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Space Use and Habitat Selection by Female Elk (*Cervus elaphus*) in an Agro-Forested landscape of Northwestern Minnesota

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ABSTRACT

Little information exists on elk (*Cervus elaphus*) space use and habitat selection in the prairie and forest transition zone of northwestern Minnesota. Studying the placement, size, and habitat composition of elk home ranges, as well as their use of habitats, could provide important insights regarding how elk use agricultural fields on private lands adjacent to large wildlife management areas where elk populations currently exist. During 2016–2017, we used GPS radio-telemetry to study female elk space use and habitat selection. We quantified home range size, habitat composition of home ranges, and 3rd-order habitat selection for elk to describe space and habitat use patterns in a predominantly agricultural landscape. Mean sizes of seasonal home ranges for elk was 48.5 km^2 and ranged between 21.2–87.7 km^2. Cultivated fields of legume and cereal crops made up nearly 50% of home ranges of female elk, whereas the remaining habitat consisted of native forest and grassland habitats. Elk exhibited strong selection for agricultural habitat, such as legumes and fallow fields, in juxtaposition with forest habitats. Female elk avoided roads and remained relatively close to forest edges when foraging in agricultural fields. We suggest that future management actions consider forestry practices and habitat improvements to extend elk calving habitat onto Wildlife Management Areas and away from agricultural habitats.

KEY WORDS agriculture, *Cervus elaphus*, conservation, elk, habitat selection, home range, space use, Minnesota.

Since the early 1900s, translocation and reintroduction of animals has been the primary management tool for restoring extirpated populations of wildlife to areas of the United States (Seddon et al. 2007, Brichieri-Colombi and Moehrenschlager 2016). For many ungulate species, translocations of animals were used to repatriate populations to former ranges or to reinforce vulnerable populations to prevent extinction (Larter et al. 2000, Seddon et al. 2005, Frair et al. 2007). For instance, populations of elk (*Cervus elaphus*) were successfully restored to human-dominated landscapes, which required developing management plans that ensured availability of critical habitat and mitigation of potential conflicts (Baasch et al. 2010, Yott et al. 2011, Popp et al. 2014). Reintroduction of elk into human-dominated landscapes occur in predominately agricultural regions where reintroduced populations often move between wildlife management areas (WMAs) and surrounding agricultural lands (Baasch et al. 2010, Crank et al. 2010, Smith et al. 2018)). Such movements are problematic, as elk are known to cause crop damage that facilitates conflict between farmers and government agencies about ungulate management (Brook 2009, Crank et al. 2010). Therefore, evaluating space use and habitat selection of elk in agricultural regions is necessary for government agencies to develop proper management plans to reduce wildlife conflict with local farming communities and garner public support for elk conservation.

Prior to European settlement, elk (*Cervus elaphus*) were numerous throughout Minnesota but overharvest of populations and habitat modifications by humans extirpated elk from the state by 1900 (Minnesota Department of Natural Resources [MNDNR] 2016). Elk were historically present in Minnesota's prairie and forest transition zone ecosystems and played an important role in the health of those ecosystems (MNDNR 2016). Through human translocation efforts by wildlife agencies and natural immigration of elk from Manitoba, Canada, there are currently about 130 elk in northwestern Minnesota. Therefore, continued presence of elk in these ecosystems has important ecological and intrinsic value. However, the ability of managers to manage habitats for use by elk is hindered by the limited information on elk ecology in northwestern Minnesota. Furthermore, elk in this region currently use a mixture of agriculture and managed lands, which has led to conflicts with agricultural producers and resulted in legislation restricting the size of the elk population (MNDNR 2016). Consequently, management of elk under this context requires analyzing space use and habitat selection by elk to predict where elk-agricultural conflicts, such as crop depredation and damage to fences caused by elk, will likely occur and how to properly mitigate these conflicts.

Elk in North America are mobile animals with large home ranges (Irwin 2002, Raedeke et al. 2002, Rosatte 2016) that select habitats with forest cover, forage, and low road densities for balancing expenditures and food intake, while reducing mortality risks (Baasch et al. 2010, Burcham et al. 1999, Ager et al. 2003, Boyce et al. 2003, Anderson et al. 2005, Beck et al. 2013). However, several studies have suggested that open-canopied vegetation communities used for foraging may be more important to elk than vegetation used for hiding cover (Hebblewhite et al. 2008, Rearden et al. 2011, Lehman et al. 2016). Within agricultural regions, elk are known to select crops that provide higher protein content and digestibility than native grasses and browse (Mould and Robbins 1981, Devore et al. 2016, Smith et al. 2018). For instance, Smith et al. (2018) reported that legumes, consisting as clover (*Trifolium* spp.) and alfalfa (*Medicago sativa*) found in foraging openings were the most consumed forage class for elk in a forest-dominant region of Missouri. Collectively, these studies suggest that elk in northwestern Minnesota may benefit from high quality agricultural forage in juxtaposition with forest cover that provides protection from predators and humans. Indeed, WMAs considered core areas for reintroduced elk in northwestern Minnesota are surrounded by intensively farmed agricultural lands. Consequently, elk in this region exploit agricultural fields close to WMAs, such as those planted with cereal and legume crops.

To improve our understanding of elk spatial and habitat requirements in northwestern Minnesota, we investigated patterns of space use and habitat selection by elk and examined their implications for elk management. To accomplish this, we quantified size of areas used by female elk and described habitats comprising those areas. We then assessed habitat selection by elk by developing resource-selection functions (RSFs) to predict and map the relative probability of habitat use by elk. This information will assist local biologists to manage habitat for elk on public lands and work with agricultural producers to minimize elk-human conflicts (MNDNR 2016).

STUDY AREA

The study area consisted of a 3-county area (Kittson, Marshall, and Roseau) in northwestern Minnesota that encompassed approximately 11,900 km^2 (Figure 1). Currently, about 130 elk reside in this region as 4 distinct sub-groups: the Caribou-Vita herd ranging between the Caribou Wildlife Management Area (WMA) and Vita, Manitoba, Canada; the Grygla herd near the cities of Gatzke and Grygla; the Lancaster North group, north of the city of Lancaster and ranging east toward the Skull Lake WMA; and the Lancaster South group, located south of Lancaster and ranging east into the Percy WMA. Approximately 50% of the land in the 3-county area was privately owned comprising agricultural croplands that were primarily soybeans and wheat interspersed with small amounts of corn, oats, and sunflowers. Approximately 20% of the landscape is forested, comprised mostly of aspen (*Populus tremuloides*), white birch (*Betula papyrifera*), and bur oak (*Quercus macrocarpa*). Other prominent land-cover types were grasslands, small woodlots, and wetlands. The climate of the study area is characterized by short, warm summers and long, cold winters.

METHODS

We captured 20 adult female elk during January 2016 using both net guns and tranquilizer darts fired from a Robinson R-44 helicopter (Cattet et al. 2004). Elk captured via net gun were hobbled and blindfolded, whereas elk captured with immobilizing agents were only blindfolded. Tranquilizer darts were loaded with Carfentanil (3.5 mg) an 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). Each animal was equipped with a global positioning system (GPS) satellite collar (GPS PLUS Iridium collars and GPS Vertex Iridium collars, VECTRONIC Aerospace GmbH, Berlin, Germany) and identifying ear tags (Orange sheep and goat 2” × 7/8” ear tags, Destron Fearing™, Dallas, TX). The GPS collars were equipped with a mortality sensor, very high frequency (VHF) beacon, and remotely triggered and timed-released mechanisms. Hair samples were collected from each elk and archived for future genetic studies. Blood samples were also taken from each elk for detection of diseases and to evaluate pregnancy status. We monitored rectal temperatures throughout processing, and if temperatures exceeded 105°F, a GPS collar was quickly fitted, and the animal was released without further data taken. A wildlife veterinarian was present during all capture operations to prepare tranquilizer darts and to consult the capture crew if an injury occurred. Elk that were darted or those that had visible injures caused by net-gun capture were administer a dose of antibiotic (10 mL LA 200, Wildlife Pharmaceuticals Inc., Windsor, Colorado). This study, including all animal handling methods, was approved by MNDNR and meets the guidelines recommended by the American Society of Mammalogists (Sikes et al. 2011).

Capture myopathy was assessed by monitoring the movement patterns of collared elk using hourly locations for 2 weeks post-capture. We censored from analyses locations collected during this time period. Following the 2-week post-capture period, GPS collars were scheduled to record a location every 4 hours (0:00, 4:00, 8:00, and so on) throughout the year. After every 11^{th} location was stored on the collar, all of the most recent locations were transmitted from the GPS collar to an iridium satellite and then transmitted from the satellite to a computer base station at the Carlos Avery MNDNR Office in Forest Lake, Minnesota.

We estimated home ranges of female elk using dynamic Brownian bridge movement models (dBBMMs). This approach uses time-specific location data to estimate probability of use along the full movement track of each animal that generates a utilization distribution (Kranstauber and Smolla 2013). We used the R package ‘move’ in program R to produce dBBMMs. We used a GPS telemetry error estimate of 20m (Frair et al. 2010) for all locations and a moving window size of 21 with a margin of 7 locations for full movement tracks of each animal. We considered the 95% and 50% contour intervals for elk as home ranges and core areas, respectively. Along with developing composite home ranges and core areas for elk, we developed seasonal ranges for them as well. To reflect anthropogenic effects of agricultural practices on the landscape, we divided each year into 2 6-month seasons based on agricultural activity: growing (1 March–31 August) and non-growing (1 September–28 February). Because our study period was 2 years, we had 4 seasons: 2016 growing season (1 March–31 August), 2016 non-growing season (1 September 2016–28 February 2017), 2017 growing season (1 March–31 August), and 2017 non-growing season (1 September 2017–28 February 2018). We then compared seasonal home ranges and core areas using analysis of variance (ANOVA) and t-tests.

We obtained annual land cover data from the United States Department of Agriculture (USDA) Cropland Data Layers (USDA 2016, USDA 2017). Because modern farming practices involve rotating crops among fields or changing plantings from year to year, we obtained landcover data for 2016–2017 when female elk were radio collared. This allowed us to account for changes in availability of crops in elk home ranges throughout the study period. We collapsed agricultural crops into 6 general agriculture classes with a 30-m resolution: cereal (e.g., barely, corn, oats, rye, sorghum, and wheat), legume (e.g., alfalfa, beans, and peas), hay, fallow fields, sod, and other crops (e.g., canola, flaxseed, flowers, potatoes, and sugarbeets). Because elk are known to use forest edges and water sources (Thomas et al. 1988, Baasch et al. 2010) and avoid roads (Boyce et al. 2003, Anderson et al. 2005, Beck et al. 2013), we also developed agriculture-forest edge, water, and road layers. We created distance raster maps for agriculture classes, agriculture-forest edges (hereafter edges), water, and roads using the 'Euclidean Distance' tool in Spatial Analyst toolbox in ArcGIS 10.6 (Environmental Systems Research Institute Inc., Redlands, California) to calculate the distance from every 30m pixel to the closest landscape feature (Benson 2013). To account for forest cover, we estimated percent tree canopy cover from the United States Geological Survey (USGS) National Land Cover Database (NLCD; USGS 2011).

As suggested by Manly et al. (2002), we followed the Design III (3rd-order selection) to assess the relationship between habitats and elk space use within their home ranges. We used individual elk as our sampling units and measured resource availability for each animal. To estimate resource selection functions (RSFs), we used a binomial approach by comparing characteristics of known locations to 3-times the number of random locations within home ranges of elk (Manly et al. 2002, Little et al. 2016). Because we used distance-based variables to assess habitat selection, we inferred selection for agriculture habitats, edge, water, and roads occurred when known locations were closer to those features than were random locations. Likewise, we inferred avoidance when known locations were farther from those features than were random locations. However, we inferred selection for forest cover when known locations had greater percentage of canopy cover values than did random locations and vice versa for avoidance of forest cover. We used generalized linear mixed models with a logit link in program R to compare habitat selection between growing and non-growing season (R Development Core Team 2013). We included random intercepts for individual elk in each model to account for correlation of habitat use within individuals and the unbalanced telemetry data since individual elk differed in their number of GPS locations. We modeled resource selection using the R package lme4 (Bates et al. 2014) with a binary (0 = random, 1 = known) response variable. Before modeling, we rescaled values for distance-based variables and forest cover by subtracting their mean and dividing by 2 standard deviations (Gelman 2008). We then used Akaike's information criterion adjusted for small sample sizes (AICc) and used ΔAICc to select which models best supported factors influencing habitat selection by elk (Burnham and Anderson 2002). We validated our best model using k-fold cross-validation. We used 10 folds (k = 10) to estimate performance of RSF models.

RESULTS

On average, home-range size (±SD) for female elk in northwestern Minnesota was 50.8 km^2 ± 14.0 and ranged between 21.2 km^2 to 87.7 km^2. Mean home-range size for female elk during our 4 designated seasons (growing 2016, non-growing 2016, growing 2017, non-growing 2017) was

48.5 km^2 ± 13.3 and ranged between 21.1 km^2 to 89.5 km^2 (Table 1). Mean seasonal home ranges for elk differed ($F_{3,70}$ = 5.22, P = 0.003), in which the 2016 growing season home ranges were smaller than those observed for the other 3 seasons (Tukey's test, P < 0.05). No differences in elk home-range sizes were detected among the 2016 non-growing, 2017 growing, and 2017 non-growing seasons (Tukey's test, P < 0.05). Mean home ranges during the 2016 growing season were approximately 23% smaller than those observed for the other 3 seasons.

On average, core-area size (±SD) for female elk in northwestern Minnesota was 7.3 km^2 ± 2.1 and ranged between 1.2 km^2 to 11.6 km^2. Mean core-area size (±SD) for female elk during our 4 designated seasons was 9.2 km^2 ± 2.6 and ranged between 3.2 km^2 to 15.0 km^2 (Table 1). Mean seasonal core areas for elk differed ($F_{3,70}$ = 12.41, P < 0.001), in which growing season 2016 core areas were smaller than those observed for the other 3 seasons (Tukey's test, P < 0.05). No difference in elk core-area sizes were detected among the 2016 non-growing, 2017 growing, and 2017 non-growing seasons (Tukey's test, P < 0.05). Mean core areas during the 2016 growing season were approximately 35% smaller than those observed for the other 3 seasons.

Home ranges and core areas of female elk comprised largely of agriculture and forested habitats (Figure 2). Between the 2016 and 2017 growing seasons, we detected no change in the percentage of cereal (t_{28} = -1.54, P = 0.135), legumes (t_{28} = -0.97, P = 0.343), other crops (t_{28} = 0.607, P = 0.549), sod (t_{28} = 1.23, P = 0.230), fallow fields (t_{28} = -1.64, P = 0.111), and water (t_{28} = 1.485, P = 0.149) in core areas of elk. However, between the 2016 and 2017 growing seasons, we detected differences in the percentage of hay (t_{28} = 6.24, P < 0.001) and forest cover (t_{28} = -1.86, P = 0.073) in core areas of elk. Core areas of elk during the 2017 growing season comprised of more hay (19.5% vs. 3.7%) and slightly less forest cover (30.0% vs. 35.0%) than did core areas during the 2016 growing season. Between the 2016 and 2017 growing seasons, we detected no change in the percentage of legumes (t_{31} = -1.53, P = 0.136), other crops (t_{31} = -1.603, P = 0.119), sod (t_{31} = 0.357, P = 0.723), water (t_{31} = 1.04, P = 0.315), and forest cover (t_{31} = -0.594, P = 0.557) in home ranges of elk. However, between the 2016 and 2017 growing seasons, we detected differences in the percentage of cereal (t_{31} = -3.43, P = 0.002), hay (t_{31} = 5.75, $P < 0.001$), and fallow fields (t_{31} = -2.47, P = 0.020) in home ranges of elk. Home ranges of elk during the 2017 growing season comprised of more hay (20.0% vs. 4.9%) and less cereal (4.5% vs. 8.3%) and fallow fields (0.2% vs. 0.03%) than did home ranges during the 2016 growing season.

When contrasting habitat composition of elk home ranges and core areas, we detected no difference in the percentage of legumes (t_{61} = 0.41, P = 0.687), hay (t_{61} = 0.45, P = 0.656), sod (t_{61} = -0.18, P = 0.860), and fallow fields (t_{61} = 0.33, P = 0.746) comprising those areas. However, we did detect differences in cereal (t_{61} = 2.25, P = 0.028), other crops (t_{61} = 4.60, $P <$ 0.001), water (t_{61} = 1.88, P = 0.065), and forest cover (t_{61} = -4.04, $P < 0.001$) comprising those areas. Core areas of elk consisted of greater proportions of forest cover (32.6% vs. 25.4%) and less cereal (4.5% vs. 6.5%), other crops (0.3% vs. 1.0%), and water (1.9% vs. 2.8%) than did their home ranges.

Except for cereal crops, all landscape features were important for predicting habitat selection by female elk during all 4 seasons (Table 2). Cereal crops were only informative of elk habitat selection during the 2016 growing and 2017 non-growing seasons. Collectively, forest cover, edges, and legumes were selected by elk during all seasons, whereas hay, sod, roads, and water were avoided by elk during the same periods. Except for the 2016 growing season, elk selected fallow fields during each season. Other crops were avoided by elk in all seasons except during the 2016 non-growing season. Spatially, differences in habitat selection revealed substantial heterogeneity in the response of elk to the agriculture-forest habitat matrix of northwestern Minnesota (Figure 3). Our RSFs suggest that elk strongly prefer areas with forest cover and will use agriculture-forest edges to exploit favorable crops such as legumes and cereal, as well as fallow fields. Our *k*-fold cross-validation correctly classified 87% of elk locations for best models selected for each of the 4 seasons.

DISCUSSION

Throughout North America, elk home-range sizes are known to be influenced by many factors, such as forage availability, juxtaposition of resources, cover quality, and human disturbances, and typically vary between 3 km^2 and 245 km^2 (Peek 2003, Anderson et al. 2005, Brook 2010, Rosatte 2016, Gingery et al. 2017). Therefore, it is not surprising that area sizes required by elk to balance energetic demands and to minimize predation risk vary depending on region, habitat quality, and distribution of food and cover resources. In northwestern Minnesota, where elk inhabit managed public and private conservation lands surrounded by large agricultural tracts, we documented seasonal home ranges for female elk ranging between 21.2 km^2 and 87.7 km^2. Seasonal home ranges for elk varied little during our study, with an average size of 48.5 km^2. Relative stability in the size of seasonal home ranges of elk in this region may result from elk congregating in small groups as non-migratory herds in forests. Additionally, home ranges for elk are generally smaller where forage is abundant and the combined use of forest habitats and agricultural fields by elk may provide enough year-round forage and protective cover to meet the life requisites of elk in the region.

In concert with size, habitat composition of elk home ranges has important implications for understanding why elk select areas to exploit resources. Most female elk in our study maintained annual home ranges of approximately 50 km^2, in which 50.4% of their home ranges consisted of agricultural fields. The predominant crop type found within elk home ranges was legumes (29.5%), followed by hay (12.3%) and cereal crops (6.5%). The remaining habitat types in elk home ranges consisted of forests (25.4%), open grasslands (21.4%), and water (2.8%). Although modern farming practices involve rotating crops among fields or changing plantings from year to year, we detected little change in the proportion of crop types in elk home ranges and core areas between the 2016 and 2017 growing seasons. Despite their moderate size and relative spatial stability, elk home ranges in northwestern Minnesota are likely large enough to accommodate rotating crops without loss of availability of important agricultural forage such as legumes and cereal crops. Additionally, female elk incorporated more forest cover in their core areas than they did agricultural habitats indicating that agriculture was predominately used as foraging areas. As noted in other studies, elk inhabiting agricultural landscapes strongly selected forage crops at the scale of the home range, but not at the parturition site (Brook 2010). Therefore, the close association of forest cover with core areas reflects the requirements for greater security and greater levels of hiding cover for elk in agricultural landscapes.

Relationships between agriculture and forest habitat and elk space use in northwestern Minnesota were similar to those reported for studies in other regions of North America and indicated the juxtaposition of forest habitats and agricultural habitats provide elk edge habitat, where quality forage and forest cover are in proximity (Sawyer et al. 2007, Baasch et al. 2010, Brook 2010, DeVore et al. 2016). Recently, Smith et al. (2018) reported that elk in Missouri selected grains and cool-season grasses over all other available forage during their study. They also noted that elk in their study exploited cultivated species in managed forage openings. Similarly, elk in our study area strongly selected for forest cover and forest edge to center their home ranges on while selecting fields planted for legumes (e.g., soybean and alfalfa fields) and, to a lesser extent, fallow and cereal fields, for foraging areas when they were adjacent to forest habitats. Indeed, elk typically remained close (<100 m) to forest cover when using agricultural fields, a behavior observed in other studies (Thomas et al. 1988, Baasch et al. 2010). Elk avoided hay, sod, roads, water, and, to a lesser extent, other crops. It is not surprising that elk avoided roads, as this behavior is commonly reported in studies and associated with avoidance of humans (Frair et al. 2008, Montgomery et al. 2013, Prokopenko et al. 2017). We suspect hay and sod farms provide elk poor foraging opportunities and little cover, especially for female elk and their calves. Water in this region is not a limiting resource and we suspect elk avoidance of water was strongly associated with elk not using large bodies of water (e.g., Thief Lake) as habitat in our analyses.

Our models suggest that elk altered their selection of habitats between growing and non-growing seasons. Most notably, elk exhibited stronger selection for forest cover, edges, and fallow fields during the non-growing season than they did in the growing season, as well as a weaker selection for legumes. As elk decreased selection for legumes during the non-growing season, they also decreased avoidance of hay and sod, other crops, roads, and water. Because elk in this region belong to a non-migratory population that is hunted, it is reasonable to assume that increased selection for forest cover and remaining close to forest habitats is a response by elk to both increasing human activity and the loss of agricultural forage during the non-growing season. During this time, elk also appear to compensate for the loss of favored crops, such as legumes, by selecting for fallow fields that likely offer foraging opportunities for grasses and forbs. Furthermore, substantial loss of agricultural forage and cover may force elk to be less selective during the non-growing season and exploit road and water edges to find additional forage.

Several studies reported that distance to roads did not influence elk selection of resources, if roads were in preferred habitats and experienced low traffic (Anderson et al. 2005, Baasch et al. 2010).

Legumes, fallow fields, and cereal represented important agricultural habitat for female elk in northwestern Minnesota. The strong selection by elk for legumes and cereal was expected for 2 reasons. First, approximately 75% of all crops in the region consisted of legumes (44%) and cereal (31%) and were more likely to be the dominant crop type juxtaposed with important forest habitat which is favored by elk. Second, because legumes and cereal have greater dietary protein and digestible energy relative to native vegetation (Burcham et al. 1999), these crops likely meet the energetic requirements of females during lactation and recovery from gestation during the post-calving season. Therefore, our analysis suggests that female elk selected foraging patches with forage of greater dietary protein and greater forest cover further from roads during the agricultural growing season, which coincides with the elk pre-parturition, parturition and post-parturition seasons. Presumably, combined use of forest cover and agricultural habitats offer protection from predators and humans and may allow for reduced vigilance and more-efficient foraging by female elk and their calves (Hernández and Laundré 2005, Seidel and Boyce 2015).

MANAGEMENT IMPLICATIONS

Since restoration efforts began in the early 1900s, several elk herds became established in northwestern Minnesota through translocations and natural immigration from Canada. These herds have established non-migratory ranges to which they use agricultural habitats adjacent to public WMAs and private natural areas. Management of elk in this agro-forest landscape will require understanding resource use by elk for managing herds that use a combination of public and private lands. If agencies want to enhance elk habitat on WMAs through habitat improvement projects, we suggest that managers consider the juxtaposition of agricultural habitat with forested habitat on WMAs favored by female elk. Currently, many managers improve habitat for elk through burning, thinning, and brush removal (Lyon and Christensen 2002) and we recommend the use of these practices to provide enough heterogeneity in habitat conditions across WMAs to provide greater hiding cover and open foraging areas on lands specifically managed for elk restoration. Furthermore, DeVore et al. (2016) suggested that forest management practices to improve elk habitat could target invasive species to address problems of invasive species while managing habitat for elk. We suggest that managers should concentrate thinning of hiding cover and canopy on the edges of WMAs and agricultural fields to discourage use of those fields, while planting forage openings on WMAs with legumes and other high-quality forage to extend elk calving areas further into WMAs and away from adjacent agricultural lands. If future management actions are taken to improve elk habitat for use during their calf-rearing season, the foraging needs of female elk and their calves should be considered so that most of their life requisites are achieved on WMAs rather than adjacent agricultural lands.

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Associate Editor:

FIGURE CAPTIONS

Figure 1. Northwestern Minnesota study area where we studied space use and habitat selection by elk during 2016–2017. Locations of elk herds are denoted by the polygons in the figure, which represent minimum convex polygons of telemetry fixes from GPS-collared female elk.

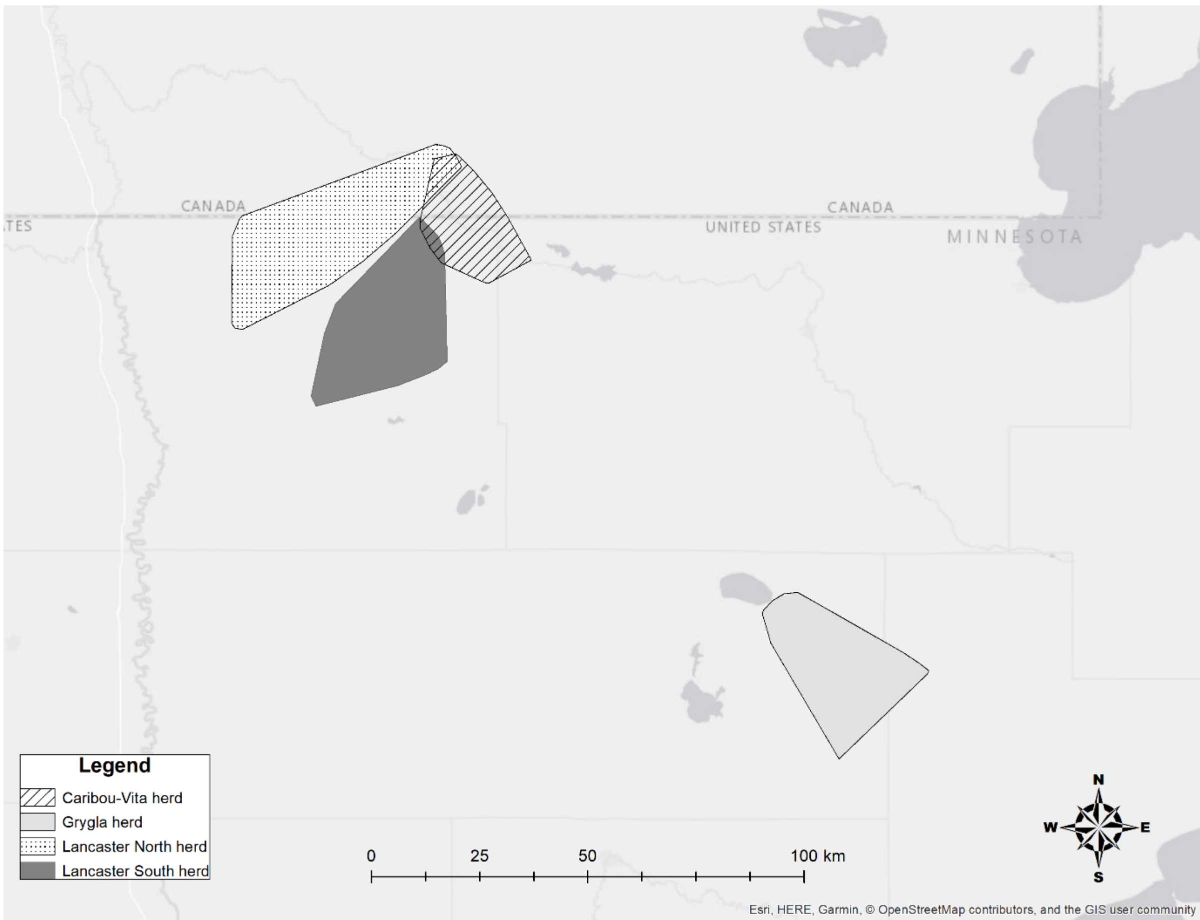


Figure 2. Habitat proportions of home ranges (HR) and core areas (CA) of female elk in northwestern Minnesota during 2016–2017.

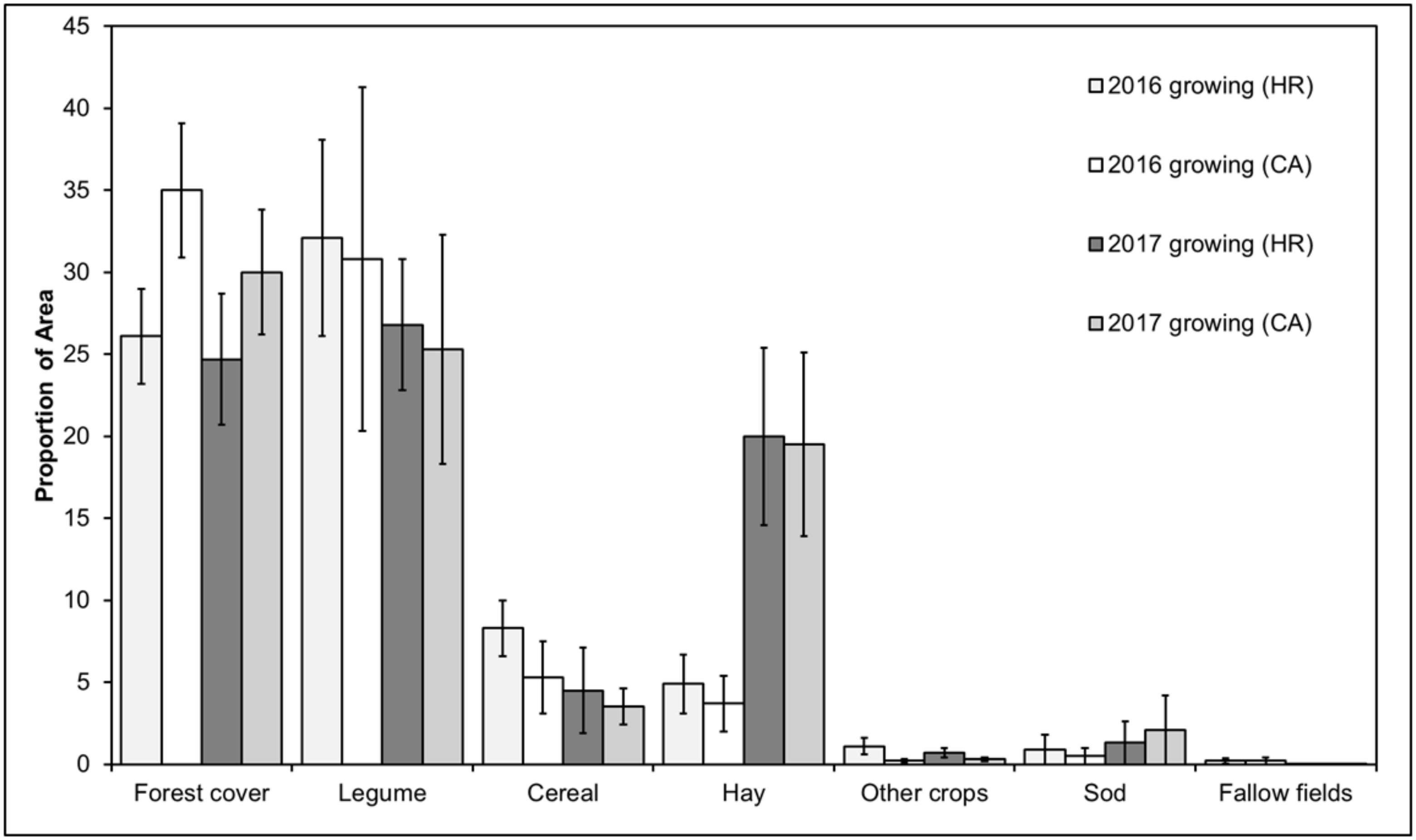
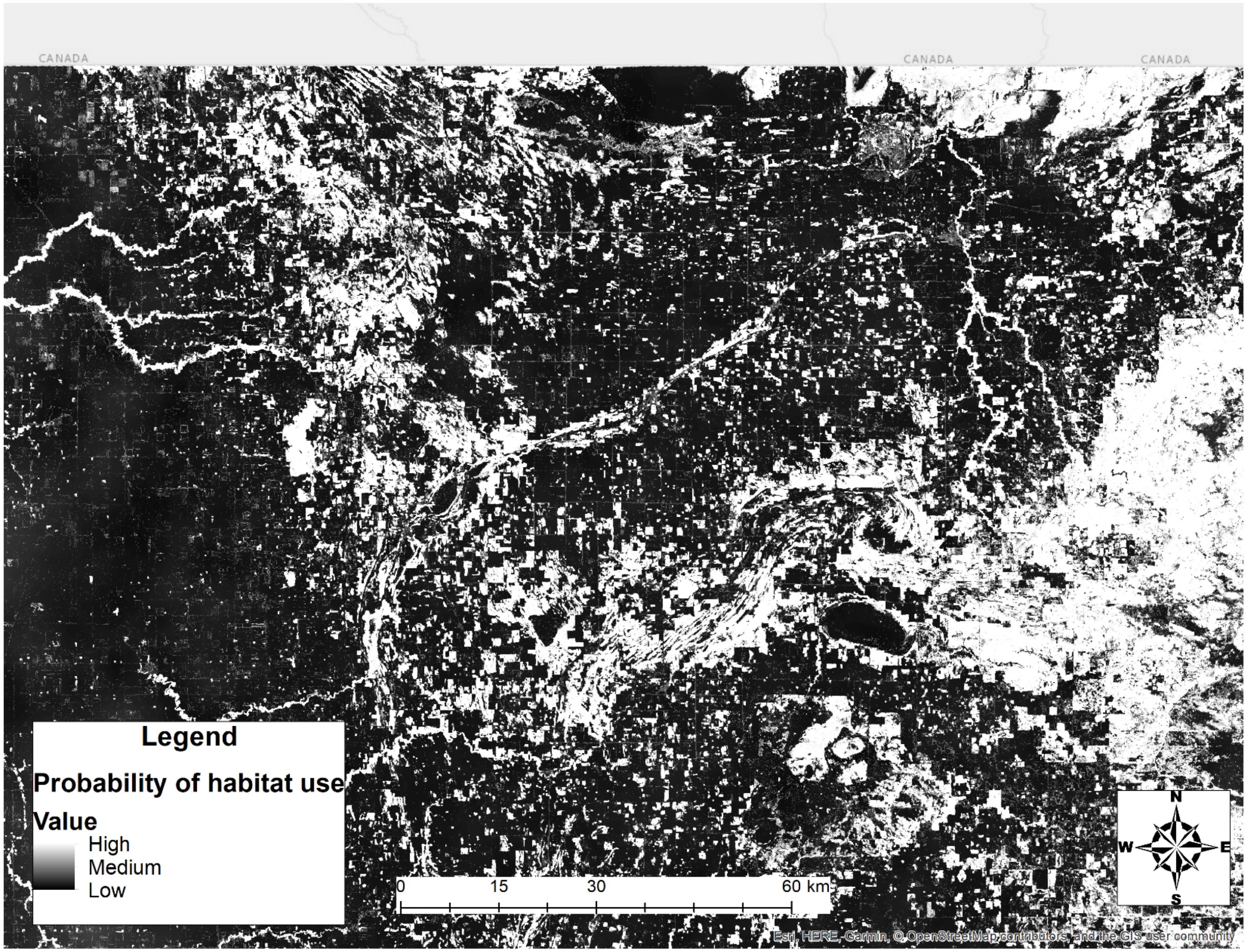


Figure 3. Relative probability of 3rd-order habitat selection by non-migratory female elk in northwestern Minnesota during 2016–2017.



TABLES

Table 1. Mean (± SD) home-range and core-area sizes of female elk in northwestern Minnesota during 2016–2017.

Season	Home range[3] (km^2)	Range of home ranges (km^2)	Core area[4] (km^2)	Range of core areas (km^2)
2016 growing[1]	39.4 ± 8.2	21.1–51.5	6.7 ± 2.1	3.2–10.9
2016 nongrowing[2]	53.2 ± 13.7	24.0–82.2	10.4 ± 2.3	5.4–15.0
2017 growing	50.7 ± 12.0	23.0–77.1	10.0 ± 2.1	5.1–14.0
2017 nongrowing	51.7 ± 14.5	38.6–89.5	10.1 ± 2.0	7.6–14.7

[1]Growing season space use was defined as areas used during March through August.

[2]Harvest season space use was defined as areas used during September through February.

[3]95% probability contour calculated from dynamic Brownian bridge movement models used to estimate the sizes of resident home ranges and transient ranges.

[4]50% probability contour calculated from dynamic Brownian bridge movement models used to estimate the sizes of resident core areas and transient biding areas.

Table 2. Summary of generalized linear mixed models for predicting seasonal 3rd-order habitat selection by female elk in northwestern Minnesota, 2016–2017. Shown are Akaike's Information Criteria for small sample sizes (AIC_c) and differences among AIC_c (ΔAIC).

Season	Model	*k*	Deviance	ΔAIC_c	ω_i
2016 growing	Full model	12	67,804	0.0	1.00
	FC[1]+FE[2]+RD[3]+WT[4]+CR[5]+HY[6]+LG[7]+OC[8]+SD[9]	11	67,864	60.1	0.00
	FC+FE+RD+WT+CR+HY+LG+SD+FF[10]	11	67,886	82.3	0.00
2016 nong-rowing	FC+FE+RD+WT+HY+LG+OC+SD+FF	11	55,295	0.0	0.70
	Full model	12	55,296	1.9	0.27
	FC+FE+WT+HY+LG+OC+SD+FF	10	55,301	6.6	0.03
2017 growing	FC+FE+RD+WT+HY+LG+OC+SD+FF	11	81,253	0.0	0.73
	Full model	12	81,255	2.0	0.27
	FC+FE+RD+WT+LG+OC+SD+FF	10	81,292	38.3	0.00
2017 non-growing	Full model	12	75,596	0.0	1.00
	FC+FE+RD+WT+HY+LG+OC+SD+FF	11	75,613	16.9	0.00
	FC+FE+RD+CR+HY+LG+OC+SD+FF	6	75,702	106.3	0.00

[1] Forest cover [2] Agriculture-forest edge [3] Roads [4] Water [5] Cereal [6] Hay [7] Legume [8] Other crops [9] Sod [10] Fallow field

Table 3. Parameter estimates for 3rd-order resource selection functions for radio-collared female elk in northwestern Minnesota during 2016–2017. Shown are β coefficients, standard error (SE), 95% confidence intervals (CI), *z*-scores, and *P*-values.

Season	Model variables	β	SE	*z*	*P*
2016 growing	Intercept	-1.068	0.109	-9.83	<0.001
	Forest cover	0.419	0.010	43.88	<0.001
	Agriculture-forest edge	-0.163	0.010	-12.95	<0.001
	Roads	0.289	0.012	23.29	<0.001
	Water	0.420	0.015	28.69	<0.001
	Cereal	-0.189	0.015	-12.95	<0.001
	Hay	0.241	0.013	18.94	<0.001
	Legume	-0.329	0.016	-20.71	<0.001
	Other crops	0.158	0.017	9.15	<0.001
	Sod	0.155	0.012	13.12	<0.001
	Fallow field	0.179	0.023	7.90	<0.001
2016 non-growing	Intercept	-1.278	0.035	-36.98	<0.001
	Forest cover	0.529	0.010	53.68	<0.001
	Agriculture-forest edge	-0.196	0.013	-15.59	<0.001
	Roads	0.041	0.014	2.94	0.003
	Water	0.133	0.015	9.08	<0.001
	Hay	0.121	0.014	8.44	<0.001

	Legume	-0.083	0.016	-5.06	<0.001
	Other crops	-0.097	0.019	-5.16	<0.001
	Sod	0.221	0.014	16.27	<0.001
	Fallow field	-0.167	0.025	6.69	<0.001
2017 growing	Intercept	-1.123	0.046	-24.39	<0.001
	Forest cover	0.395	0.009	45.37	<0.001
	Agriculture-forest edge	-0.294	0.011	-25.70	<0.001
	Roads	0.406	0.010	37.31	<0.001
	Water	0.326	0.013	24.90	<0.001
	Hay	0.080	0.013	6.37	<0.001
	Legume	-0.358	0.014	-26.04	<0.001
	Other crops	0.102	0.011	9.13	<0.001
	Sod	0.143	0.013	11.18	<0.001
	Fallow field	-0.113	0.013	-8.83	<0.001
2017 non-growing	Intercept	-1.129	0.024	-47.06	<0.001
	Forest cover	0.492	0.009	56.97	<0.001
	Agriculture-forest edge	-0.239	0.012	-20.88	<0.001
	Roads	0.179	0.013	14.26	<0.001
	Water	0.139	0.013	10.69	<0.001
	Cereal	-0.063	0.015	-4.33	<0.001

Hay	0.141	0.013	11.26	<0.001
Legume	-0.309	0.015	-21.27	<0.001
Other crops	0.157	0.011	14.37	<0.001
Sod	0.353	0.013	27.62	<0.001
Fallow field	-0.183	0.012	-15.01	<0.001