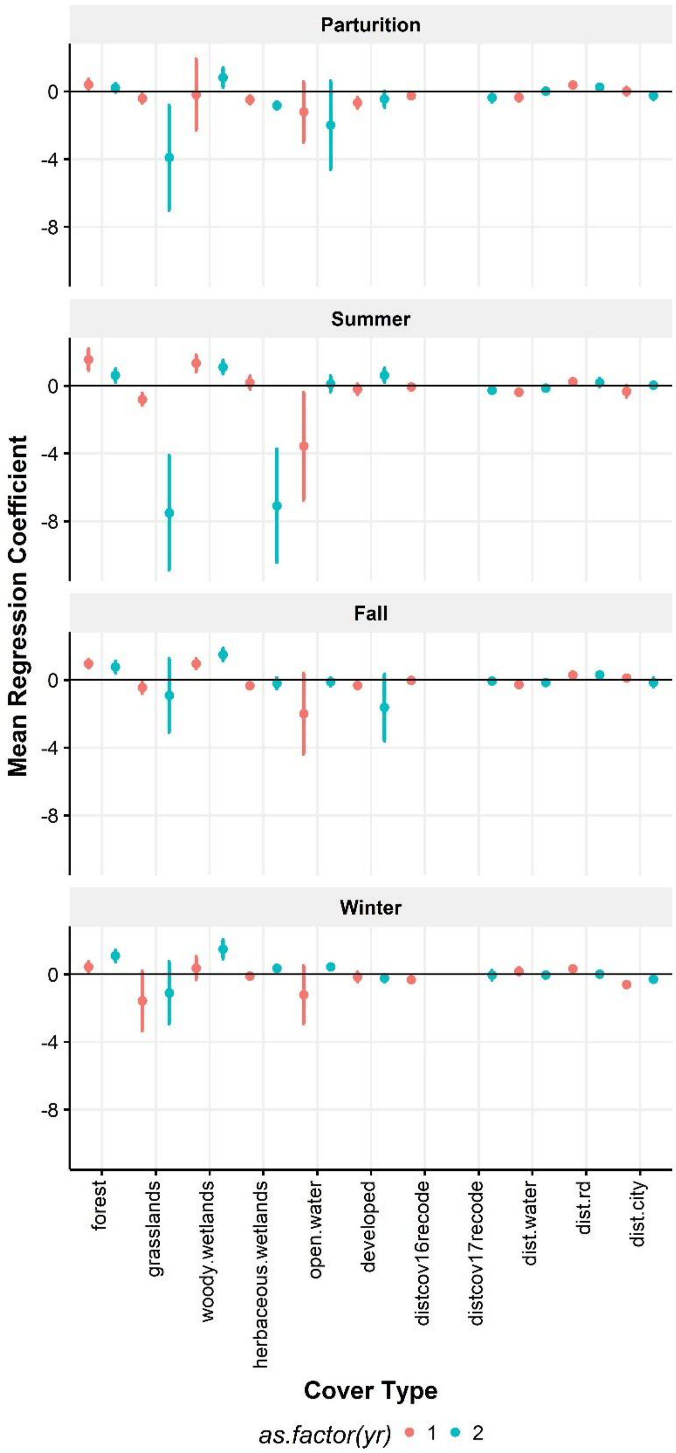

*Figure 3-7 Coarse Cover Resource Selection Function model comparing random locations (available) and elk locations (used) in coarse cover variables and measuring proximity probability to important landscape features for each season in northwestern Minnesota. We used crops as the reference level (represented by the zero line) for the habitat variables in this model. Selection is considered greater than that of crop when the regression coefficient is >0 and error bars (1.96*SE) do not overlap 0.*

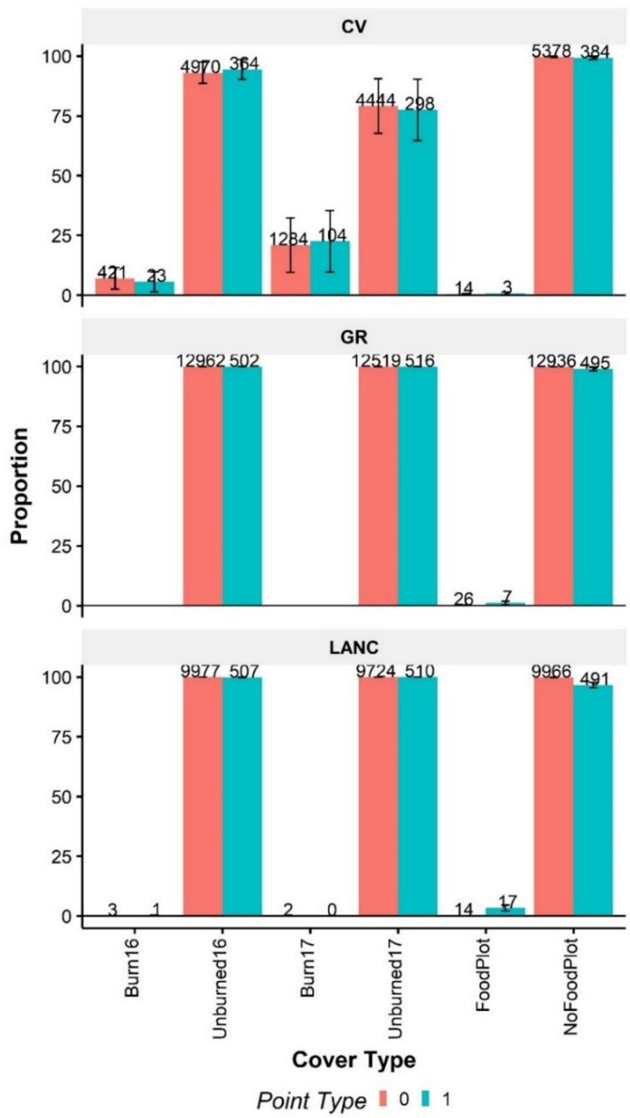

Figure 3-8 The percentage (±95%CI) of used (blue bars) locations and available (red bars) locations, in different management treatment areas, averaged across both years. The number above each bar shows the average number of locations found in the cover type for each elk.

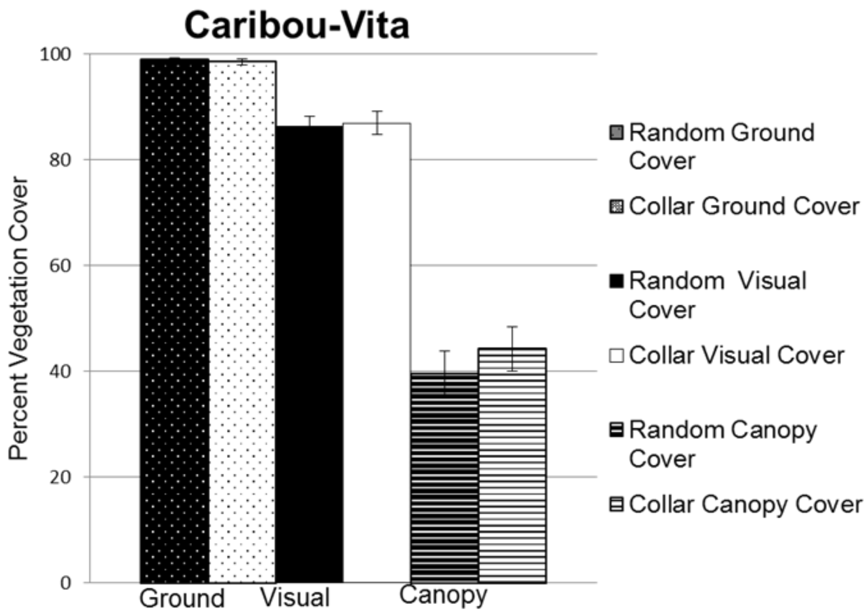

Figure 3-9a. A visual comparison of the percent vegetation cover (±1SE), at elk locations and randomly generated locations in northwestern Minnesota. These measurements are averages for percent ground cover, percent visual cover, and percent canopy cover for the Caribou -Vita sub-group. No significant difference was seen between percent cover measured at collar locations from those measured at randomly generated locations.

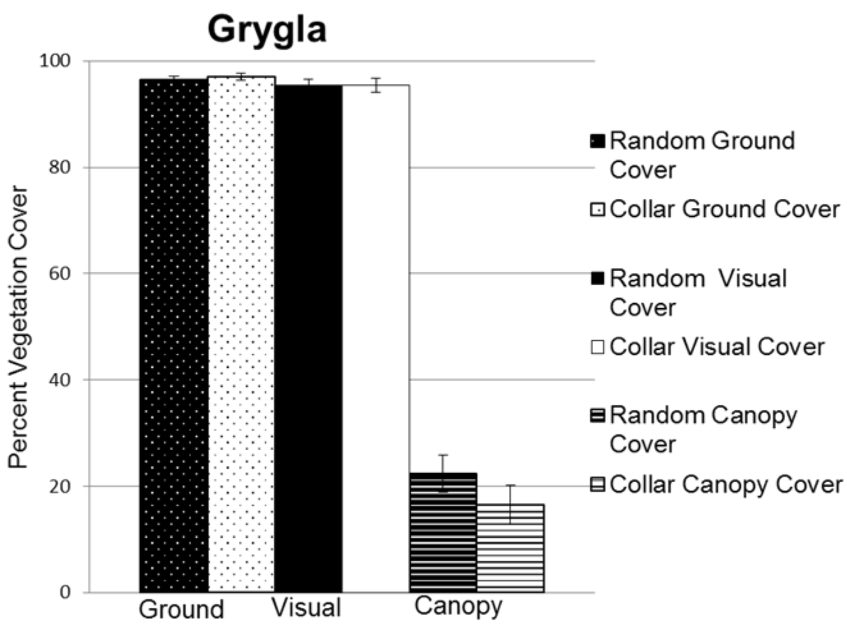

Figure 3-9b. A visual comparison of the percent vegetation cover (±1SE), at elk locations and randomly generated locations in northwestern Minnesota. These measurements are averages for percent ground cover, percent visual cover, and percent canopy cover for the Grygla sub-group. No significant difference was seen between percent cover measured at collar locations from those measured at randomly generated locations.

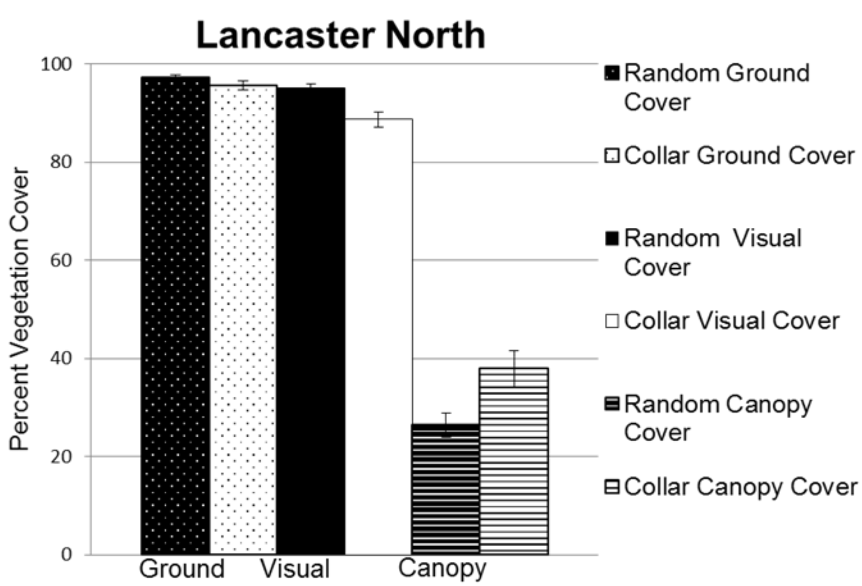

Figure 3-9c. A visual comparison of the percent vegetation cover (±1SE), at elk locations and randomly generated locations in northwestern Minnesota. These measurements are averages for percent ground cover, percent visual cover, and

percent canopy cover for the Lancaster North (LN) sub-group. Collared elk in the LN sub-group had a preference for areas with more canopy cover than what was available on the landscape ($p<0.001$). LN elk also showed a preference for areas with less visual cover than what was available to them ($p<0.001$).

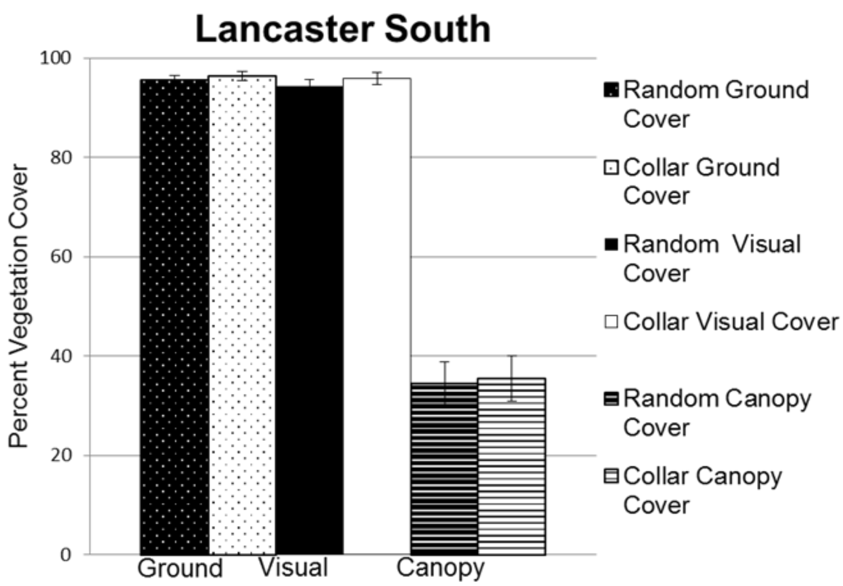

Figure 3-9d. A Visual comparison of the percent vegetation cover (±1SE), at elk locations and randomly generated locations in northwestern Minnesota. These measurements are averages for percent ground cover, percent visual cover, and percent canopy cover for the Lancaster South sub-group. No significant difference was seen between percent cover measured at collar locations from those measured at randomly generated locations.

Figure 3-9 A visual comparison of the percent vegetation cover, at elk locations and randomly generated locations in northwestern Minnesota for 4 sub-groups of elk.

Tables

Table 3.1.Cover Classifications used in Resource Selection Functions (RSFs). Coarse cover reclassifications were used in the first model comparing crop use to other habitat classifications. Seasonal reclassifications were used in the second model comparing crop use across the different seasons: parturition (15 April to 30 June), summer (1 July to 31 August), fall (1 September to 31 December) and winter (1 January to 14 April).

Value	Class Name	Coarse Cover Recode	Parturition Recode	Summer Recode	Fall Recode	Winter Recode
0	Background	Background	Background	Background	Background	Background
1	Corn	Crops	Corn	Corn	Corn	Fallow/Idle Cropland
5	Soybeans	Crops	Soybeans	Soybeans	Soybeans	Fallow/Idle Cropland
6	Sunflower	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
21	Barley	Crops	Barley	Other Crops	Other Crops	Fallow/Idle Cropland
22	Durum Wheat	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
23	Spring Wheat	Crops	Wheat	Wheat	Wheat	Fallow/Idle Cropland
24	Winter Wheat	Crops	Wheat	Wheat	Wheat	Wheat
27	Rye	Crops	Other Crops	Other Crops	Other Crops	Other Crops
28	Oats	Crops	Oats	Oats	Other Crops	Fallow/Idle Cropland
29	Millet	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
31	Canola	Crops	Canola	Other Crops	Other Crops	Fallow/Idle Cropland
32	Flaxseed	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
36	Alfalfa	Crops	Alfalfa	Alfalfa	Alfalfa	Fallow/Idle Cropland
37	Other Hay/Non Alfalfa	Crops	Other Hay/Non Alfalfa	Other Hay/Non Alfalfa	Other Hay/Non Alfalfa	Other Hay/Non Alfalfa
39	Buckwheat	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
41	Sugarbeets	Crops	Other Crops	Sugarbeets	Other Crops	Fallow/Idle Cropland
42	Dry Beans	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
43	Potatoes	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
44	Other Crops	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
53	Peas	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
57	Herbs	Crops	Other Crops	Other Crops	Other Crops	Fallow/Idle Cropland
58	Clover/Wildflowers	Grasslands	Grasslands	Grasslands	Grasslands	Grasslands
59	Sod/Grass Seed	Grasslands	Grasslands	Grasslands	Grasslands	Grasslands
61	Fallow/Idle Cropland	Crops	Fallow/Idle Cropland	Fallow/Idle Cropland	Fallow/Idle Cropland	Fallow/Idle Cropland
111	Open Water	Open Water	Open Water	Open Water	Open Water	Open Water
121	Developed/Open Space	Developed	Developed	Developed	Developed	Developed
122	Developed/Low Intensity	Developed	Developed	Developed	Developed	Developed
123	Developed/Med Intensity	Developed	Developed	Developed	Developed	Developed
124	Developed/High Intensity	Developed	Developed	Developed	Developed	Developed
131	Barren	Barren	Barren	Barren	Barren	Barren
141	Deciduous Forest	Forest	Forest	Forest	Forest	Forest
142	Evergreen Forest	Forest	Forest	Forest	Forest	Forest
143	Mixed Forest	Forest	Forest	Forest	Forest	Forest
152	Shrubland	Forest	Forest	Forest	Forest	Forest
176	Grass/Pasture	Grasslands	Grasslands	Grasslands	Grasslands	Grasslands
190	Woody Wetlands	Woody Wetlands	Woody Wetlands	Woody Wetlands	Woody Wetlands	Woody Wetlands
195	Herbaceous Wetlands	Herbaceous Wetlands	Herbaceous Wetlands	Herbaceous Wetlands	Herbaceous Wetlands	Herbaceous Wetlands

R Code Appendix

Supplementary Material A: Code used to create Brownian Bridge Movement Models (BBMMS):

```
### Template code for fitting BBMM home ranges
### Prepared by Dr. Véronique St-Louis (MNDNR Biometrics Unit) edited by Alicia Freeman

### This code reads locations from .csv files as opposed to geodatabases

### ADAPTED FROM FROM MANUAL OF SPATIAL ECOLOGY ONLINE

# load libraries -----------------------------------------------------------
  require(gpclib)
  require(foreign)
  require(lattice)
   library(adehabitatMA)
  library(raster)
  library(sp)
  library(rgdal)
  library(maptools)
  library(chron)
  library(plyr)
  library(BBMM)
  library(caTools)
  library(bitops)

# Set working directory ---------------------------------------------------

setwd("C:/… … …")

myfiles<-list.files(pattern=".csv")

season<-c('part','summ','harv','wint') # list of seasons
year<-c('2016','2017','2018') #list of years
yr.st<-c('yr1','yr2')

# Parturition: 15 April - 30 June
# Summer: 1 July - 31 August
#Harvest: 1 September - 31 December
#Winter: 1 January - 14 April

# create a dataframe where the home range areas will be saved
    hr.area<-data.frame(hrid=NA,seas=NA,yr=NA,contour=NA,area=NA)
    hr.area.annual<-data.frame(hrid=NA,yr.study=NA,contour=NA,area=NA)

    # database loop -----------------------------------------------------------

  for (i in 1:length(myfiles)){ # start loop through all location files

   #  Print which elk is being processedas well as time.
   cat(paste('Working on elk ID',myfiles[i]))
```

```
  print(Sys.time())

# read in file
  locs <- read.csv(myfiles[i],stringsAsFactors=FALSE) #read-in one of the location files

# Format dates and times
   locs$date.timeGMToff<-as.POSIXct(locs$date.timeGMToff, format="%Y-%m-%d
%H:%M:%S",tz="Etc/GMT+6") # transform back to GMT-06

   # Assign seasons and years
   locs$yr<-strftime(locs$date.timeGMToff,format="%Y")
   tmp<-strftime(locs$date.timeGMToff,format="%m-%d")

#seasons
   locs$seas<-NA
   locs$seas[tmp>="04-15" & tmp <="06-30"]<-"part"
   locs$seas[tmp>="07-01" & tmp <="08-31"]<-"summ"
   locs$seas[tmp>="09-01" & tmp <="12-31"]<-"harv"
   locs$seas[tmp>="01-01" & tmp <="04-14"]<-"wint"

#year.study
   locs$year.study<-NA
   locs$year.study[locs$date.timeGMToff>="2016-04-15" & locs$date.timeGMToff <="2017-04-14"]<-
"yr1"
   locs$year.study[locs$date.timeGMToff>="2017-04-15" & locs$date.timeGMToff <="2018-04-14"]<-
"yr2"

   for (y.st  in 1:length(yr.st)){

     ##### BBMM ANNUAL WITH ALL LOCATIONS

     locs.sub.y<-locs[locs$year.study==yr.st[y.st],]     #subset original data so that only this season and
year is processed
     locs.sub.y<-locs.sub.y[!is.na(locs.sub.y$CollarID),]

     #Sort Data in chronological order
     locs.sub.y <- locs.sub.y[order(locs.sub.y$date.timeGMToff),]

     timediff <- diff(locs.sub.y$date.timeGMToff) # in minutes
     timediff<-as.numeric(timediff, units = "mins")

     # remove first entry without any difference
     locs.sub.y <- locs.sub.y[-1,]
     locs.sub.y$timelag <-as.numeric(abs(timediff)) # add timelag to dataframe


     # Convert coordinates to UTM
     coords <- data.frame(ID = 1:length(locs.sub.y[,1]), X = locs.sub.y$Longitude...., Y =
locs.sub.y$Latitude....)
     coordinates(coords) <- c("X", "Y")
     proj4string(coords) <- CRS("+proj=longlat +datum=WGS84")  ## assign that currently the X and Y
are in lat long

     locs.sub.y.utm <- spTransform(coords, CRS("+proj=utm +zone=15 +datum=WGS84")) # transform in
UTM zone 15
```

```
locs.sub.y$X.utm<-locs.sub.y.utm$X # append X and Y to main matrix of locations
locs.sub.y$Y.utm<-locs.sub.y.utm$Y
#
# remove large time lags
locs.sub.y<-locs.sub.y[locs.sub.y$timelag<=480,]

### end conversion to UTM

# ### generating reference grid
RESO <- 30 # grid resolution (m)
BUFF <- 5000 # grid extent (m) (buffer around location extremes)
XMIN <- RESO*(round(((min(locs.sub.y$X.utm)-BUFF)/RESO),0))#CHANGE to UTMn and UTMe
YMIN <- RESO*(round(((min(locs.sub.y$Y.utm)-BUFF)/RESO),0))
XMAX <- XMIN+RESO*(round(((max(locs.sub.y$X.utm)+BUFF-XMIN)/RESO),0))
YMAX <- YMIN+RESO*(round(((max(locs.sub.y$Y.utm)+BUFF-YMIN)/RESO),0))
NRW <- ((YMAX-YMIN)/RESO)
NCL <- ((XMAX-XMIN)/RESO)
# 6.4.2. Generation of refgrid
refgrid<-raster(nrows=NRW, ncols=NCL, xmn=XMIN, xmx=XMAX, ymn=YMIN, ymx=YMAX)
# ##Get the center points of the mask raster with values set to 1
refgrid <- xyFromCell(refgrid, 1:ncell(refgrid))

# Use brownian.bridge function in package BBMM to delineate home range
bbmm.tmp = brownian.bridge(x=locs.sub.y$X.utm, y=locs.sub.y$Y.utm, time.lag=locs.sub.y$timelag,
                           location.error=25,cell.size=30)

#Save results for all contours
contours = bbmm.contour(bbmm.tmp, levels=c(50, 95,99),plot=F)

bbmm.contour = data.frame(x = bbmm.tmp$x, y = bbmm.tmp$y, probability = bbmm.tmp$probability)


# Create a shapefile with contour lines

# Make sure the data is properly projected

out.raster <- rasterFromXYZ(bbmm.contour,crs=CRS("+proj=utm +zone=15
+datum=WGS84"),digits=2)

for (z in 1:length(contours$Z)){

  out <- rasterToContour(out.raster,levels=contours$Z[z])

  out=SpatialLines2PolySet(out)
  out=PolySet2SpatialPolygons(out)
  out=as(out, "SpatialPolygonsDataFrame")


writeOGR(obj=out,dsn=".",layer=paste(myfiles[i],"_",yr.st[y.st],"_bbmm_",contours$Contour[z],sep=""),driv
er="ESRI Shapefile")

  # add a write to table for the area
  hr.dat.annual<-c(myfiles[i],yr.st[y.st],contours$Contour[z],area(out))
  hr.area.annual<-rbind(hr.area.annual,hr.dat.annual)
```

```
        write.csv(hr.area.annual,'C:/Users/Alicia
Gaming/Desktop/BBMM_Season_Files/BBMM_Annual_Seasonal/hr_areas_annual.csv')

        remove(out)

      } # end of contour z loop


      ##### END OF ANNUAL HOME RANGE FOR THE TWO YEARS OF STUDY

    } # end of year of study loop

# start loop through years
    for (y in 1:length(year)){

    # start loop through seasons
    for (s in 1:length(season)){

   locs.sub<-locs[locs$yr==year[y]&locs$seas==season[s],]    #subset original data so that only this
season and year is processed

   if (empty(locs.sub)) next #if there isn't a combination of a particular year and season, it skips to the next
on the list

   #Sort Data
   locs.sub <- locs.sub[order(locs.sub$date.timeGMToff),]

   timediff <- diff(locs.sub$date.timeGMToff) # in minutes
   timediff<-as.numeric(timediff, units = "mins")

   # remove first entry without any difference
   locs.sub <- locs.sub[-1,]
   locs.sub$timelag <-as.numeric(abs(timediff)) # add timelag to dataframe

   # Convert to UTM
   coords <- data.frame(ID = 1:length(locs.sub[,1]), X = locs.sub$Longitude...., Y = locs.sub$Latitude....)
   coordinates(coords) <- c("X", "Y")
   proj4string(coords) <- CRS("+proj=longlat +datum=WGS84")  ## assign that currently the X and Y are
in lat long

   locs.sub.utm <- spTransform(coords, CRS("+proj=utm +zone=15 +datum=WGS84")) # transofmr in
UTM zone 15

   locs.sub$X.utm<-locs.sub.utm$X # append X and Y to main matrix of locations
   locs.sub$Y.utm<-locs.sub.utm$Y

   # remove large time lags
   locs.sub<-locs.sub[locs.sub$timelag<=480,]

   ### end conversion to UTM

   ### generating reference grid
    RESO <- 30 # grid resolution (m)
    BUFF <- 5000 # grid extent (m) (buffer around location extremes)
    XMIN <- RESO*(round(((min(locs.sub$X.utm)-BUFF)/RESO),0))#CHANGE to UTMn and UTMe
    YMIN <- RESO*(round(((min(locs.sub$Y.utm)-BUFF)/RESO),0))
```

```
 XMAX <- XMIN+RESO*(round(((max(locs.sub$X.utm)+BUFF-XMIN)/RESO),0))
 YMAX <- YMIN+RESO*(round(((max(locs.sub$Y.utm)+BUFF-YMIN)/RESO),0))
 NRW <- ((YMAX-YMIN)/RESO)
 NCL <- ((XMAX-XMIN)/RESO)
# 6.4.2. Generation of refgrid
 refgrid<-raster(nrows=NRW, ncols=NCL, xmn=XMIN, xmx=XMAX, ymn=YMIN, ymx=YMAX)
# ##Get the center points of the mask raster with values set to 1
 refgrid <- xyFromCell(refgrid, 1:ncell(refgrid))

# Use brownian.bridge function in package BBMM to run home range
bbmm.tmp = brownian.bridge(x=locs.sub$X.utm, y=locs.sub$Y.utm, time.lag=locs.sub$timelag,
location.error=25,cell.size=30)

#Save results for all contours
contours = bbmm.contour(bbmm.tmp, levels=c(50, 95,99),plot=F)

bbmm.contour = data.frame(x = bbmm.tmp$x, y = bbmm.tmp$y, probability = bbmm.tmp$probability)


# Create a shapefile with contour lines
# Make sure the data is properly projected

out.raster <- rasterFromXYZ(bbmm.contour,crs=CRS("+proj=utm +zone=15
+datum=WGS84"),digits=2)

for (z in 1:length(contours$Z)){

out <- rasterToContour(out.raster,levels=contours$Z[z])

out=SpatialLines2PolySet(out)
out=PolySet2SpatialPolygons(out)
out=as(out, "SpatialPolygonsDataFrame")


writeOGR(obj=out,dsn=".",layer=paste(myfiles[i],"_",season[s],"_",year[y],"_bbmm_",contours$Contour[z],
sep=""),driver="ESRI Shapefile")

# add a write to table for the area
hr.dat<-c(myfiles[i],season[s],year[y],contours$Contour[z],area(out))
hr.area<-rbind(hr.area,hr.dat)

write.csv(hr.area,'C:/… … …/BBMM_Season_Files/BBMM_Annual_Seasonal/hr_areas.csv')

remove(out)

  } # end of contour z loop

}#end season

 }#end year

       } # end of myfiles
 }#end year

       } # end of myfiles
```

Supplementary Material B: Code used to create Resource Selection Functions (RSFs):

```
## R script to evaluate resource selection functions for elk, using gps-collar data collected in Northwestern Minnesota.
## this will compute the RSFs (using logistic equation models), store results, and calculate summary statistics on regression coefficients .

## Prepared by Dr. Véronique St-Louis, MNDNR Biometrics Unit
## Last update 3 October 2018

# Set working directory ---------------------------------------------------

main.dir<-'C:/… … …'
out.dir<-'C:/… … …'

# read data generated in the elk covariate code; this is from the code elk_recodecrop.r
dat.all<-read.csv(paste(main.dir,'../../Desktop/R_Figures/elk_covar_CMPLnew_recode.csv',sep=""))
dat.all$herd2<-dat.all$herdid
#levels(dat.all$herd2)<-c("LANC","LN","LS","GR","CV")
dat.all$herd2<-gsub("LN","LANC",dat.all$herd2)
dat.all$herd2<-gsub("LS","LANC",dat.all$herd2)


# load libraries
library(lme4)
library(doBy)

# Step 1. Exploratory analysis

## In this section I suggest making exploratory figures to understand the quality and distribution of the data (e.g., distribution of the continuous variables, outliers, etc...)

#ggplot(dat.all, aes(x=xvar, y=yvar)) +
 # geom_point(shape=1) +    # Use hollow circles
  #geom_smooth(method=lm)   # Add linear regression line
#  (by default includes 95% confidence region)


# Step 2. Resource selection analysis

## fit one model per elk, season, and year, and then average the results

## Make list of IDs to be able to loop through all elk, seasons, and years
elk.list<-unique(dat.all$elkid)
seas.list<-unique(dat.all$seas)
yr.list<-unique(dat.all$yr)

## list the landcover type levels for the landcover covariates
cover.coarse.list<-levels(dat.all$Cover.Coarse)
cover.coarse.list<-tolower(cover.coarse.list) #removes upper case

## first build a data frame where the coefficients will be stored for all 4 sub-groups separately
```

```
#mymod.coefs<-data.frame(yr=NA,seas=NA,herdid=NA,elkid=NA, dist.rd=NA,distcover6=NA,
distcover17=NA, dist.water=NA, dist.city=NA, data.frame(matrix(NA, nrow=1,ncol =
length(cover.coarse.list))))
#colnames(mymod.coefs)[10:ncol(mymod.coefs)]<-cover.coarse.list #adjust the number (6 here)
depending which continuous variable(s) is(are) used in the model

#mymod.coefs$herdid<-as.factor(mymod.coefs$herd) #set herd id as a factor
#levels(mymod.coefs$herdid)<-c("CV","GR","LN","LS")

#mymod.coefs$seas<-as.factor(mymod.coefs$seas) #set herd id as a factor
#levels(mymod.coefs$seas)<-c("p","s","h","w")


## build a table to store coefficients' standard errors
#mymod.SE<-data.frame(yr=NA,seas=NA,herdid=NA,elkid=NA,dist.rd=NA,distcover6=NA,
distcover17=NA, dist.water=NA, dist.city=NA,data.frame(matrix(NA, nrow=1,ncol =
length(cover.coarse.list))))
#colnames(mymod.SE)[10:ncol(mymod.SE)]<-cover.coarse.list

## same thing to store a table of p-values
#mymod.pvals<-data.frame(yr=NA,seas=NA,herdid=NA,elkid=NA,dist.rd=NA,distcover6=NA,
distcover17=NA, dist.water=NA, dist.city=NA,data.frame(matrix(NA, nrow=1,ncol =
length(cover.coarse.list))))
#colnames(mymod.pvals)[10:ncol(mymod.pvals)]<-cover.coarse.list

#For the combined LN/LS herds (LNCS)
mymod.coefs<-data.frame(yr=NA,seas=NA,herd2=NA,elkid=NA, dist.rd=NA,distcov16recode=NA,
distcov17recode=NA, dist.water=NA, dist.city=NA, data.frame(matrix(NA, nrow=1,ncol =
length(cover.coarse.list))))
colnames(mymod.coefs)[10:ncol(mymod.coefs)]<-cover.coarse.list #adjust the number (6 here)
depending which continuous variable(s) is(are) used in the model

mymod.coefs$herd2<-as.factor(mymod.coefs$herd) #set herd id as a factor
levels(mymod.coefs$herd2)<-c("CV","GR","LANC")

mymod.coefs$seas<-as.factor(mymod.coefs$seas) #set herd id as a factor
levels(mymod.coefs$seas)<-c("p","s","h","w")


## repeat the same to build a table to store coefficients' standard errors
mymod.SE<-data.frame(yr=NA,seas=NA,herd2=NA,elkid=NA,dist.rd=NA,distcov16recode=NA,
distcov17recode=NA, dist.water=NA, dist.city=NA,data.frame(matrix(NA, nrow=1,ncol =
length(cover.coarse.list))))
colnames(mymod.SE)[10:ncol(mymod.SE)]<-cover.coarse.list

## same thing to store a table of p-values
mymod.pvals<-data.frame(yr=NA,seas=NA,herd2=NA,elkid=NA,dist.rd=NA,distcov16recode=NA,
distcov17recode=NA, dist.water=NA, dist.city=NA,data.frame(matrix(NA, nrow=1,ncol =
length(cover.coarse.list))))
colnames(mymod.pvals)[10:ncol(mymod.pvals)]<-cover.coarse.list


for (i in 1:length(elk.list)) { #loops  through all species

  for (s in 1:length(seas.list)) { # loops through all seasons
```

```
  for (y in 1:length(yr.list)) { # loop through both study years

    if (i==1 & s==1 & y==1) it=1 else it = it + 1    # set the number of iteration, i.e., the row where the data will be saved in the final data frame

    ## subset the data with the right elk, season, and year
    mydat<-dat.all[dat.all$elkid==elk.list[i] & dat.all$seas==seas.list[s]&dat.all$yr==yr.list[y],]


    ## Skip to next iteration if the dataframe is empty, i.e., if for a given elk there is no data for that combination of year and season
    if (nrow(mydat) == 0) next

    ## setting the reference level
    levels(mydat$Cover.Coarse) # this allows you to look at the current level
    mydat$Cover.Coarse<-relevel(mydat$Cover.Coarse,"Forest") # assign reference level,

    # Fit regression model; scale/normalize the continuous variable. If you have several continuous variables this helps
    if(yr.list[y]=="1"){ mymod<-
glm(used~Cover.Coarse+scale(dist.rd)+scale(dist.water)+scale(distcov16recode)+scale(dist.city),data=mydat,family=binomial(link="logit"))
    }
    if(yr.list[y]=="2"){
    mymod<-
glm(used~Cover.Coarse+scale(dist.rd)+scale(dist.water)+scale(distcov17recode)+scale(dist.city),data=mydat,family=binomial(link="logit"))
    }

    ## Data storage

    # vector of coefficients, SE, and pvalues for each variable in the model. This excludes the intercept, hence the [-1,].
    mod.coefs<-summary(mymod)$coefficients[-1,1]
    mod.SE<-summary(mymod)$coefficients[-1,2]
    mod.pval<-summary(mymod)$coefficients[-1,4]

    #####

    # Now append the results to tables of coefficients, SE, and p-values

    # Fix names so that it matches between the table of coefficients and the column names of the data frame that we created
    names(mod.coefs)<-tolower(names(mod.coefs))
    names(mod.coefs)<-gsub("cover.coarse","",names(mod.coefs))
    names(mod.coefs)<-gsub("scale","",names(mod.coefs))
    names(mod.coefs)<-gsub("\\(","",names(mod.coefs))
    names(mod.coefs)<-gsub("\\)","",names(mod.coefs))

    ## regression coefficients
    mymod.coefs[it, colnames(mymod.coefs) %in% names(mod.coefs)] <- merge(mymod.coefs[it, colnames(mymod.coefs) %in% names(mod.coefs)],t(mod.coefs),all=T) # this will place the values of "mod.coefs" , i.e., the coefficients from the model, in the table "mymod.coefs" in the the column that match (i.e., the names and colnames match)
```

```
    mymod.coefs[it,c(1:4)]<-mydat[1,c("yr","seas","herd2","elkid")] # this places the right year, season, herdid, and elk id in the able for that specific model iteration.

    #P-Values
    # Fix names so that it matches between the table of coefficients and the column names of the data frame that we created
    names(mod.pval)<-tolower(names(mod.pval))
    names(mod.pval)<-gsub("cover.coarse","",names(mod.pval))
    names(mod.pval)<-gsub("scale","",names(mod.pval))
    names(mod.pval)<-gsub("\\(","",names(mod.pval))
    names(mod.pval)<-gsub("\\)","",names(mod.pval))

    ## regression p-values
    mymod.pvals[it, colnames(mymod.pvals) %in% names(mod.pval)] <- merge(mymod.pvals[it, colnames(mymod.pvals) %in% names(mod.pval)],t(mod.pval),all=T) # this will place the values of "mod.pval" , i.e., the "P-Values" from the model, in the table "mymod.pval" in the the column that match (i.e., the names and colnames match)

    mymod.pvals[it,c(1:4)]<-mydat[1,c("yr","seas","herd2","elkid")] # this places the right year, season, herdid, and elk id in the able for that specific model iteration.


    #Standard Error SE
    # Fix names so that it matches between the table of coefficients and the column names of the data frame that we created
    names(mod.SE)<-tolower(names(mod.SE))
    names(mod.SE)<-gsub("cover.coarse","",names(mod.SE))
    names(mod.SE)<-gsub("scale","",names(mod.SE))
    names(mod.SE)<-gsub("\\(","",names(mod.SE))
    names(mod.SE)<-gsub("\\)","",names(mod.SE))

    ## regression p-values
    mymod.SE[it, colnames(mymod.SE) %in% names(mod.SE)] <- merge(mymod.SE[it, colnames(mymod.SE) %in% names(mod.SE)],t(mod.SE),all=T) # this will place the values of "mod.SE" , i.e., the "Standard Error" from the model, in the table "mymod.SE" in the the column that match (i.e., the names and colnames match)

    mymod.SE[it,c(1:4)]<-mydat[1,c("yr","seas","herd2","elkid")] # this places the right year, season, herdid, and elk id in the able for that specific model iteration.

    ### Now delete all outputs for that model, to ensure that it is not carried over to the next iteration.
    remove(mod.coefs)
    remove(mod.SE)
    remove(mod.pval)
    remove(mymod)
    remove(mydat)


   } # end year loop

  } # end season loop

} # end elkid loop

mymod.coefs<-mymod.coefs[!is.na(mymod.coefs$yr),]# clean the data and remove iterations that were skipped with no results
```

```
write.csv(mymod.coefs,paste(out.dir,'landcover_model_coefs.csv',sep="")) # write result file for the regression coefficients.

mymod.pvals<-mymod.pvals[!is.na(mymod.pvals$yr),]
write.csv(mymod.pvals,paste(out.dir,'landcover_model_pvalues.csv',sep="")) #write result file for p-values.

mymod.SE<-mymod.SE[!is.na(mymod.SE$yr),]
write.csv(mymod.SE,paste(out.dir,'landcover_model_SE.csv',sep=""))#write result file for standard errors.
```