M.L. 2015 Project Abstract
For the Period Ending June 30, 2018

PROJECT TITLE: Movement and Seasonal Habitat Use of Minnesota Elk
PROJECT MANAGER: Lou Cornicelli
AFFILIATION: Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Wildlife
MAILING ADDRESS: Minnesota Department of Natural Resources
CITY/STATE/ZIP: 500 Lafayette Rd., St. Paul, MN 55155
PHONE: 651-259-5202
E-MAIL: lou.cornicelli@state.mn.us
WEBSITE: http://www.dnr.state.mn.us/wildlife/index.html
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2015, Chp. 76, Sec. 2, Subd. 03k

APPROPRIATION AMOUNT: $200,000
AMOUNT SPENT: $198,425
AMOUNT REMAINING: $1,575

Overall Project Outcome and Results

The results of this study represent some of the first scientific knowledge of elk in Minnesota. By monitoring 20 adult female elk for 2 years, we were able to characterize the extent to which the 4 subgroups of elk in northwestern Minnesota utilize the landscape. Additionally, we identified habitats preferred by elk across seasons. Annual home ranges of elk were large, ranging from 71 km^2 and 112 km^2. Seasonal home ranges for elk varied little during our study, with an average size of 48.5 km^2. Elk primarily selected for forested habitats, particularly on Wildlife Management Areas. Elk utilized open areas in close proximity to forested cover, including agricultural crops such as legumes and cereal grains, and fallow fields. Based on the movements of GPS-collared elk, female elk do not interact with other females outside of their distinctive subgroups. Elk in northwestern Minnesota are non-migratory and maintained home ranges in the same general areas across the 2 years we monitored them. Our results provide specific information about the locations and movements of elk in Minnesota and habitats preferred by the species. This knowledge will enable managers to direct management to improve habitats most likely to be used by elk. Such efforts will improve the condition of elk and aid in minimizing elk-human conflicts.

Project Results Use and Dissemination

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2015 Work Plan

Date of Report: December 31, 2018

Date of Next Status Update Report: Final Report

Date of Work Plan Approval: June 25, 2015

Project Completion Date: June 30, 2018

Does this submission include an amendment request? No

PROJECT TITLE: Movement and Seasonal Habitat Use of Minnesota Elk

Project Manager: Lou Cornicelli

Organization: Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Wildlife

Mailing Address: Minnesota Department of Natural Resources

City/State/Zip Code: 500 Lafayette Rd., St. Paul, MN 55155;

Telephone Number: 651-259-5202

Email Address: lou.cornicelli@state.mn.us

Web Address: http://www.dnr.state.mn.us/wildlife/index.html

Location: The project will be conducted in the Minnesota counties of Beltrami, Kittson, Marshall, and Roseau.

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$200,000**
	Amount Spent:	**$198,425**
	Balance:	**$1,575**

Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 03k

Appropriation Language:
$200,000 the first year is from the trust fund to the commissioner of natural resources to collect biological information about Minnesota elk, including movements and habitat use to enable long-term, sustainable management. This appropriation is contingent on a $50,000 match from state or non-state sources. This appropriation is available until June 30, 2018, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Movement and Seasonal Habitat Use of Minnesota Elk

II. PROJECT STATEMENT: Elk (*Cervus elaphus*) were numerous across the Minnesota prairie and forest transition zone prior to settlement by Europeans. Due mainly to conversion of habitat to agriculture and over-exploitation, elk were extirpated from Minnesota by the early 1900s. Through restoration efforts and immigration, there are currently about 150 elk in northwest Minnesota (Figure 1). The primary objective of this study is to provide baseline information necessary to efficiently accelerate management of elk and their habitats for future enhancement of elk in the state. We will affix Global Positioning System (GPS) collars to 20 adult elk and study their movements and preferences for habitats. This study will provide the first information collected about movements, home ranges, and habitat use by elk in Minnesota. A two-pronged approach, including spatial analysis of elk movements and direct measurement of habitat characteristics, is necessary to classify fine-scale habitats preferred by elk in Minnesota. This information will enable MNDNR to improve management practices and to identify additional patches of habitat likely to be used by elk, which may be managed to aid in enhancing the population size and range extent of elk in the future. The goals of this project are to: 1) describe the home range sizes and movements of adult elk, and 2) characterize seasonal habitat use of elk at the landscape level and identify fine-scale habitat features preferred by elk. These data will inform future management of the population and will help design strategies to improve the habitats essential to elk. In subsequent research, MNDNR will use data generated in the proposed study to develop landscape level maps with Global Information Systems (GIS) to identify additional areas ideal for improving elk habitats to promote the enhancement of elk numbers and their range extent.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of January 1, 2016: In collaboration with researchers from Minnesota State University-Mankato, we have recruited a Masters student to work on the project. The detailed methods for the study are being solidified in the graduate student's research proposal. MNDNR staff are preparing to capture 20 adult female elk in February 2016. A contract to capture elk was awarded through a competitive bid process to a company, which is highly experienced in the capture and handling of elk. GPS collars are being manufactured and tested. MNDNR staff from research, operations, information technology, and information and education are completing additional logistical tasks associated with the elk capture event.

Project Status as of July 1, 2016: In a highly collaborative effort, we captured 20 adult female elk, affixed GPS collars on the animals, and began collecting their locations via satellites. We are monitoring their movements, delineating seasonal home ranges, and have begun vegetation surveys. The elk are generally segregated among 4 distinct herds, which we describe as the Caribou-Vita, Lancaster north, Lancaster south, and Grygla subgroups. We are actively communicating with private landowners in the elk range to gain access to their properties for vegetation sampling. The Nature Conservancy is also cooperating to allow access to their landholdings and to communicate with us about their habitat management practices. There is continued interest in the project from the public, and we have periodically provided updates to private citizens, our partners, and the media upon request.

January 1, 2017 -Amendment request to change the project manager to Lou Cornicelli to replace Gino D'Angelo. Amendment approved by LCCMR 1-18-17.

Project Status as of January 1, 2017: The Masters student's research proposal was completed and will be published in the 2016 MNDNR Wildlife Research Summaries. Early results and vegetation sampling methods were presented at the July Minnesota DNR Region 1 meeting, as well as an August meeting between three elk projects that were started concurrently in Minnesota and North Dakota, USA and Manitoba, Canada. Vegetation sampling was completed on August 17th, totaling 500 plots. These data are currently being organized for analysis. We are continuing to delineate seasonal home ranges and movement patterns for each of the 4 subgroups of elk. These subgroups have continued to remain separate with no overlap among the subgroups.

The graduate student has begun preparations to create a more recent and accurate land cover classification map for the study area. This will be used to better analyze habitat use.

Project Status as of July 1, 2017: No update required.

Amendment Request as of January 1, 2018: We request an amendment to reallocate funds that were unspent and totaled $25,764 from three aspects of the project in Activity 1: 1) through a competitive bid process, we saved $17,500 on elk capture; 2) we refurbished GPS collars owned by MNDNR from a previous project and saved $5,716; 3) we utilized sampling equipment from other MNDNR projects and used funding provided by MNDNR to purchase supplies which left unspent $2,548 for equipment and supplies. We request permission to reallocate the unspent funds from Activity 1 to Activity 2. We propose to use $24,813 to sub-contract the services of a post-doctoral researcher (4.5 months, 75% salary, 25% benefits) to conduct specialized analyses of seasonal habitat use of adult elk (i.e., revised activity 2 budget). This will require integrating GPS locations of elk with spatial data about habitat collected in the field and remotely sensed land cover data to improve understanding of detailed habitat selection of elk during the growing season. We request to allocate the remaining $951 of unspent funding in Activity 1 to data acquisition fees in Activity 2 to allow for continuation of data collection until June 30, 2018 to gain additional information about seasonal habitat use by elk.

Amendment Approved by LCCMR 1/8/2018

Project Status as of January 1, 2018: We defined biologically relevant seasons for elk in Minnesota based on their movements and created home ranges for the first full year. Analysis on the fine-scale habitat data was published in the 2016 MNDNR Wildlife Research Summaries. We are now focusing on analyses of landscape-level assessment of habitat use. For this purpose, more data is being assembled with the intention of using Resource Selection Functions to analyze landscape-level habitat use. The 2016 Cropland Data Layer (CDL) was found to be the most recent landcover classification available. The 2017 CDL will also be used once it has been published in early February 2018. We continue to investigate how seasons and habitats influence elk use of the landscape in northwest Minnesota.

Amendment Request as of June 30, 2018: We request a no-cost extension of the project timeline to December 31, 2018. We identified additional avenues of analysis for the elk movement data, which require extended computer processing time. We also extended the collection of elk location data through the spring as requested in the amendment approved by LCCMR on 01/08/2018. In light of these developments, the Masters student will need more time to complete analyses and the writing of her thesis. Following the amendment request, we also moved forward with the development of an agreement with University of Georgia for a post-doctoral researcher to conduct specialized analyses of seasonal habitat use by elk. The contracting process was lengthy, the contract was not awarded until April 12, 2018, and ultimately delayed the start of work. We respectfully request this extension to deliver the final project report and associated deliverables, including the manuscript developed from the work of the post-doctoral researcher, by December 31, 2018.

Amendment Approved by LCCMR 6/29/18: We approve extending the time for you to provide the final report to the LCCMR from August 15, 2018 until December 31, 2018. We understand that all efforts on the project between June 30, 2018 and December 31, 2018 will be done with other funding sources.

Project Status as of June 30, 2018: We continue to conduct analyses for the 2 full years of elk movement data. The Masters student is continuing to write her thesis as analyses are completed. The members of the project team are providing regular input to improve the deliverables. We executed the contract with the University of Georgia for a post-doctoral researcher to analyze fine-scale habitat use of elk during the growing season. We are in the process of compiling and transferring data to the researcher.

Overall Project Outcomes and Results: The results of this study represent some of the first scientific knowledge of elk in Minnesota. By monitoring 20 adult female elk for 2 years, we were able to characterize the extent to which the 4 subgroups of elk in northwestern Minnesota utilize the landscape. Additionally, we identified habitats preferred by elk across seasons. Annual home ranges of elk were large, ranging from 71 km^2 and 112 km^2. Seasonal home ranges for elk varied little during our study, with an average size of 48.5 km^2. Elk primarily selected for forested habitats, particularly on Wildlife Management Areas. Elk utilized open areas in close proximity to forested cover, including agricultural crops such as legumes and cereal grains, and fallow fields. Based on the movements of GPS-collared elk, female elk do not interact with other females outside of their distinctive subgroups. Elk in northwestern Minnesota are non-migratory and maintained home ranges in the same general areas across the 2 years we monitored them. Our results provide specific information about the locations and movements of elk in Minnesota and habitats preferred by the species. This knowledge will enable managers to direct management to improve habitats most likely to be used by elk. Such efforts will improve the condition of elk and aid in minimizing elk-human conflicts.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Describe home range sizes and movements of adult elk.

Description: Beginning in January 2016, we will capture 20 adult elk and fit them with GPS collars. We will set GPS collars to collect multiple daily locations of elk for one year. GPS collars will be programmed to obtain locations approximately every 2-4 hours. Locations will be automatically downloaded from Iridium satellites. We will segregate locations into discrete seasonal periods to determine home range sizes of elk and core areas of use during biologically critical time periods of the year, including pre-parturition, parturition, post-parturition, breeding, and post-breeding. We will calculate the size and spatial orientation of home ranges, and we will use a subset of clustered locations to develop core areas. Additionally, we will examine shifts in home ranges, changes in core areas of use among seasons, and spatial overlap among collared study animals.

Summary Budget Information for Activity 1:	**ENRTF Budget:**	**~~$151,089~~ $127,873**
	Amount Spent:	**$126,492**
	Balance:	**$1,430**

Outcome	**Completion Date**
1. Capture 20 adult elk and fit with GPS collars	3/15/2016
2. Complete collection of location data from collared elk	3/15/2017
3. Analyze locations to determine annual home ranges, seasonal home ranges, and movement patterns	9/30/2017
4. Report findings	~~6/30/2018~~ 12/31/2018

Activity Status as of January 1, 2016: Preparations for the elk capture event are progressing, and weather depending, elk will be captured during February 15-26, 2016. The Master student, Alicia Freeman, is finalizing her research proposal, which includes methods for analyzing elk home ranges and movements. As collars are received from the manufacturer, we are programming and testing them to ensure proper functionality before deployment on elk. MNDNR Area Staff began securing permissions from private landowners to capture elk on their properties. MNDNR submitted a grant proposal to Rocky Mountain Elk Foundation, and an additional $10,000 will be provided by the organization to cover the costs of veterinary care and chemical immobilization drugs.

Activity Status as of July 1, 2016: During February 2016, we conducted elk capture, which was coordinated by MNDNR research and included assistance from MNDNR operations and law enforcement, staff from the Fond du

Lac Band of Lake Superior Chippewa, the Minnesota Zoo, and Kiwi Air. A total of 21 adult female elk were captured via netgunning and tranquilizer darting during a 3-day capture operation. Seventeen adult female elk were collared in Kittson County and 3 elk were also collared in Marshall County near Grygla. One elk was fatally injured during capture, and was submitted for necropsy to the veterinary diagnostic lab at the University of Minnesota. The animal was healthy with no abnormalities noted. Currently, all 20 collared elk are alive and their collars are functioning normally. We have begun delineating seasonal home ranges and movement patterns for each elk using GIS. No mixing of the 4 subgroups of elk has been observed. Analysis of movement data has revealed some interesting movement patterns, which likely indicate calving activity.

Activity Status as of January 1, 2017: To quantitatively analyze the home ranges and movements of the collared elk, the graduate student is testing 2 software programs. ArcMET is a program created for the purpose of analyzing GPS collar data, and Spatial Ecology is a commonly used program for analyzing home range and movement data. A mortality signal was detected from one of the collars, and confirmed by local MNDNR management staff. The carcass of the elk and collar were recovered, and the elk was submitted for necropsy to the University of Minnesota veterinary diagnostic lab. The cause of death was determined to be parasitic liver flukes. The recovered collar will be used for further accuracy testing based on some anomalies observed over the summer. The other 19 elk are alive and 18 collars are functioning normally. One collar is no longer sending VHF signals but is still sending regular GPS locations. Some behavioral differences can be distinguished between summer and winter movement data.

Activity Status as of July 1, 2017: No update required.

Activity Status as of January 1, 2018: We created seasonal home ranges that show how elk use of the landscape changes throughout the year. To create and quantitatively analyze elk home ranges, we have chosen to use the programs ArcMET and R. ArcMET is useful for creating home ranges using the Brownian Bridge Movement Model method. Currently there are 17 collared elk still alive on the project. A second collared elk died of from complications during parturition, specifically a ruptured bladder. No elk calf was seen by the local management staff at the site of the mortality. Hunting tags for elk cows were given out this year. Area management staff requested that the hunters avoid collared animals, however, one elk cow tag was filled by a collared cow. The hunter willingly returned the collar, and gave as much information on the situation as he could remember. The rest of the 17 collared cows are continuing to move normally. All collars are continuing to function normally and collect GPS locations. One collar has a faulty VHF beacon, but it does not affect the GPS function.

Activity Status as of June 30, 2018: We completed data collection for the 17 collared elk remaining on the project. We attempted to use remote triggering to drop collars off of elk from aircraft and on the ground. We successfully dropped 15 of 17 collars, enabling downloading of all data, including those points not previously transmitted to satellites. Additional attempts are currently being made to retrieve the other 2 collars. All data have been integrated into analyses of seasonal home ranges.

Final Report Summary: We collected 2 years of locational data from 20 adult female elk in northwestern Minnesota, including 17 elk which survived and possessed functioning collars throughout the entire study. Three elk died during the study, however the data from deceased elk were utilized for analyses during the time periods when they were alive. Elk in Minnesota do not exhibit significant migratory behavior. The adult female elk we monitored maintained annual home ranges typical in size for the species, averaging between 71 km^2 and 112 km^2. We found elk had high fidelity for the areas they used both annually and seasonally. Seasonal home ranges averaged 48.5 km^2 and ranged between 21-88 km^2. The female elk we monitored remained in their respective 4 sub-groups and we did not observe interactions among sub-groups.

ACTIVITY 2: Evaluate seasonal habitat use of adult elk.

Description: Within each seasonal core area for individual elk, we will select randomly 5 location points recorded by GPS collars to sample habitat characteristics. At each sampling point, we will center a sampling array oriented to a randomly generated azimuth. Sampling arrays will be sampled once during the growing season. Procedures will generally follow previously established methods for elk habitat evaluations.

Within each sampling plot, the following variables will be recorded: 1) woody seedlings-species and height; 2) percent cover of bare ground, litter, forbs, grasses, woody vegetation or other conditions to be described; 3) biomass of herbaceous plants by species, 4) percent plant cover in vertical zones, 5) canopy coverage, and 6) a record all trees and shrubs by species and diameter at breast height.

Summary Budget Information for Activity 2:

ENRTF Budget:	**~~$48,911~~ $72,127**
Amount Spent:	**$71,982**
Balance:	**$145**

Outcome	Completion Date
1. Determine landscape-level habitats used by elk	9/30/2017
2. Characterize fine-scale habitat features preferred by elk	3/15/2018
3. Report findings and make recommendations	~~6/30/2018~~ 12/31/2018

Activity Status as of January 1, 2016: We are finalizing the methods to be used to evaluate the seasonal habitat use of elk, but no other work was conducted for this activity.

Activity Status as of July 1, 2016: Using seasonal home ranges delineated for elk, we are beginning to analyze landscape-level habitat use of elk via GIS. The fine-scale vegetation sampling methods were finalized. We began field surveys to measure habitat features at locations used by elk and at a selection of random locations not used by elk within the same habitat types. Vegetation sampling is being conducted on public and private lands where permission was obtained, and will continue throughout summer 2016.

Activity Status as of January 1, 2017: The data from the completed fine-scale vegetation sampling is currently being organized to analyze differences between elk-determined locations and random locations. This information will be shared on a poster at two professional conferences in February 2017. More accurate landcover maps are being created using aerial photography remote sensing habitat classification techniques, for analyzing both fine-scale and landscape-level habitat use.

Activity Status as of July 1, 2017: No update required.

Activity Status as of January 1, 2018: The home ranges created for Activity 1 will be used as boundaries for Activity 2. We are working to describe the habitats within these home ranges and we will use Resource Selection Functions (RSFs) to analyze how elk use different habitats. We compiled different habitat layers for the RSFs, and we are developing methods to extract metrics for elk use of different habitats.

Activity Status as of June 30, 2018: We are utilizing all elk locations collected and the habitat layers we compiled to evaluate landscape-level habitat use, and fine-scale habitat use of elk during the growing season.

Final Report Summary: Elk primarily utilized forested habitats and agricultural fields and fallow fields adjacent to forest edges. Regarding agricultural crops, elk selected for legumes, hay, and cereal grains, particularly adjacent to Wildlife Management Areas and other natural cover types. During the non-growing season, elk shifted their use of habitats to forest cover, edges, and fallow fields. At the fine-scale structural level, elk selected for areas with denser canopy cover and less visual cover. Elk avoided hay, sod, roads, and water. Elk

likely avoided roads to minimize interactions with humans. 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.

V. DISSEMINATION:

Description: The results of the study will be reported in the MNDNR Summaries of Wildlife Research Findings, in a Master's thesis, in a peer-reviewed scientific journal, and in professional presentations at conferences. Also, the results will be shared with MNDNR area wildlife managers via summary reports and direct consultation. Working with the MNDNR Office of Communications and Outreach, we will publicize widely to the public about the progress and findings of the research.

Status as of January 1, 2016: We have presented information about the study in several internal MNDNR meetings, at public information events, and in interviews with the media (please see below).

Status as of July 1, 2016: The study continues to attract regular media attention and project partners have conducted numerous interviews with the media. The project proposal and some early observations about elk movements will be published in the MNDNR summary of research findings.

Publications:

Publication outlet	Title	Authors
Summary of wildlife research findings. Division of Fish and Wildlife, Minnesota Department of Natural Resources, St. Paul, Minnesota	Seasonal home ranges, movements, and habitat use of female elk in northwest Minnesota	Alicia E. Freeman, Gino J. D'Angelo, John D. Krenz

Presentations:

Event	Topic	Presenters
MNDNR Region 1 Wildlife Meeting, Bemidji, MN	Overview of elk movements study	Gino D'Angelo
MNDNR Section of Wildlife, Wildlife School, Camp Ripley, MN	Overview of elk movements study	Gino D'Angelo
Elk management plan public meeting, New Brighton, MN	Overview of elk movements study	Alicia Freeman
Elk management plan public meeting, Lancaster, MN	Overview of elk movements study	Alicia Freeman
Elk management plan public meeting, Grygla, MN	Overview of elk movements study	Alicia Freeman
Midwest Fish and Wildlife Conference, Lincoln, NE; February 7, 2017	Seasonal home ranges, movements, and habitat selection of female elk in northwestern Minnesota	Alicia Freeman
Minnesota Chapter of The Wildlife Society, Callaway, MN; February 15, 2017	Seasonal home ranges, movements, and habitat selection of female elk in northwestern Minnesota	Alicia Freeman
Minnesota State University-Mankato Biology Seminar Series, Mankato, MN; March 24, 2017	Seasonal home range and fine-scale habitat selection of female elk in northwestern Minnesota	Alicia Freeman

Rocky Mountain Elk Foundation, Minnesota Volunteer Fun Days, Lake Bronson, MN; August 26, 2017	Seasonal home range and fine-scale habitat selection by female elk (*Cervus elaphus*) in northwestern Minnesota	Alicia Freeman

Media Interviews:

Media outlet	Reporter	People interviewed	Date	Internet location
Grand Forks Herald	Brad Dokken	Gino D'Angelo	June 2015	http://www.grandforksherald.com/outdoors/wildlife/3760725-dnr-plans-gps-elk-study-northwest-minnesota
Minnesota Outdoor News	Pat Miller	Gino D'Angelo, Blane Klemek	July 2015	
Minnesota Public Radio	Dan Gunderson	Gino D'Angelo	October 2015	
KFAN Radio	Billy Hildebrand	John Williams	January 2016	
Lakeland Public Television	Jackson Brunner	John Williams	February 2016	
Minnesota Outdoor News	Javier Serna	John Williams	February 2016	
Minnesota Outdoor News	Javier Serna	Gino D'Angelo	February 2016	
Minnesota News Network	Scott Peterson	Gino D'Angelo	February 2016	
Minnesota Public Radio	Dan Gunderson	Gino D'Angelo	February 2016	
KEYC TV Mankato	Colin Oraskovich	Gino D'Angelo, Alicia Freeman	February 2016	
KFGO Radio	Dan Hammer	Gino D'Angelo	February 2016	
AM 890 Ag News Farm Talk Radio	Mick Kjar	Gino D'Angelo	February 2016	
KMSU Radio	Gabe Hewitt	Gino D'Angelo	February 2016	
KQ92 Radio	Jon Michael	Gino D'Angelo	February 2016	
Grygla Eagle Newspaper	Kari Sundberg	Gino D'Angelo, John Williams	February 2016	
Pioneer Press	Dave Orrick	Gino D'Angelo	February 2016	http://www.twincities.com/2016/02/16/minnesota-elk-research-yes-thats-a-thing-as-of-today/
WDAZ Television	Ryan Laughlin	Gino D'Angelo, Lou Cornicelli, John Williams, Blane Klemek, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	http://www.wdaz.com/news/minnesota/3950398-first-ever-mn-elk-tracking-program-begins
Lakeland Public Television	Mary Kielar	Gino D'Angelo, Lou Cornicelli, John Williams, Blane Klemek, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	http://lptv.org/dnr-begins-first-ever-elk-research-project-in-minnesota/

Grygla Eagle Newspaper	Kari Sundberg	Gino D'Angelo, Lou Cornicelli, John Williams, Blane Klemek, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	
North Star News		Gino D'Angelo, Lou Cornicelli, John Williams, Blane Klemek, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	http://www.page1publications.com/103640/1811/02252016ns
Thief River Falls Times	Brad Dokken	Gino D'Angelo, Lou Cornicelli, John Williams, Blane Klemek, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	http://www.grandforksherald.com/outdoors/wildlife/3952734-elk-research-projects-get-ground-helicopter
Minnesota Outdoor News	Javier Serna	Gino D'Angelo, Lou Cornicelli, John Williams, Blane Klemek, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	
The Outdoor Report	Wes Gall	Gino D'Angelo, Lou Cornicelli, John Williams, Blane Klemek, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	
Associated Press	Steve Karnowski	Gino D'Angelo, Lou Cornicelli, John Williams, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	http://www.startribune.com/researchers-begin-outing-gps-radio-collars-on-minnesota-elk/369127251/
KARE 11 Television	Laura Betker	Gino D'Angelo, Lou Cornicelli, John Williams,	February 2016	http://www.kare11.com/news/dnr-collars-elk-in-northwestern-mn/45521470

Northland Outdoors Radio	Brian Peterson	Ruth Anne Franke, Joel Huener, Kristi Coughlon Gino D'Angelo, Lou Cornicelli, John Williams, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	http://www.northlandoutdoors.com/2016/02/17/getting-a-handle-on-elk-in-the-northland/
Minnesota Outdoor News	Joe Albert	Gino D'Angelo, Lou Cornicelli, John Williams, Ruth Anne Franke, Joel Huener, Kristi Coughlon	February 2016	
Grand Forks Herald	Brad Dokken	Gino D'Angelo, John Williams	February 2016	http://www.grandforksherald.com/outdoors/wildlife/3952734-elk-research-projects-get-ground-helicopter
KTRF Radio	Key Teters	John Williams	February 2016	
WILD 102 Radio	Jack Swanson	Lou Cornicelli	February 2016	
Bugle Magazine	Nicky Ouellet	Gino D'Angelo	March 2016	
The Outdoor Report	Wes Gall	Gino D'Angelo, Ryan Tebo, Alicia Freeman	June 2016	

Status as of January 1, 2017:

Status as of July 1, 2017:

Status as of January 1, 2018:
Publications:

Publication outlet	Title	Authors
Summary of wildlife research findings. Division of Fish and Wildlife, Minnesota Department of Natural Resources, St. Paul, Minnesota (2016)	Seasonal home ranges, movements, and habitat use of female elk in northwest Minnesota	Alicia E. Freeman, Gino J. D'Angelo, Veronique St. Louis Lou Cornicelli John D. Krenz
Summary of wildlife research findings. Division of Fish and Wildlife, Minnesota Department of Natural Resources, St. Paul, Minnesota (2017)	Seasonal home ranges, movements, and habitat use of female elk in northwest Minnesota	Alicia E. Freeman, Gino J. D'Angelo, Veronique St. Louis Lou Cornicelli John D. Krenz

Status as of June 30, 2018:

Minnesota State University-Mankato Biology Seminar Series, Mankato, MN; April 27, 2018	Seasonal home ranges and habitat use by female elk in northwestern Minnesota	Alicia Freeman

Final Report Summary:

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Professional/Technical/Service Contracts:	~~$144,000~~ $152,264	1 Graduate student ($91,000) – for 3 years (50% research assistantship) to lead fieldwork for analysis of home range and habitat data. Elk capture (~~$33,000~~ $15,500) – wildlife helicopter capture company (to be determined) to capture and handle 20 adult elk. Iridium satellite data acquisition (~~$20,000~~ $20,951) – transmission of locations and mortality messages.
Equipment/Tools/Supplies:	~~$52,548~~ $44,284	GPS collars for adult elk (~~$50,000~~ $44,284) – 20 collars @ ~~$2,500~~ $2,215 each to collect data, transmit temperature data and mortality signals. Vegetation sampling supplies (~~$2,548~~ $0) – measurement devices and associated supplies.
Other: Direct & Necessary Costs	$3,452	DNR Direct & Necessary Costs ($3,452) – services to support this appropriation (*Please see footnote).
TOTAL ENRTF BUDGET:	**$200,000**	

* Direct support services. DNR's direct and necessary costs pay for activities that are directly related to and necessary for accomplishing appropriated programs/projects. In addition to itemized costs captured in our proposal budget, direct and necessary costs cover Financial Support (~$1,372), Communication Support (~$1,141), Planning Support (~$704), and Procurement Support (~$235) that are necessary to accomplishing funded programs/projects. Department Support Services are described in the agency Service Level Agreement, and billed internally to divisions based on rates that have been developed for each area of service. These services are directly related to and necessary for the appropriation. Department leadership services (Commissioner's Office and Regional Directors) are not assessed. Those elements of individual projects that put little or no demand on support services such as large single-source contracts, large land acquisitions, and funds that are passed-thru to other entities are not assessed Direct and Necessary costs for those activities.

Explanation of Use of Classified Staff: Funds will not be used to pay for classified staff.

Explanation of Capital Expenditures Greater Than $5,000: N/A.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: N/A.

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: ~~1.5 FTE~~ 1.95 FTE.

B. Other Funds: To meet and exceed the $50,000 funding match required in the appropriation law, MNDNR Section of Wildlife will provide a total of $69,250 in funding from the State Game and Fish Fund to directly support this research project including technology support ($20,000), student workers ($11,250), supplies and veterinary services (~~$13,000~~ $10,000), travel ($20,000), and a spotter plane for elk capture ($5,000). Additionally, multiple employees from the MNDNR Section of Wildlife, Farmland Populations and Research Group will devote approximately 25% effort to the project throughout its 36-month duration (Total salary ~$63,656).

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
State Game and Fish Fund			
MNDNR Section of Wildlife	$20,000	$0	Technology support for programming GPS collars, GPS and GIS work.
MNDNR Section of Wildlife	$11,250	$10,683	Student workers ($11,250) – to assist graduate student with vegetation sampling (750 hours @ $15/hr).
MNDNR Section of Wildlife	$5,000	$5,910	Project supplies – additional vegetation sampling supplies, GPS units, digital camera, capture supplies.
~~MNDNR Section of Wildlife~~ Rocky Mountain Elk Foundation*	~~$8,000~~ $10,000	$10,000	Immobilization and reversal drugs for elk capture, and veterinary services.
MNDNR Section of Wildlife	$20,000	$17,287	Travel to study area and per diem by elk project management staff, graduate student, and student workers.
MNDNR Section of Wildlife	$5,000	$7,508	Spotter plane to be used during elk capture efforts.
MNDNR Section of Wildlife, Farmland Populations and Research Group	$63,656	$31,828	Multiple employees (36 months, 25% effort) – project management, field work, data analyses, reporting.
TOTAL OTHER FUNDS:	**$134,906**	**$83,216**	

* Funding obtained December 2015 through Rocky Mountain Elk Foundation PAC Grant to include immobilizing drugs and additional consultation by wildlife veterinarians.

VII. PROJECT STRATEGY:

A. Project Partners:

Dr. Lou Cornicelli, MNDNR, project manager; Dr. Gino D'Angelo, ~~MNDNR~~ University of Georgia, primary investigator; ~~Dr. Lou Cornicelli, MNDNR, co-investigator;~~ Mr. John Williams, MNDNR, collaborator; Ms. Leslie McInenly, MNDNR, collaborator; Mr. Joel Huener, MNDNR, collaborator; Dr. Veronique St.-Louis, collaborator. Dr. Marrett Grund left state service, and Dr. Lou Cornicelli shifted his role to aid in managing the project as ~~co-investigator~~ project manager. Dr. Gino D'Angelo left state service for a faculty position and assumes the role as primary investigator.

B. Project Impact and Long-term Strategy:

This study will provide the first scientifically collected information about movements, home ranges, and habitat use by elk since reestablishment of the species in Minnesota. Improving our understanding about seasonal movement patterns and habitat use of elk will facilitate population monitoring processes, help evaluate current habitat and depredation management actions, and will allow MNDNR to develop science-based options for managing elk and their habitats. This study will provide MNDNR with the data necessary to identify portions of northwest Minnesota that are most likely to support viable and sustainable elk populations.

Procurement and manipulation of habitats to benefit elk in Minnesota is essential to the long-term management, enhancement, and viability of the species. Empirical evidence of the most effective habitat management strategies or the habitats most suited to manipulation to meet elk management goals is lacking. Identifying the habitat conditions critical to elk at key seasonal periods will improve application of specific management strategies where they are most needed. This will be an immediate benefit of the proposed research. Using data about elk movements, we will inform managers about the preferences of elk for landscape level habitat features. Results of fine-scale habitat evaluations will identify microhabitat characteristics important to elk, which may be achieved throughout the landscape by habitat management. Also, knowledge of elk locations in winter will improve the efficiency, accuracy, and precision of population surveys.

Data collected from this study will establish foundational information for more advanced analysis of the spatial relationships of habitat types and configurations. In subsequent research, we plan to use data collected from the currently proposed study to develop resource selection functions for elk in northwestern Minnesota. We will test variables important to predicting elk habitat use relative to available habitats in the region including landcover, distance to roads, distance to agriculture, distance to public land, and others habitat features elucidated as potentially important during our analyses of home ranges and local level habitat evaluations. This information will allow us to create predictive maps of habitats most suitable to elk, which will assist MNDNR in making informed predictions about the potential for natural expansion of elk across the landscape and other areas suitable to expansion of elk.

As an added benefit, the proposed research will stimulate the public's interest and understanding of elk and their habitats. By enhancing elk numbers and management, economic growth associated with elk-related recreation is quite likely.

C. Funding History: No portions of this project or any other elk research by MNDNR were funded previously by the Environment and Natural Resources Trust Fund. Although MNDNR has not previously conducted scientific research on Minnesota elk, management of the elk herds and associated habitats has increased in recent years. Since the 1990s, MNDNR has conducted habitat management on public and private land to benefit elk and to minimize elk-human conflicts. From 2010-2014, MNDNR spent approximately $100,000 to survey elk and estimate their population size to aid in setting harvest quotas. In 2014, MNDNR utilized a total of $166,830 in funding from a variety of sources to improve elk management, including $73,890 in DNR funding, and grants from the Conservation Partners Legacy of the Outdoor Heritage Fund ($52,500), Minnesota Deer Hunters Association ($2,250), and the Rocky Mountain Elk Foundation ($38,190).

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:

A. Parcel List: N/A

B. Acquisition/Restoration Information: N/A

IX. VISUAL COMPONENT or MAP(S): Please see attached map.

X. RESEARCH ADDENDUM: Please see attached research addendum.

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 1, 2016; July 1, 2016; January 1, 2017; July 1, 2017; ~~and~~ January 1, 2018; and June 30, 2018. A final report and associated products will be submitted ~~between June 30 and August 15, 2018~~ before December 31, 2018.

Environment and Natural Resources Trust Fund
M.L. 2015 Project Budget

Project Title: Movement and Seasonal Habitat Use of Minnesota Elk
Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 03k
Project Manager: Lou Cornicelli
Organization: Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Wildlife
M.L. 2015 ENRTF Appropriation: $200,000
Project Length and Completion Date: 3 Years, June 30, 2018
Date of Report: December 31, 2018

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Activity 1 Budget 01/01/2018	Amount Spent	Activity 1 Balance	Revised Activity 2 Budget 01/01/2018	Amount Spent	Activity 2 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM								
Professional/Technical/Service Contracts								
Graduate student ($91,000) - 1 person, 0.5 FTE, 3 years, 75% salary, 25% benefits	$45,500	$45,356	$144	$45,500	$45,356	$144	$91,000	$288
Wildlife helicopter capture company to capture and handle 20 adult elk, competitive bid	$15,500	$15,500	$0	$0	$0	$0	$15,500	$0
Data acquisition fees for transmission of locations and mortality messages from iridium satellites	$20,000	$18,714	$1,286	$951	$951	$0	$20,951	$1,286
Post-doctoral researcher ($24,813) - 1 person, 0.45 FTE, 4.5 months, 75% salary, 25% benefits	~~$0~~	~~$0~~	$0	$24,813	$24,812	$1	$24,813	$1
Equipment/Tools/Supplies			$0			$0		
GPS collars for adult elk, 20@$2,500 each	$44,284	$44,284	$0	$0	$0	$0	$44,284	$0
Miscellaneous sampling equipment and supplies (i.e., tape measures, densitometers, cover boards, rangefinders, miscellaneous field supplies, etc.)	$0	$0	$0	$0	$0	$0	$0	$0
Direct support services. DNR's direct and necessary costs pay for activities that are directly related to and necessary for accomplishing appropriated programs/projects. In addition to itemized costs captured in our proposal budget, direct and necessary costs cover Financial Support (~$1,372), Communication Support (~$1,141), Planning Support (~$704), and Procurement Support (~$235) that are necessary to accomplishing funded programs/projects.	$2,589	$2,589	$0	$863	$863	$0	$3,452	$0
COLUMN TOTAL	**$127,873**	**$126,443**	**$1,430**	**$72,127**	**$71,982**	**$145**	**$200,000**	**$1,575**

31 December 2018

Corresponding Author: Joseph W. Hinton

Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA 30605

E-mail address: jhinton@uga.edu; Tel.: 706 542 1181; fax: 706 542 8356

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

JOSEPH W. HINTON[1] *Warnell School of Forestry and Natural Resources, University of Georgia, 180 E. Green Street, Athens, GA 30605, USA*

ALICIA E. FREEMAN *Department of Biological Sciences, Minnesota State University-Mankato, Trafton Science Center South, Mankato, MN 56001, USA*

GINO J. D'ANGELO *Warnell School of Forestry and Natural Resources, University of Georgia, 180 E. Green Street, Athens, GA 30605, USA*

VÉRONIQUE ST-LOUIS *Division of Fish and Wildlife, Minnesota Department of Natural Resources, 5463 W. Broadway Avenue, Forest Lake, MN 55025*

LOUIS CORNICELLI *Division of Fish and Wildlife, Minnesota Department of Natural Resources, 500 Lafayette Road, St. Paul, MN 51555, USA*

[1] *E-mail address: jhinton@uga.edu*

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

156 then compared seasonal home ranges and core areas using analysis of variance (ANOVA) and t-
157 tests.

158 We obtained annual land cover data from the United States Department of Agriculture
159 (USDA) Cropland Data Layers (USDA 2016, USDA 2017). Because modern farming practices
160 involve rotating crops among fields or changing plantings from year to year, we obtained
161 landcover data for 2016–2017 when female elk were radio collared. This allowed us to account
162 for changes in availability of crops in elk home ranges throughout the study period. We collapsed
163 agricultural crops into 6 general agriculture classes with a 30-m resolution: cereal (e.g., barely,
164 corn, oats, rye, sorghum, and wheat), legume (e.g., alfalfa, beans, and peas), hay, fallow fields,
165 sod, and other crops (e.g., canola, flaxseed, flowers, potatoes, and sugarbeets). Because elk are
166 known to use forest edges and water sources (Thomas et al. 1988, Baasch et al. 2010) and avoid
167 roads (Boyce et al. 2003, Anderson et al. 2005, Beck et al. 2013), we also developed agriculture-
168 forest edge, water, and road layers. We created distance raster maps for agriculture classes,
169 agriculture-forest edges (hereafter edges), water, and roads using the 'Euclidean Distance' tool in
170 Spatial Analyst toolbox in ArcGIS 10.6 (Environmental Systems Research Institute Inc.,
171 Redlands, California) to calculate the distance from every 30m pixel to the closest landscape
172 feature (Benson 2013). To account for forest cover, we estimated percent tree canopy cover from
173 the United States Geological Survey (USGS) National Land Cover Database (NLCD; USGS
174 2011).

175 As suggested by Manly et al. (2002), we followed the Design III (3rd-order selection) to
176 assess the relationship between habitats and elk space use within their home ranges. We used
177 individual elk as our sampling units and measured resource availability for each animal. To
178 estimate resource selection functions (RSFs), we used a binomial approach by comparing

179 characteristics of known locations to 3-times the number of random locations within home
180 ranges of elk (Manly et al. 2002, Little et al. 2016). Because we used distance-based variables to
181 assess habitat selection, we inferred selection for agriculture habitats, edge, water, and roads
182 occurred when known locations were closer to those features than were random locations.
183 Likewise, we inferred avoidance when known locations were farther from those features than
184 were random locations. However, we inferred selection for forest cover when known locations
185 had greater percentage of canopy cover values than did random locations and vice versa for
186 avoidance of forest cover. We used generalized linear mixed models with a logit link in program
187 R to compare habitat selection between growing and non-growing season (R Development Core
188 Team 2013). We included random intercepts for individual elk in each model to account for
189 correlation of habitat use within individuals and the unbalanced telemetry data since individual
190 elk differed in their number of GPS locations. We modeled resource selection using the R
191 package lme4 (Bates et al. 2014) with a binary (0 = random, 1 = known) response variable.
192 Before modeling, we rescaled values for distance-based variables and forest cover by subtracting
193 their mean and dividing by 2 standard deviations (Gelman 2008). We then used Akaike's
194 information criterion adjusted for small sample sizes (AICc) and used ΔAICc to select which
195 models best supported factors influencing habitat selection by elk (Burnham and Anderson
196 2002). We validated our best model using k-fold cross-validation. We used 10 folds (k = 10) to
197 estimate performance of RSF models.

198 **RESULTS**

199 On average, home-range size (±SD) for female elk in northwestern Minnesota was 50.8 km^2 ±
200 14.0 and ranged between 21.2 km^2 to 87.7 km^2. Mean home-range size for female elk during our
201 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

294 home ranges on while selecting fields planted for legumes (e.g., soybean and alfalfa fields) and,
295 to a lesser extent, fallow and cereal fields, for foraging areas when they were adjacent to forest
296 habitats. Indeed, elk typically remained close (<100 m) to forest cover when using agricultural
297 fields, a behavior observed in other studies (Thomas et al. 1988, Baasch et al. 2010). Elk avoided
298 hay, sod, roads, water, and, to a lesser extent, other crops. It is not surprising that elk avoided
299 roads, as this behavior is commonly reported in studies and associated with avoidance of humans
300 (Frair et al. 2008, Montgomery et al. 2013, Prokopenko et al. 2017). We suspect hay and sod
301 farms provide elk poor foraging opportunities and little cover, especially for female elk and their
302 calves. Water in this region is not a limiting resource and we suspect elk avoidance of water was
303 strongly associated with elk not using large bodies of water (e.g., Thief Lake) as habitat in our
304 analyses.

305 Our models suggest that elk altered their selection of habitats between growing and non-
306 growing seasons. Most notably, elk exhibited stronger selection for forest cover, edges, and
307 fallow fields during the non-growing season than they did in the growing season, as well as a
308 weaker selection for legumes. As elk decreased selection for legumes during the non-growing
309 season, they also decreased avoidance of hay and sod, other crops, roads, and water. Because elk
310 in this region belong to a non-migratory population that is hunted, it is reasonable to assume that
311 increased selection for forest cover and remaining close to forest habitats is a response by elk to
312 both increasing human activity and the loss of agricultural forage during the non-growing season.
313 During this time, elk also appear to compensate for the loss of favored crops, such as legumes,
314 by selecting for fallow fields that likely offer foraging opportunities for grasses and forbs.
315 Furthermore, substantial loss of agricultural forage and cover may force elk to be less selective
316 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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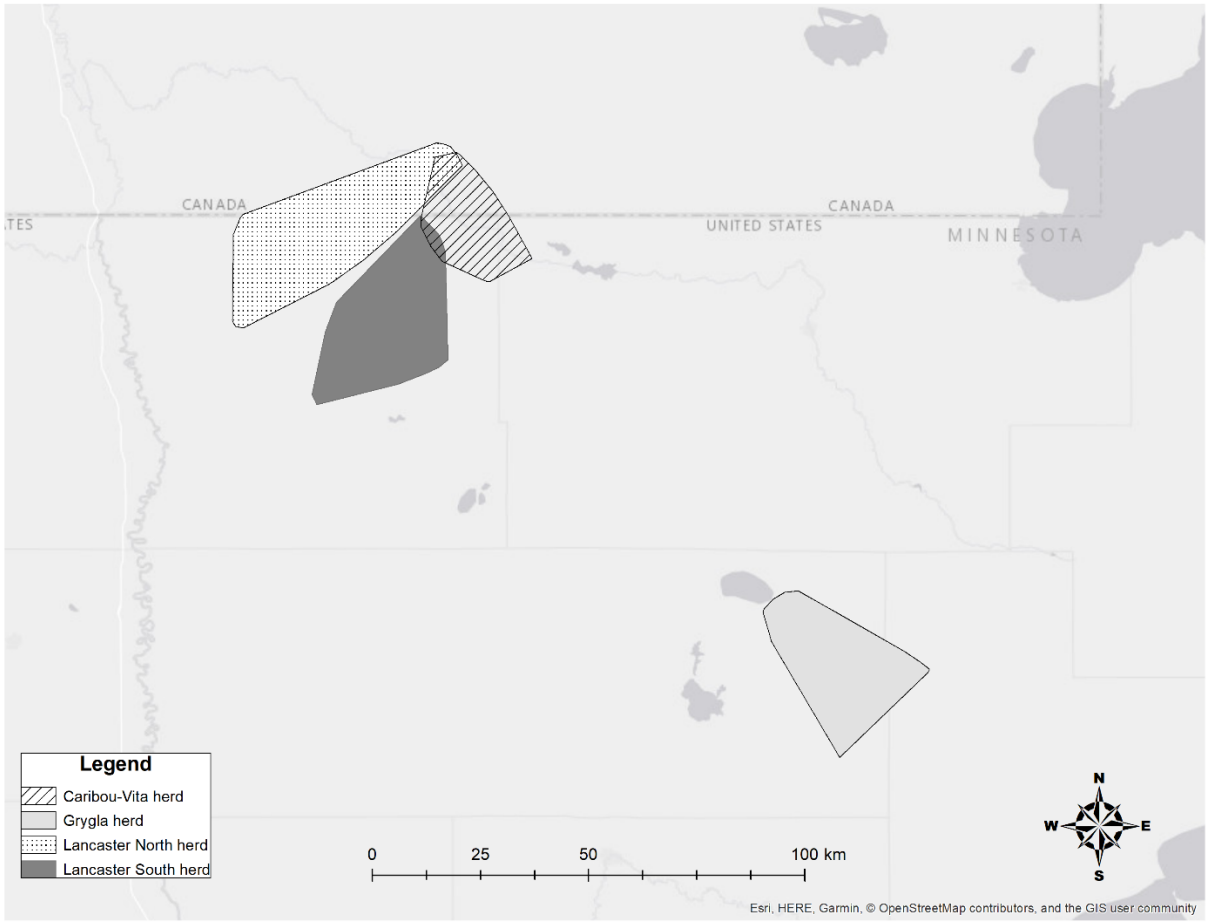
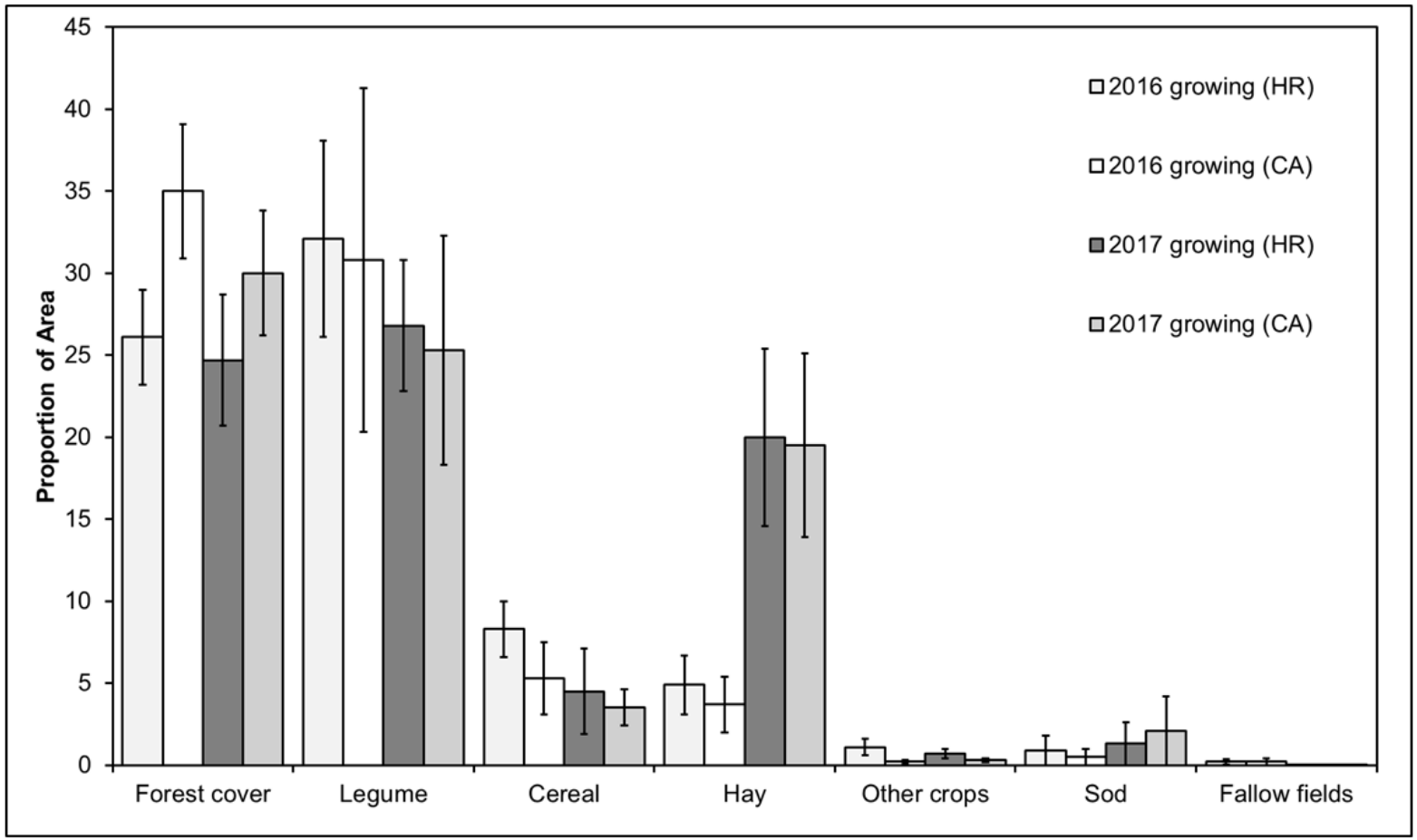
493 *Associate Editor:*

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.



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



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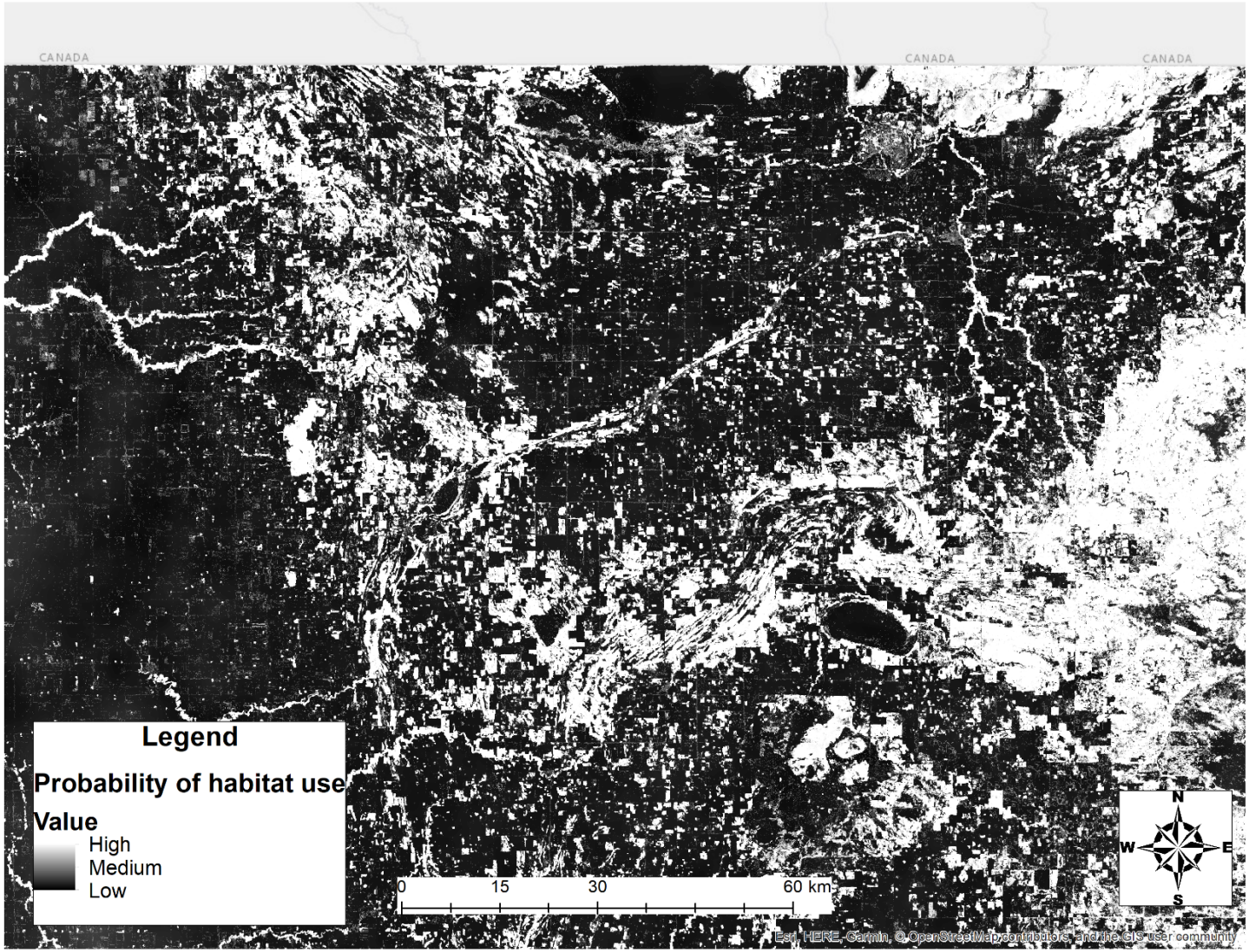
503 Figure 3. Relative probability of 3rd-order habitat selection by non-migratory female elk in northwestern Minnesota during 2016–2017.



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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.

514 **Table 2.** Summary of generalized linear mixed models for predicting seasonal 3rd-order habitat selection by female elk in
515 northwestern Minnesota, 2016–2017. Shown are Akaike's Information Criteria for small sample sizes (AIC_c) and differences among
516 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

517 [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

518

519 **Table 3.** Parameter estimates for 3rd-order resource selection functions for radio-collared female elk in northwestern Minnesota during
520 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

521