January 2017

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Recommended Citation

Amor, Jacqueline Marie, "An Evaluation Of Elk Home Range Variation In North Dakota" (2017). *Theses and Dissertations*. 2160.
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AN EVALUATION OF ELK HOME RANGE VARIATION IN NORTH DAKOTA

by

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Bachelor of Science, Clemson University, 2012

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

December
2017

This thesis, submitted by Jacqueline Amor in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the Univeristy of North Dakota and is hereby approved.

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Department	Geography and GIS
Degree	Master of Science

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Jacqueline Amor

11/16/2017

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ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to the members of my advisory committee for their guidance and support during my time in the master's program at the University of North Dakota. This study was funded by North Dakota Game and Fish Department in Bismarck, North Dakota, USA. We thank Standing Rock Sioux Tribe, Sustainable Development, Manitoba Canada, W. David Walter, Brett Goodwin, Susan Felege, and NDView Scholarship for review comments and/or contributions to this project.

ABSTRACT

In North Dakota, dispersing elk (*Cervus elaphus*) were colonizing areas of suitable habitat in Turtle Mountain, Pembina Hills, and Porcupine Hills, ND, USA. Although these 3 elk herds were small (~100–250 individuals each), they had been responsible for crop depredation in these areas. The North Dakota Game and Fish Department (NDGF) had little information on these elk herds. In cooperation with Standing Rock Sioux Reservation and Manitoba Department of Sustainable Development, NDGF contracted with the University of North Dakota (UND) to collect and analyze critical baseline information to better manage these elk herds. The objectives of this study were to determine 1) population estimates and demographic composition; 2) home range and habitat selection; and 3) biological and cultural carrying capacities. We used helicopters to capture 15 adult female elk, affixed Global Positioning System (GPS) collars, and gathered 6 GPS locations per day from each animal (one fix per four hours) to determine home ranges for daily, seasonal, and hunting season intervals over a period of 1 year (2016–2017). We conducted home range analyses using Brownian Bridge spatial techniques in R statistical software, which are currently among the most robust methods to analyze these data. We found that home ranges from the 3 herds were significantly different from one another ($P < 0.05$), and gun season ($P < 0.0001$), winter ($P < 0.05$) and nightly ($P < 0.05$) movements were significantly different than our baseline comparables.

CHAPTER I

REVIEW OF ELK ECOLOGY AND MANAGEMENT

Introduction

North American elk (*Cervus canadensis*) are charismatic large ungulates that were historically the most widely distributed cervid in North America (Seabloom 2011, Geist et al. 2000). Their historic range comprised the northwestern coast of the U.S. into California, and spanning the southwest into Mexico; elk herds were also distributed into southern Canada and to the east of the Cascade and Sierra mountains (Seabloom 2011). Although researchers have argued the taxonomic status of North American elk and European and Asian red deer (*Cervus elaphus*), some consider them both to be a subspecies belonging to one circumpolar species (Heffelfinger 2000). Elk fall within the order Artiodactyla, suborder Ruminatia, and family Cervidae (Knue 1991).

Elk were historically important to Native Americans; they provided food, clothing, weapons, decoration, implements, spiritualism and medium of exchange (McCabe 2002, Laliberte and Ripple 2003). Elk were also important for European settlers because they provided food, clothing, shelter and implements (Kellert and Smith 2000). Because of unregulated hunting in the 19th century, elk became largely extirpated in the eastern U.S.; since then, elk have been reintroduced into some of their previous historic locations (Seabloom 2011, Geist et al. 2000, Johnson et al. 2013). Elk management efforts in many areas of North America were successful, and today, elk are cherished by hunters, wildlife watchers, nature enthusiasts and photographers.

In the U.S., federally managed public land provides millions of acres of suitable elk habitat where people may observe elk and other wildlife species, especially in the western states where elk are common (Lyon and Christensen 2002). Thus, elk have high social and economic values based on the amount of money generated through hunting permits and for local businesses that count on the hunters and wildlife watchers that elk attract (Lyon and Christensen 2002). Moreover, wildlife management and conservation agencies including the Rocky Mountain Elk Foundation collectively contributed $1.1 billion in 2011 in support of conserving habitat and species including elk (Congressional Sportsmen's Foundation 2013). A primary draw for outdoor recreation is hunting; it allows sportsmen and women to identify with personal linkages with reliance on the natural environment (e.g., for food or connection with being outdoors; Schorr et al. 2014). Elk hunting licenses provide revenue for elk conservation (Lyon and Christensen 2002); the North American Model for Wildlife Conservation is dependent on hunting participation and funding from license sales for wildlife conservation (Schorr et al. 2014). In North Dakota, the first limited season on elk was held in 1982 on the Pembina Hills herd (Knue 1991). The hunt was then closed during the 1987 and 1988 seasons, but opened again in 1989. Today, elk hunting in North Dakota has expanded to the Little Missouri National Grasslands, and the Turtle Mountain in the north (Knue 1991). A limited elk hunt conducted by Standing Rock Sioux Tribe in Sioux County in 2015. Three of the smaller herds vary in size from about 100 to 250 animals (Pembina Hills approx. 130, Turtle Mountain approx. 220. Porcupine Hills approx.100.; W. F. Jensen, NDGF, personal communication). North Dakota elk hunting permits are available via lottery and are generally restricted to a once in a lifetime lottery permit.

Elk are an adaptable species, given their large historical range and variety of ecosystems in which they live (Skovlin et al. 2002). For example, elk thrive in habitats such as coastal rain forests, dry forests and chaparrals, cool shrub forests, prairies of the Midwest, mixed conifer-hardwoods of the East, and montane habitats of the Rockies (Seabloom 2011). Areas where they have been restored to their previous range include Tennessee, Pennsylvania, and Kentucky (Williams et al. 2002, Wichrowski et al. 2005, Kindall et al. 2011), which also have limited elk hunts like North Dakota (Tennessee Wildlife Resource Agency 2017, Pennsylvania Game Commission 2017, Kentucky Department of Fish and Wildlife Resources 2017). Rocky Mountain elk (*Cervus elaphus nelsoni*) were first reintroduced to Dunn County, North Dakota, in 1942 from Yellowstone National Park (Knue 1991, Strassler 1996). Elk (*Cervus elaphus*) returned to North Dakota from Canada about 80 years after the last native elk was harvested in the state (Knue 1991, O'Gara and Dundas 2002). These elk became established in the Pembina River Valley within the northeastern corner of the state where they presumably migrated from Canada (Knue 1991, O'Gara and Dundas 2002). There are three elk populations that have since become established in North Dakota since the 1970s, and they reside in the Pembina Hills (Cavalier and Pembina counties), the Badlands (Dunn, McKenzie, Billings, Golden Valley, and Slope counties), the Turtle Mountain area (Bottineau and Rolette counties), and the Porcupine Hills (Sioux County; NDGF 2017).

In some portions of their range, elk conservation and management success, paired with the adaptability of elk may also lead to overabundance and human-wildlife conflicts including property damage, crop depredation, loss of native plant regeneration, damage to natural habitat (e.g., aspen stands), vehicle collisions, and disease transmission to livestock and other wild ungulates (Hegel et al. 2009, Walter et al. 2010*a*, DeVore 2014, Brenan et al. 2015). Elk can recolonize from original locations of inhabitance (Keller et al. 2015) resulting in landowner intolerance in some areas, especially farmers (Hegel et al. 2009, Walter et al. 2010*a*, DeVore 2014, DeVore et al. 2016). Damage to native habitat may result in reverse succession and lead to low biodiversity and an increase in invasive species that can dominate landscapes (Kauffman et al. 2010, Walter et al. 2010*a*, Johnson et al. 2014, Painter et al. 2015). Elk have a strong homing instinct and invariably return to their usual winter quarters, which can result in repeated depredation annually (Bach 1945, Knue 1991).

Ecosystem Function

Elk are a keystone species that play a pivotal role in ecosystem function; biotic communities depend on their presence (Cooperrider 2002, Greenberg et al. 2016). For example, elk are a food source for large predators and scavengers, modify habitats by foraging, and transport plant seeds (Cooperrider 2002, Ripple and Beschta 2011, Parsons et al. 2013). Elk foraging can change habitat composition by altering plant species at site, watershed, and ecoregional scales (Kay and Chadde 1992, Wagner et al. 1995, Cooperrider 2002, Greenberg et al., 2016, Ripple and Beschta 2011, Parsons et al. 2013). Foraging on saplings, for example, provides for more leafy plants that subsequently precipitate change in habitat composition, altering the number of sprouting trees in forest understories. The resulting increase in cover provides habitat for smaller mammals, rodents and birds. However, overgrazing and foraging can erode riverbanks, altering river flow and river bank stability as well as aquatic life. The introduction of wolves can reverse this chain of reaction and control the way elk manipulate the ecosystem by preying on elk (Painter et al. 2015). Elk carcasses provide food for predators such as wolves, and bears (Painter et al. 2015, Ripple and Beschta 2011). The role of these predators preying on elk can manipulate movement and foraging sites for elk by forcing them to travel distances potentially outside their home range. This helps reverse and transform the environment from previous states, which benefit other species by allowing saplings to grow, creating understory habitat; this is known as a trophic cascade (Ripple et al. 2001, Kauffman et al. 2010, Ripple and Beschta 2011, Painter et al. 2015).

Natural History

In North America, elk are the second largest mammal in the Cervidae family after moose (*Alces alces*; Seabloom 2011). Males and females weigh 300–500 kg and 200–285 kg, respectively (Wisdom and Cook 2000, Seabloom 2011). Both sexes are characterized by dark manes and a yellow rump patch; their bodies are generally reddish brown during the summer months, while in winter months their bodies are more grayish brown (Seabloom 2011). Distinguishing characteristics in the Cervidae family include sexual dimorphism in body size and females lacking antlers. Polygynous cervids are characteristically dimorphic due to male’s competition for mating rights (Hudson et al. 2002, Stewart et al. 2015). Male antler growth is a cyclical process and takes approximately 90 days to grow to full size (Hudson and Haigh 2002). Size of antlers depends on age, health, and testosterone levels. The anatomy of elk antlers consists of the pedicle, brow and bay tines, beams, and branching points (Hudson and Haigh 2002) and can be 60–90 cm long (O’Gara and Dundas 2002). Average female length measurements are 226.4 cm for body, 11.5 cm for tail, 67.4 cm for hind foot, and 20.5 cm for ear; conversely, average male length measurements are 234.1 cm for body, 12.3 cm for tail, 70 cm for hind foot, and 21.8 cm for ear (Seabloom 2011). Female and male elk can live to be 15 and 10 years, respectively; under high harvest pressure, however, they usually live less than 5 years (Boyd 1978, Bryant and Maser 1982).

Movements

Elk are able to move long distances quickly and follow migratory patterns with the changing of seasons (Wisdom and Cook 2000). In mountainous states, elk have distinct winter and summer ranges that are related to altitude; herds spend summer months at higher elevations following green up where forage quality is highest, followed by the advancing of snow (Knue 1991, White et al. 2010, Johnson et al. 2013, Merkle et al. 2016). Migratory elk herds are generally found in mountainous regions where they are able to move in response to seasonal changes (Irby et al. 2002, Merkle et al. 2016). In North Dakota, elevation differentiation is small compared to other states where elk are found, possibly resulting in shorter movements compared to more mountainous states. Elevation differences are found in North Dakota's Turtle Mountain (152–213 meters; Henderson et al. 2002) Pembina Hills (60–90 meters; Gill and Cobban 1965), and Porcupine Hills (100–140 meters; USGS).

Foraging

The capability of elk to select and efficiently digest a wide variety of forages allows them to successfully thrive and occupy a diversity of environments. Elk exhibit a mixed feeding strategy (Geist 2002) and are considered to be both browsers and grazers, falling between both of these digestive specializations both anatomically and functionally (Hudson et al. 2002, Walter et al. 2010*b*). Elk are able to digest fibrous plants but are more selective of nutritious plants, preferably grasses and forbs (Wisdom and Cook 2000, Christianson and Creel 2008). There is high variability for foraging ranges, seasons and years among elk, and this is related to a strong relationship to forage availability and phenology, which is important information for managing elk herds. Natural, high quality forage is not always available to elk in times like late summer and winter, but agricultural crops may offset nutrient deficiencies in some areas (e.g., winter wheat, waste grain; Cook 2002, Walter et al. 2010*b*). Elk select habitat based on season, weather, predator avoidance, cover, hunters, biting insects, and forage quality and availability (Skovlin et al. 2002). Landscape topography such as slope, aspect, and elevation also affect elk habitat selection (Skovlin et al. 2002). Elk in North Dakota inhabit oak-aspen forests, birch-aspen forests, oak-ash forest, cottonwood forest, hardwood and juniper draws, grasslands and agricultural lands (Seabloom 2011). Elk typically use forested areas during the day in the summer and then feed in grasslands and agricultural lands during the night, and shift between forested cover and open grassland during winter diurnal hours. Elk are likely to compete directly with cattle and interfere with agriculture due to their grazing habits (Knue 1991). Studies of elk populations in various states have shown that grass and grass-like plants are an important food source for elk throughout the seasons, becoming most important in early and late summer, and least important in winter (Boyd 1978). During the winter, forage availability is mainly affected by snow depth; elk tend to move to where snow depth is reduced and available vegetation is accessible (Cook 2002). During spring, elk forage on grasses that sprout early and switch to forbs and shrubs as summer progresses (i.e., elk follow green up of plant species; Cook 2002).

Breeding

During the rut, one dominant bull elk will gather a harem of females, demonstrating a polygynous mating system (Wisdom and Cook 2000). Bulls exhibit bugling behavior by exerting high-pitched frequencies to attract females for mating (Geist 2002). Males will defend their harem by sparring with other bull elk, antler rubbing on trees and shrubs, bugling, and wallowing (Wisdom and Cook 2000). Bull elk will also intensify their scent by spraying urine on themselves or into their wallow and subsequently rolling in the urine-soaked mud (Geist 2002). By defending their harem, males establish a dominance hierarchy among other males within their territory (Wisdom and Cook 2000). After the rut, bull elk will band together and will seclude themselves from cows, marking a time when males recover from exhaustion and injuries endured during the rut (Geist 2002).

Body weight is strongly related to puberty and conception rates in elk (Hudson and Haigh 2002). Male elk have the ability to reproduce as yearlings, and females are usually ready for breeding at the age of 2.5 years, once they have reached adequate body size (Wisdom and Cook 2000), at which point they can reproduce annually. Female elk normally carry one calf (twinning occurs in >1%) for approximately 255 days (Hudson and Haigh 2002). Calving season usually peaks during first week of June but may vary annually and by location (Hudson and Haigh 2002). During this time, female elk become restless and seek solitude away from the herd; they may not rejoin the herd for up to a month after parturition (Hudson and Haigh 2002). Elk calves usually are hiders born with spotted coats for camouflage and have minimum scent to help avoid predation (Geist 2002). Female calves reach mature weight quicker than males; an additional summer after birth will bring females close to mature weight, while males may take up to 4 or 5 years to reach their mature weight (Hudson and Haigh 2002). Adult female elk that do not have sufficient nutritional intake on an annual basis may be unable to reproduce (Cook 2002).

Behaviors

Elk are cursorial mammals adapted for running with their heads held high to help them identify predators and avoid obstacles (Geist 2002). In open areas, elk implement a selfish herd security strategy in which individuals group themselves closely together to minimize predation (Geist 2002). When elk are not in open spaces, they rely more on habitat cover surrounding them (Geist 2002). Female and male elk have different primary goals related to security. A cow's ultimate goal is calf security; she will spend more time in covered areas. Conversely, bull elk will spend more time foraging for food in secure locations to maximize body growth to be successful during the mating season (Geist 2002). Sexual segregation occurs in the spring; females remain in large herds to protect calves and males (including yearlings) tend to roam freely and behave independently (Geist 2002). Bulls will have larger home ranges and establish a territory before cows, and will seek forested areas over open-spaces (Flook 1970, Mitchell et al. 1977, Geist 2002).

Management

At the landscape level, elk populations are generally managed by state wildlife agencies, while smaller areas may be managed by tribal or federal wildlife managers on these lands. For these resource agencies to properly manage elk herds, a minimum of data need to be collected. For example, population size and demographics are especially important for estimating biological and cultural carrying capacities of elk herds (Irwin 2002). Biological carrying capacity is the maximum population level the environment can support, whereas cultural carrying capacity is the maximum population level set by the tolerance of people in a given area (Carpenter 2000). Techniques used to collect data on elk migration and ecological patterns can consist of aerial fixed wing surveys, observations of neck-banded individuals, GPS and radio-collar tracking, ear tag returns, and track counts (Irwin 2002). Aerial surveys are used to collect migration route data by observing tracks and routes in the snow and through forested areas (Irwin 2002), and GPS and radio-collar tracking can collect finer detailed locations of collared animals by taking a fix at certain hours of the day. In some instances, aerial surveys may be combined with GPS-collared "Judas" animals. Such an animal is considered one that will rejoin the herd, allowing researchers to find that animal and gathering data on surrounding herd members (McIlroy and Gifford 1997).

Mortality

Hunting is the main cause of elk mortality, and hunter-harvest can account for up to 90% of bull elk mortalities in areas with elk hunting seasons (Raedeke et al. 2002). Other causes of mortality include predation by cougars, wolves, and bears (Ripple and Beschta 2011, Sargeant et al. 2011, Painter et al. 2015). Moreover, severe winter and poor nutrition may lead to low energy levels and difficulty with fleeing predators and starvation (Wisdom and Cook 2000, Bender et al. 2008). Diseases primarily causing mortality in elk include a parasitic brainworm (*Parelaphostrongylus tenuis*) passed from infected deer (*Odocoileus spp.)* and chronic wasting disease (CWD). Deer infected with brainworm will excrete a meningeal worm larvae-infested mucus membrane on its fecal matter, which infect gastropods. Gastropods then serve as intermediate hosts that cervids ingest when foraging on vegetation, thereby infecting others and causing the fatal neurological disease (Jacques et al. 2015). The infectious agent of CWD is an extremely resistant, nearly indestructible protein particle called a prion (Thorne et al. 2002). CWD is a disease that attacks an elk's central nervous system, resulting in 100% mortality (Monello et al. 2014, Galloway et al. 2017, Hoover et al. 2017). Another cause of mortality are elk-vehicle collisions (Gunson et al. 2006, Gagnon et al. 2007, Keller et al. 2015).

Demographics

Migration. – Yellowstone National Park (YNP) is home to a large elk herd of approximately 6,000 animals that migrate during different times of the year. White et al. (2010), documented movements of the northern YNP elk herd to identify factors that affect timing of migration, selection of migratory routes and summer ranges, and fidelity within migration. At the beginning of the study, 140 adult female elk were radio collared using helicopter net gunning and darting, and summer and winter locations were tracked. Precipitation and green-up influenced timing of spring migration for elk, and the general migration routes and areas used by elk were similar to those before wolf (*Canis lupus*) reintroduction. Autumn migration tended to be delayed but was not correlated with wolf predation or elevation, it was most likely due to avoid hunting risk (White et al. 2010). Given a paucity of research, it is unclear whether smaller elk herds engage in the same type of migratory behavior.

Middleton (2013) observed 4,500 elk in the Absaroka Mountains of Wyoming and those that migrate to YNP, noting cow ratios and habitat quality between migrating elk and resident elk. Data from this study suggest that YNP migrants experienced a decrease in calf recruitment and lower pregnancy rates, meaning lower reproductive success than resident, non-migratory elk. The authors suggested that this phenomenon could be because of diminishing ecological conditions that favor migration and growing predator numbers such as grizzly bears and wolves. In addition, long-term drought reduced habitat quality in the study area. Thus, when ecological conditions that favor migrations are diminished, population declines may occur in wilderness landscapes and protected parks (Middleton 2013). Apex predators of elk, save for an occasional mountain lion (*Puma concolor*), are generally lacking in Bottineau, Rolette, Cavalier, Pembina, and Sioux counties, North Dakota, where elk herds are much smaller by comparison. However, drought or diminished habitat quality may potentially be a contributing factor to elk migration patterns and habitat selection in these areas.

Multiple factors may determine where migrant elk travel (Robinson et al. 2010). For example, habitat quality, ecological conditions, and predation are major contributing factors. A study conducted in Alberta, Canada, tracked two groups of elk: partially migrant and non-migratory residents. Overlap between these two groups occurred during the winter months, and increased as winter progressed. Resident elk experienced predation more at night than migrants and tended to stay closer to human occupied land to avoid predation risks. Wolves avoided these areas during the day but at night moved closer to human activity. Resident elk were consistently found closer to human activity than migrants, which may suggest habituation to human activity (Robinson et al. 2010). Migrant and resident elk do not have the same predation risk and cannot be compared equally, but wolf predation has had an impact on where elk were migrating and to resident elk locations (Robinson et al. 2010). The presence of wolves in most of North Dakota is expected to remain nonexistent or sporadic, with possible dispersion from Minnesota and Manitoba (U.S. Fish & Wildlife Service 2013). Wolf populations in North Dakota could potentially manipulate size and migratory patterns of the small elk herds in the Bottineau and Rolette counties and Pembina and Cavalier counties, should their populations increase.

Habitat selection. – Habitat resource selection can help determine the distribution of resources on which elk herds depend. This analysis can be conducted by collecting their distribution and abundance in North Dakota (Boyce and McDonald 1999, Allen et al. 2016). Sawyer et al. (2007) examined habitat selection of elk in a non-forested region in southeastern Wyoming. In this study, female adult elk were captured via net-gunning and helicopter, and GPS and VHF collars were affixed to captured animals. These researchers developed resource selection functions for elk in 2003 and 2004, and their results suggested that elk were able to meet their year-round forage and cover requirements for survival in non-forested areas that provided low human traffic, a dominant shrub community, and elevation range (Sawyer et al. 2007).

Another study examined seasonal habitat selection by elk in north central Utah (Beck et al. 2013). Here the researchers predicted that elk seasonal habitat selection reflected influences from proximity to roads, variation in cover, and topographic features that maximize the trade-off between adequate forage and security cover. The authors suggested that topographic features influenced the seasonal movements of elk, and they were able to discern which habitats were favored during the different times of the year.

Remote sensing has been useful to differentiate habitat types and the preferences elk are using during the year within their home ranges (Beck et al. 2013)

In British Columbia, Canada, winter habitat relationships of deer and elk in temperate interior mountains were studied (Poole and Mowat 2005). The authors compared mule deer (*Odocoileus hemionus*) and elk preferences during winter months and demonstrated how snow depth affected habitat choices. Snow tract transects were taken in 8 areas using a hip-chain to measure distance and they recorded tracks and trails using GPS along their transects. White-tailed deer and mule deer avoided areas with >40 cm of snow and elk avoided areas >50 cm of snow (Poole and Mowat 2005). Late-winter snow depth had a positive relationship with elevation and a negative relationship with slope and solar radiation (Poole and Mowat 2005). Deer selected old forests for cover, while elk selection among forest stands was weak. Snow depth and habitat cover are important to consider for habitat management because winter energy budgets are a balance between nutrient intake and cost of locomotion (Poole and Mowat 2005).

Home Range

Home range is considered to be the area in which an individual moves, and this information can inform spatial distribution of an animal population (Anderson et al. 2005). Understanding home range and habitat use across a landscape can explain variation among individuals and how space use and preference of habitat interact with one another. (Allen et al. 2016). Home ranges can differ based on the timing of the year and seasonal changes. A study analyzing elk herds in YNP (Wyoming), Canadian Rockies, Alberta, and northern Wisconsin found that winter home ranges were larger than summer home ranges (Anderson et al. 2005). The mean home ranges in the summer for elk in Alberta, Wisconsin, and YNP were 5.296 ha, 2.134 ha, and 13.468 ha, respectively. The mean home ranges in the winter for elk in Alberta, Wisconsin, and YNP were 10.104 ha, 2.841 ha, and 17.974 ha, respectively. Landscape factors between forage biomass and carrying capacity may inform relationships in determining elk home range size during different seasons (Kie et al. 2002, Anderson et al. 2005).

Seidel and Boyce (2016) used GPS relocation data from two populations of elk, exploring how foraging path selection may influence the structure and development of home ranges. The study followed 12 GPS-collared elk during summer 2012. To identify the elk's foraging patches, clusters of telemetry relocations were examined weekly from the GPS dataset for each elk using program SaTScan (Kulldorff et al. 2005, Seidel and Boyce 2016). Kernel density estimation (KDE) was used to demonstrate patterns in range use and home range estimation for individual animals (Worton 1989, Seidel and Boyce 2016). The authors demonstrated that forage availability alone did not define the value of foraging patches for elk. Their analysis demonstrated that elk selected foraging patches with a high forage biomass, the greatest amount of forest cover, and lowest traffic usage on the nearest roads (Seidel and Boyce 2016).

More recently, the use of Brownian Bridge Movement Models (BBMM) have been used for GPS tracking data because it includes temporal structure and explicitly models movement paths of animals within their home ranges, also referred to as utilization distributions (UD; Kranstauber et al. 2012). BBMM allows for order of locations and time spent between them, as well as applying conditional random walks in between points (Kranstauber et al. 2012). These techniques are demonstrated by Nicholson et al. (2016), who estimated seasonal ranges and migration routes of caribou

(*Rangifer tarandus granti*) movements in the central Arctic. The authors captured and GPS-collared 57 caribou via helicopter and net gun. Collars were programmed to take a fix location every 47 hours during winter (November–April) and 5 hours during the summer (May–October). They modelled 5 different periods: winter, spring, migration, calving, summer, and fall migration. For summer and winter ranges, fixed-kernel density estimators were used, and for migration route delineation, BBMM was used to provide UDs of areas along migration routes. BBMM allowed for population-level migration route predictions which assesses the variation in movement patterns and provides species' habitat relationships for management requirements (Nichelson et al. 2016).

Understanding that elk home ranges are dependent on high-quality habitat rather than foraging on low quality habitat within a closer range may help demonstrate why elk may or may not be traveling farther distances within our study areas in Cavalier, Pembina, Bottineau, Rolette, and Sioux counties. What we can learn from other research conducted in Canada and other parts of the U.S. is that elk herds are exhibiting partial migration depending on available ecological resources, climate harshness, and predator pressure. Considering the elk populations that I will be studying are generally smaller than previously studied populations, understanding what factors impact elk migration will be beneficial to understanding herds under these circumstances. Key information used for management is awareness of location, seasonal changes in movement, and land cover type utilized. Understanding home range and habitat selection may clarify how quality of habitat on the landscape and space use are related (Allen et al. 2016). This type of research can greatly benefit our knowledge regarding these newly established elk herds and will ultimately help NDGF better manage these herds.

North Dakota Research

The most recent research conducted on elk in North Dakota took place in 2007 and 2014 (Sargeant and Oehler 2007, Sargeant 2014). Sargeant and Oehler (2007) estimated pregnancy rates, survival rates, age ratios, and sex ratios for elk reintroduced at TRNP to understand population growth. Pregnancy rates and survival rates are important for management because they can explain whether the population is expanding and by how quickly. Age and sex ratios can determine whether the population is successful at recruitment and availability of sexually mature adult elk, respectively. Wildlife managers incorporate these data into models to assist in managing elk. Overall, the herd increased from 47 elk in March 1985 to 350 In January 1993 (Sargeant and Oehler 2007). These researchers combined vital rates in a population projection model and compared model projections with observed elk numbers and population ratios. Data from this study suggests that there was a high rate of survival in juveniles up until 8 months, that elk populations were increasing, and that there was a 1.2 female to male sex ratio (Sargeant and Oehler 2007). Of the adult and sub-adult female elk, 93.8 percent were pregnant. The overall rate of increase was affected by environmental variation in vital rates and by chance variation in numbers of births, numbers of deaths, and sex ratios at birth (Sargeant and Oehler 2007). They also took into account those elk that were harvested during a legal hunting season, other mortalities within the park, and those that lost communication with the GPS collars used for gathering data. In this study, a mild environment and abundant forage contributed to high recruitment and survival rates (Sargeant and Oehler 2007). Their data projections have been most useful for comparing hypothetical management strategies in short-term management planning and to display how slowly or quickly a population can advance with using these types of rates and ratios.

In 2014, use of water developments by elk was examined in TRNP. The frequency of elk populations around permanent water sources was examined, and it was hypothesized that elk would stay a relative distance from water sources, but their findings showed greater distances than predicted (Sargeant 2014). The authors only took into account non-migratory elk in TRNP; from the results collected, the water needs and usage by free-ranging elk in this area is still not well understood.

Prior research in North Dakota is limited to elk movement and food habitats in the badlands (Sullivan 1988, Westfall 1989, Strassler 1996, and Osborn et al. 1997). Sullivan (1988) examined the TRNP elk herd to determine the distribution, habitat use, and effects of elk presence on other species and habitat. The population size nearly doubled over 2 years (47 to 80 elk) along with their home range (35 to 75 km^2). Their habitat use increased in variety; graminoids were the most utilized forage for fall, winter, and spring, and these elk foraged on forbs in the summer. Their feeding habits suggested that they foraged in early morning and late evening and utilized grasslands from spring to fall and through the day in winter if cover was not sought.

Westfall (1989) studied 8 elk previously equipped with radio-collars in TRNP to determine home range and habitat use during 4 seasons from 1987–1988. Over a 4 year period, the population had grown at a logarithmic rate of 0.31. Also, the elk bulls segment of the population (like the Turtle Mountain herd) had segregated from cow elk during this study (Westfall 1989). The largest home ranges occurred in summer for bulls (80 km^2) and cow-calves (62.6 km^2). Male elk appeared to prefer more rugged terrain over females, but all elk foraged primarily on upland grasslands throughout all 4 seasons.

Overhead cover was used at a similar rate during winter months and elk preferred to bed down near foraging areas during this time. Overhead cover was used during summer months.

Strassler (1996) estimated home ranges and habitat use on 10 collared elk in the northern badlands of North Dakota. The data show that the herd had 4 distinct herd segments, exhibiting seasonal movements and home range fidelity. This elk herd originated from an accidental release of Rocky Mountain elk in 1977 (Knue 1991, Strassler 1996). Average home ranges were 0.4–12.1 km^2 for the 10 collared adult cow elk. Minimum convex polygons (MCP) were used to calculate home ranges. MCP is a method that creates a convex polygon around the least amount of locations that encloses all other locations (Millspaugh et al. 2012, Silvy 2012). The habitat use analysis separated the two herds, Killdeer Mountain, and northern Badlands. The authors separated their analysis into summer and fall seasons and found that the elk herds during both seasons used grass only in the early morning hours or early evening hours, and spent majority of their time in forested areas throughout the day and night. The elk herds favored oak/ash forests compared to any other habitat. The Killdeer Mountain elk and northern badlands elk did not exhibit migration behavior, but did have seasonal movements that overlapped with each other like the Turtle Mountain and Pembina Hills herds.

There was a study conducted where fecal samples and rumen were examined from elk in the northern Badlands and Pembina Hills elk herds (Osborn et al. 1997). The technique of using fecal samples was proven useful for describing diets, and both sampling techniques demonstrating that Pembina Hills elk consumed 79% gramminoids that was 60% corn, while elk in the northern Badlands consumed 67% gramminoids consisting of 24% corn and 12% wheatgrasses. Knowing the composition of elk diets is important for management to understand what habitat they prefer to use to what is available or not available.

Finally, a genetics study evaluated the relatedness of North Dakota and regional elk populations (Denome 1998). This research revealed few differences between elk herds around the country and no significant validation for the maintenance of the Manitoba subspecies.

Study Approaches

From the aforementioned research projects pertaining to elk in North Dakota, we have learned that these elk can make seasonal movements between summer and fall-winter home ranges, use a wide variety of agricultural crops, and that elk have high annual recruitment and survival rates. Despite research conducted on North Dakota elk, there are still gaps in information related to elk management in the state. Elk presumably dispersing from established herds in Canada and North Dakota badlands have started to colonize small areas of suitable habitat in Bottineau, Rolette, Cavalier, Pembina, and Sioux counties. These elk populations are of smaller size (100 to 250 individuals), however, as large herd animals, even modest-sized elk herds can cause localized depredation problems; particularly when they cross political jurisdiction lines such as international and reservation borders. In this case, borders of interest include North Dakota, USA, and Manitoba, Canada. To manage an elk herd, we need to establish the numbers and demographic composition of the herd, size of the area that the herd inhabits, and biological and cultural carrying capacities of these areas. NDGF had little information on these new, potentially burgeoning elk herds.

The benefits gleaned from this project will help inform future North Dakota elk management by providing a detailed description of daily and seasonal movements of cow elk throughout a period up to two years; helping managers to assess the boundaries of current management units; helping managers assess the relative importance of various habitat types to elk; helping managers assess when and where elk may be available for harvest; providing demographic composition of the three elk herds; providing an estimate of population growth rates via fixed-wing aircraft; determining elk behavioral response to fixed-wing aircraft population monitoring; and providing some preliminary information for comparing future survey methodologies (e.g., remote cameras and/or UAS applications). Moreover, results from this study may also inform regional wildlife managers who manage elk herds (e.g., Minnesota Department of Natural Resources, Manitoba Sustainable Development). Specific objectives for this project are as follows:

Objectives

1. Conduct a literature review of elk ecology as it relates to informing better management in North Dakota.
2. Collect baseline information on the number and demographic composition of three elk herds.
3. Determine home range and habitat selection of these herds.
4. Determine seasonal movements of female elk.
5. Enhance the ability to set harvest rates to coincide with population management goals.
6. Determine annual number of calves per cow surviving until fall in each herd.

7. Determine annual hunter harvest rates for radio-collared yearling and adult females.
8. Determine winter mortality rates for radio-collared females after winter aerial surveys have been completed.
9. When possible, evaluate the sightability of elk, via winter aerial surveys, and compare to other population indices.

Study Area

The study area locations are located in Bottineau and Rolette counties (Turtle Mountain herd) along the Canadian border in north-central North Dakota, Cavalier and Pembina counties (Pembina Hills herd) located along the Canadian border in northeastern North Dakota, and Sioux County (Porcupine Hills herd) at the south-central part of North Dakota along the North and South Dakota state boundaries (Fig.1). Turtle Mountain is located in Bottineau and Rolette counties, which is our main area of interest for this herd. The Turtle Mountain is the result of harder capstone that resisted glaciation during the last ice age, and rise 200 to 27m above the surrounding prairie This area is a wooded, supporting oak-aspen forests (Seabloom 2011) that includes numerous small lakes and wetlands with interspersed agricultural fields, pasture land, and hay fields, especially near the south of the border (Maskey 2008). The Turtle Mountains on the Canadian side the border is primarily a provincial park of oak-aspen forest. The Pembina Hills in Cavalier and Pembina counties are relatively similar to the habitat of Turtle Mountain except that cropland and agricultural fields are more prevalent. There are coulees and rivers that have eroded the drift prairie forming the Pembina Hills. The Porcupine Hills in Sioux County were formed from an escarpment rising 120m above the surrounding prairie with eroded drainages running east to the Missouri River. The habitat consists mixed grass prairie, cropland, and woody drainages of green ash (*Fraxinus pennsylvanicus*) and bur oak (*Quercus macriocarpus*).

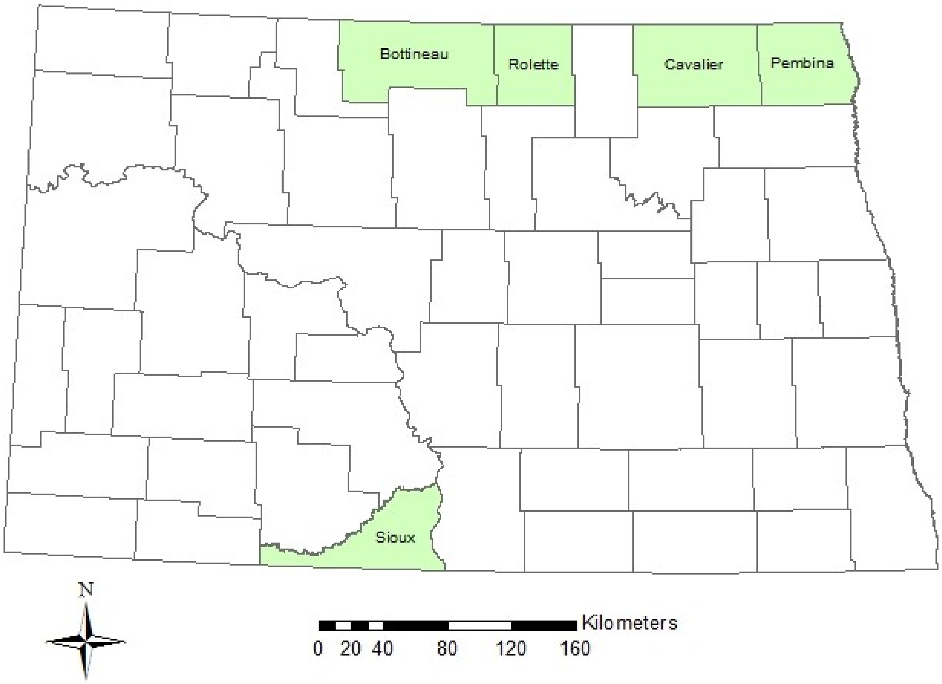


Figure 1. Study areas of elk herds in North Dakota

Methods

A total of 15 female elk were captured with helicopters and affixed with GPS collars (5 elk from each of the 3 counties). I conducted spatial analysis for each of the 15-collared elk using R (Calenge 2006, Pinheiro et al. 2017) for home range analysis, and ESRI ArcMap, Environmental Systems Research Institute, Inc., Redlands, CA for GPS location data management and habitat suitability assessment. I developed 95% and 50% Brownian Bridge Movement Model (BBMM) home ranges to determine overall home range and core areas, respectively. Home ranges are estimated within R following the

Manual of Applied Spatial Ecology (Walter and Fischer 2016). I obtained land cover classifications from the National Land Cover Dataset (NLCD) 2011 (Homer et al. 2015), Annual Crop Inventory (ACI) 2011 from Agriculture and Agri-Food Canada (AAFC), and ESRI world imagery basemap for best available high-resolution imagery. To determine factors that affect adult female elk resource selection, I created resource selection functions (RSFs) by comparing used locations collected from GPS locations to random available locations for night and day for each of the five seasons: winter, calving, summer, archery hunting season, and firearm hunting season. My methods corresponded to within home range (third order) to avoid bias of capture location and homogeneity at the landscape scale. I developed a set *a priori* models which represent effects of season, time of day, and land cover type. I analyzed models using general linear models in R to determine best fit.

Hypotheses

We hypothesized elk within our study areas would have reduced migration distance compared to other studies based on herd size and minor changes in topographic features and elevation gradient within our study areas. We also hypothesized differences in movement patterns depending on herd, season, and time of day.

Study Limitations

Project funding precluded a larger sample size for this study, which is generally viewed by NDGF as a pilot project. Thus, we were unable to assess a full suite of environmental or biological factors that predict or explain elk home ranges. Moreover, we programmed GPS collars to collect fix data for 2 years maximum. Our study took place from February 2016–April 2017, and during this time period 2 of our collared elk were harvested during the hunting season. Thus, we do not have a winter home range for elk #4 (Pembina Hills herd) and elk #9 (Turtle Mountain herd).

CHAPTER II

SEASONAL HOME RANGES OF THREE SMALL ELK HERDS IN NORTH DAKOTA

INTRODUCTION

Elk (*Cervis canadensis*) are large, charismatic ungulates that once were the most widely distributed cervid in North America before they were extirpated from most of their range in the late 1800s (Geist et al. 2000, Seabloom 2011, Keller et al. 2015), and extirpated from North Dakota about 1900 (Knue 1991). Since then, elk have been reintroduced into historical locations and have expanded their range (Yott et al. 2011). Their dispersal and reintroduction from historical range has led to recolonization of areas with suitable habitat (Müller et al. 2017), and today, elk are again among the most widely distributed member of the deer family in North America (Sawyer et al. 2007). In North Dakota, an elk herd first appeared in the Pembina Hills of Cavalier and Pembina counties in the early 1970s. In 1977, as a result of an accidental release, elk became established in the Killdeer Mountains in Dunn and McKenzie counties. In 1985, Theodore Roosevelt National Park (TRNP) released 47 elk into the southern unit in Billings County. Over time, elk from TRNP have established themselves in several small herd throughout the southern Little Missouri National Grasslands in Billings, Golden Valley and Slope counties. In the late 1980s and early 1990's the North Dakota Game and Fish Department began receiving reports of elk in the Porcupine Hills of Sioux County. These animals presumably had dispersed from TRNP (W. F. Jensen, NDGF, personal communication). In the early 1990's incidental observations of bull elk were reported in the Turtle Mountains (Bottineau and Rolette counties). Recently, however, new observations of small groups of elk have been reported in the Turtle Mountains along the border with

Manitoba, Canada. Baseline biological information such as population demographics, movements, and home range sizes is limited for the Pembina Hills, Turtle Mountain, and Porcupine Hills elk herds.

Elk are a keystone species that can have positive and negative effects on habitat, other species (e.g., trophic cascade) and people (Noss and Cooperrider 1994, Greenberg et al. 2016). In the U.S., for example, federally managed public land provides millions of acres of suitable elk habitat where people may observe elk and other wildlife species, especially in the western states where elk are common (Lyon and Christensen 2002). Thus, elk have high social and economic values, such as funds generated through hunting permits and for local businesses that benefit from hunters and other wildlife recreationists that elk attract (Lyon and Christensen 2002). Conversely, overpopulation can lead to human-wildlife conflicts such as property damage, crop depredation, car collisions, and disease transmission (Hegel et al. 2009, Walter et al. 2010*a*, DeVore 2014, Brenan et al. 2015). These negative impacts can lead to lower landowner tolerance (i.e., reduced cultural carrying capacity), especially from growers experiencing crop depredation from elk (Hegel et al. 2009, Walter et al. 2010*a*, DeVore 2014, DeVore et al. 2016).

Conservation and management success, paired with elk adaptability, is dependent on knowing population sizes and movements (Richard et al. 2014). Studying movements of individual elk, we gain insight into population distributions, resource use, dispersal strategies, social interactions, and general patterns of space use (Horne et al. 2007). In addition, habitat resource selection can provide insights on resource-use patterns that influence survival and fitness in various habitats (Boyce and McDonald 1999). Understanding range expansion of newly colonized elk populations can provide insight on maximum sustainable rates of increase which is essential to efficient management (Sargeant and Oehler 2007). Although elk are among the most widely distributed and studied species, supportive data for elk ecology and management has often focused on forested environments in more montane habitats (Irby et al. 2002, Sawyer et al. 2007, Merkle et al. 2016). Moreover, there are a paucity of studies that address elk ecology and management in North Dakota, with most focusing on the Killdeer Mountains and TRNP in the western part of the state (Sullivan 1988, Westfall 1989, Strassler 1996, Osborn et al. 1997).

North Dakota Game and Fish Department (NDGF) had little information on 3 North Dakota elk herds during a time when some landowners and farmers were reporting elk herds frequenting their croplands in areas where they once were rarely or infrequently observed (W. F. Jensen, NDGF, personal communication). We attempted to collect baseline ecological information on elk herds in the Turtle Mountain, Pembina Hills, and Porcupine Hills areas of North Dakota to enhance the ability to set harvest rates to coincide with population management goals. Our study objectives were to obtain baseline information on the demographics (via winter aerial surveys), movements (seasonal and diel), and habitat selection of elk within these 3 herds. We also attempted to determine annual number of calves per cow surviving until fall in each herd, hunter harvest rates for yearling and adult females, and winter mortality rates. Here we present results from these inquiries, but reserve habitat selection analyses for a separate report. We hypothesized elk within our study areas would have reduced migration distance compared to other studies based on herd size and minor changes in topographic features and elevation gradient within our study areas. We also hypothesized differences in movement patterns depending on herd, season, and time of day.

METHODS

Study Area

Our study areas were generally restricted to northern and southern North Dakota, a state with a continental climate marked by hot summers (record high 49 ℃) and harsh, cold winters (record low -51 ℃), with an average annual precipitation of 42.7 cm (Seabloom 2011, Wilckens et al. 2016). We selected study areas based on farmer complaints about increased elk sightings. Our study areas included a location in the northcentral portion of the state known as the Turtle Mountain (Bottineau and Rolette counties), northeastern portion of the state known as the Pembina Hills (Cavalier and Pembina counties), and one location in the southcentral part of the state, referred to as the Porcupine Hills (Sioux County; Fig. 1). Turtle Mountain, straddles the U.S. and Canadian border, and rises 200–275 m above the surrounding prairie, allowing oak-aspen forests to thrive in these areas (Seabloom 2011). Common tree species include aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), box elder (*Acer negundo*), and bur oak (*Quercus macrocarpa*; Seabloom 2011). Turtle Mountain is a patchwork of forest, small lakes and wetlands, and agriculture fields; especially on the U.S. side of the border (Maskey 2008, Seabloom 2011). The Canadian portion of the Turtle Mountains is primarily managed as a provincial park, and thus an oak-aspen forest. The Pembina Hills are similar in vegetation to Turtle Mountain except that cropland and agriculture fields are more prevalent. There are also coulees (deep ravines) and rivers in Pembina Hills; downcutting of these rivers differentiates this terrain from Turtle Mountain.

The Porcupine Hills consist of highly eroded areas, steep escarpments and buttes, and rise 120m above surrounding plains, approximately 730 m above sea level. A dryer landscape dominates the Porcupine Hills. The habitat consists of woody draws of ash bur oak forests within eroded draws surrounded by mixed and shortgrass prairie, including blue grama (*Bouteloua gracilis*), western wheatgrass (*Pascopyrum smithii*), prairie Junegrass *(Koeleria macrantha*), needle-and-thread (*Hesperostipa comate*), needleleaf sedge (*Carex duriuscula*), yarrow (*Achillea millefolium*), gumweed (*Grindelia squarrosa*), silver sage (*Salvia argentea*) , and prickly pear cactus (*Opuntia polyacantha*) (Seabloom 2011, Wilckens et al. 2016).

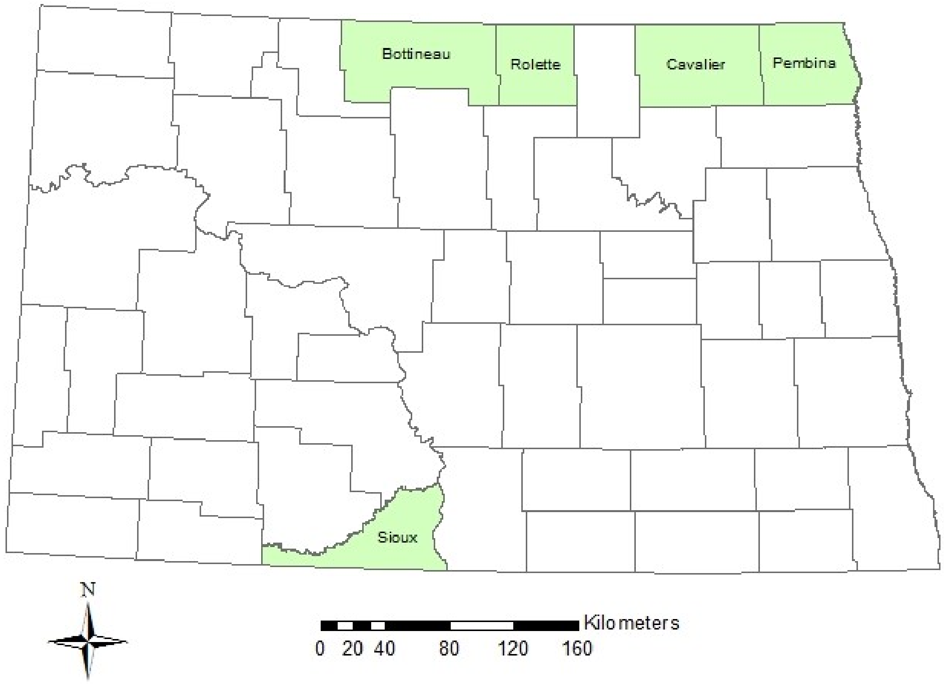


Figure 2. Project study areas comprised: 1) Bottineau and Rolette, 2) Cavalier and Pembina, and 3) Sioux counties, North Dakota, USA.

Data Collection

Capture. – In February 2016, we captured 15 adult female elk via helicopter (Native Range Capture Service, Elko, NV, USA) and net-gun based on techniques modified from Webb et al. (2008). We fitted captured elk with global positions system (GPS) tracking collars capable of <3 m location accuracy (2016 production; Advanced Telemetry Systems, Minnesota, USA). Collars (Iridium Model #G2110E) were programmed to record a GPS location once every 4 hours, providing 6 locations per day and battery life until May 2018. During the winter of 2016–2017, we flew aerial surveys in a fixed-wing aircraft once per month, depending on snow cover, to collect population estimates of elk associated with each of our collared elk. One person from the research team would accompany the pilot and record demographics of elk surrounding each collared elk. We would fly directly to each elk using VHF frequency. Using data sheets, we would record the total number of elk and category: spike bulls (1.5 years-of-age) raghorn (3–5 points, small thin antlers; Stent and Phillips 2013) bulls (2.5 years-of-age), adult bulls (≥3 years-of-age), cows (≥1.5 years-of-age), and calves (>1 year of age). One aerial survey was conducted in transects in all 3 study areas, counting all elk observed without flying directly to collared elk. Other aerial surveys conducted flew systematic transects covering a designated study area at 1.7 km intervals. All aspects of animal capture and handling were approved by the University of North Dakota Institutional Animal Care and Use Committee (Sikes et al. 2016; IACUC Protocol #1602-1).

Estimating and Comparing Home Ranges. – We used Brownian Bridge Movement Models (BBMM; Bullard 1999) to estimate home ranges for each elk and time period of interest. BBMM accounts for proportional intensity of area use and nonindependence of observations over short time periods, assuming that movements are random during the interval between fixes (Kranstauber et al. 2012, Walter et al. 2015). Because we wished to test whether elk use habitat differently at varying times of day and year, we estimated home ranges for each elk separately for each time period of interest, including diel (daytime and nighttime) and during 5 biologically or management-defined seasons: calving (May 1–June 30), summer (July 1–August 31), archery elk hunting season (September 1–September 30), gun elk hunting season (October 1–December 31), and winter (January 1–April 30). Daytime and nighttime were determined based on a sun angle calculation which determines the sunset and sunrise to categorize “nighttime” or “daytime” based on latitude and longitude, and time of year. We estimated BBMM’s for each combination of time of day and using both 50% and 95% isopleth contours in the R package adehabitatHR (Calenge 2006; R version 3.3.2, https://www.r-project.org/, accessed 10 January 2017). We used scripts from the Manual of Applied Spatial Ecology (Walter and Fischer 2016) to run all adehabitatHR analyses.

To test for differences among herds, and effects of time of day and season, we used a general linear mixed effects model (Zuur et al. 2009) with individual elk treated as a random effect. We cannot assume that home range estimates derived from a single individual at different times are statistically independent, and treating elk identity as a random effect accounts for potential pseudo-replication. Elk were included in models as a nested effect within herds. Our primary focus, however, was discerning differences among herds and effects of specific times and seasons, and not on distinctive or typical behavior of individual elk. Accordingly, all other factors were considered fixed effects, for which estimates of effects would be generated. We considered herd, season, and time of day as categorical factors, requiring the designation of a baseline in which to compare other levels. We used summer as the baseline for estimating seasonal effects, daytime as the baseline for time of day, and Pembina County as the baseline for herd differences. We analyzed $\log_{10}$-transformed home range estimates to meet the assumptions of residual normality. We used R package nlme (Pinheiro et al. 2017; R version 3.3.2, https://www.r-project.org/, accessed 10 May 2017) to estimate models with main effects and two-way interactions to test for differences among factors that depended on other factor levels. We did not consider our analysis as a model selection problem because our goal was to test the effects of all of the included factors and not simply to produce a single or set of models that yielded the optimal prediction of home range size.

RESULTS

Population Estimates. – Project staff flew a total of 4 times in each study area, locating GPS-collared elk, and counting the total number of spike bulls, raghorn bulls, adult bulls, cows, and calves surrounding targeted elk (Table 1). We flew once over Porcupine Hills elk in December 2016 without using telemetry but in transects to locate them. We counted 110 individuals at this time that did not target collared elk. We flew once over Pembina Hills elk in January 2017 without using telemetry but in transects to locate them. We counted 97 individuals at this time that did not target collared elk. We flew once over Turtle Mountain elk in February 2017 without using telemetry but in transects to count those seen. We counted 62 individuals at this time that did not target collared elk. During an aerial survey, both sides of the Canadian border were flown by Turtle Mountain and more than 190 elk were counted without using telemetry (Smith 2017). This suggests that there are multiple herds of elk in the Turtle Mountains, of which we had collars in only one of these herds. While flying over all elk herds, it was hard to distinguish calves, cows, rag horns, and adult bulls since the elk were running through forested area. Therefore, we were not able to complete a demographic composition of our elk herds. Mortality rates of our elk was 13%, 2 collared elk out of 15 were harvested during the 2016 hunting season.

Table 1. Elk population estimates based on 4 aerial surveys in Turtle Mountain, Pembina Hills, and Porcupine Hills, North Dakota, USA during 2016–2017.

Herd	**Date**	**Individuals in herd**
Turtle Mountains	March 2016	40
	February 2017	53
	February 2017	190[1]
	March 2016	77
Pembina Hills	December 2016	120
	February 2017	77
	March 2017	116
	March 2016	39
Porcupine Hills	December 2016	78
	December 2016	110
	February 2017	45
	March 2017	97

[1] Survey flown on both sides of the border (Smith 2017).

Home Range Estimation. – We collected 36,051 GPS locations from 15 GPS-collared elk during February 2016–April 2017 (Figures 5–19). The largest 95% isopleth contour for herd home range was from the Porcupine Hills elk herd at $\bar{x}$ = 31.9 km^2 (95% CI: 27.9–35.9; Table 2). Similarly, the largest 50% isopleth contour for herd home range was from the Porcupine Hills elk herd at $\bar{x} = 5.6$ km^2 (95% CI: 4.7–6.5; Table 3). The largest 95% isopleth contour home range for season was from the Pembina Hills herd during gun season at $\bar{x} = 47.5$ km^2 (95% CI: 34.5–60.6; Table 4). The largest 50% isopleth contour home range for season was from the Porcupine Hills herd during gun season at $\bar{x} = 8.3$ km^2 (95% CI: 6.5–10.1; Table 5). The largest home range for time of day was from the Pembina Hills herd during the nighttime at $\bar{x} = 36.9$ km^2 (95% CI: 26.2–47.5; Table 6). Figures 3 and 4 represent heterogeneity of home ranges. Seasonal and time differences are consistent among the 3 herds during our study.

Table 2. Mean 95% elk home range size (km^2) by herd, North Dakota, USA, 2016–2017.

			95% CI	
Herd	**Mean**	**SE**	**Lower**	**Upper**
Turtle Mountain	18.5	2.6	13.4	23.7
Pembina Hills	29.5	3.2	23.1	36.2
Porcupine Hills	31.9	2.0	27.9	35.9

Table 3. Mean 50% elk home range size (km^2) by herd, North Dakota, USA, 2016–2017.

			95% CI	
Herd	**Mean**	**SE**	**Lower**	**Upper**
Turtle Mountain	3.1	0.4	2.3	3.8
Pembina Hills	4.5	0.5	3.5	5.6
Porcupine Hills	5.6	0.4	4.7	6.5

Table 4. Mean 95% elk home range size (km^2) by herd and season, North Dakota, USA during 2016–2017.

				95% CI	
Herd	**Season**	**Mean**	**SE**	**Lower**	**Upper**
Turtle Mountain	Calving	10.8	0.9	8.7	13.0
	Summer	8.7	1.0	6.5	11.0
	Archery	11.6	2.7	5.5	17.7
	Gun	46.1	6.6	31.2	61.0
	Winter	14.6	1.6	10.9	18.3
Pembina Hills	Calving	23.1	7.9	5.06	41.2
	Summer	22.9	6.0	9.3	36.6
	Archery	13.7	2.2	8.8	18.7
	Gun	47.5	5.8	34.5	60.6
	Winter	43.7	7.42	26.2	61.3
Porcupine Hills	Calving	30.7	4.5	20.5	40.8
	Summer	31.5	5.0	20.1	42.9
	Archery	19.5	2.2	14.5	24.4
	Gun	43.3	5.0	32.0	54.6
	Winter	34.6	1.2	31.9	37.4

Table 5. Mean 50% elk home range size (km^2) by herd and season, North Dakota, USA during 2016–2017.

				95% CI	
Herd	**Season**	**Mean**	**SE**	**Lower**	**Upper**
Turtle Mountain	Calving	2.0	0.3	1.4	2.6
	Summer	1.7	0.2	1.2	2.3
	Archery	2.3	0.5	1.1	3.5
	Gun	7.0	0.9	4.8	9.1
	Winter	2.2	0.1	1.9	2.4
Pembina Hills	Calving	3.6	1.1	1.1	6.0
	Summer	3.8	0.9	1.8	5.9
	Archery	2.1	0.4	1.1	3.0
	Gun	7.9	1.1	5.3	10.5
	Winter	5.6	1.1	2.9	8.3
Porcupine Hills	Calving	6.3	1.3	3.5	9.2
	Summer	4.7	0.7	3.2	6.2
	Archery	2.9	0.5	1.9	4.0
	Gun	8.3	0.8	6.5	10.1
	Winter	5.8	0.4	4.8	6.7

Table 6. Mean 95% elk home range size (km^2) by herd and time, North Dakota, USA during 2016–2017.

				95% CI	
Herd	**Time**	**Mean**	**SE**	**Lower**	**Upper**
Turtle Mountain	Day	15.8	3.7	8.1	23.4
	Night	21.3	3.5	14.1	28.5
Pembina Hills	Day	22.4	3.5	15.3	29.6
	Night	36.9	5.1	26.2	47.5
Porcupine Hills	Day	30.2	2.5	25.1	35.4
	Night	33.6	3.2	27.1	40.1

Table 7. Mean 50% elk home range size (km^2) by herd and time, North Dakota, USA during 2016–2017.

				95% CI	
Herd	**Time**	**Mean**	**SE**	**Lower**	**Upper**
Turtle Mountain	Day	2.6	0.5	1.6	3.6
	Night	3.5	0.6	2.3	4.6
Pembina Hills	Day	3.4	0.5	2.4	4.4
	Night	5.7	0.8	4.0	7.4
Porcupine Hills	Day	5.2	0.5	4.2	6.3
	Night	6.0	0.7	4.6	7.4

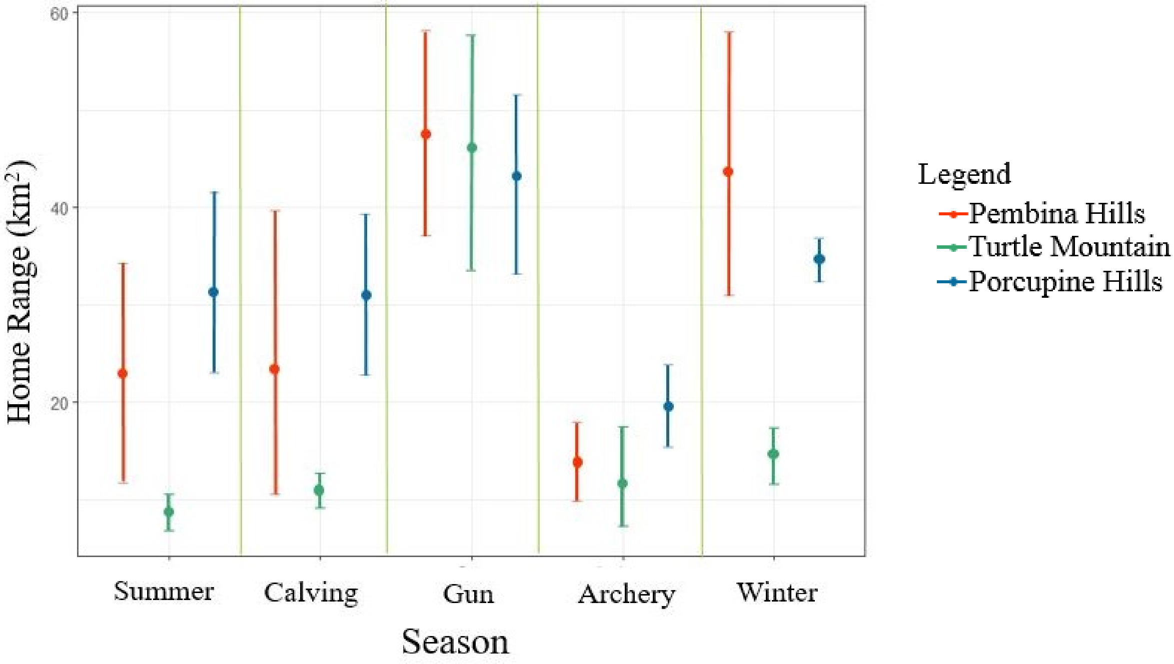


Figure 3. 95% confidence intervals and means of home range (km^2) distribution based on season and herd in Turtle Mountain, Pembina Hills, and Porcupine Hills, North Dakota, USA during 2016–2017.

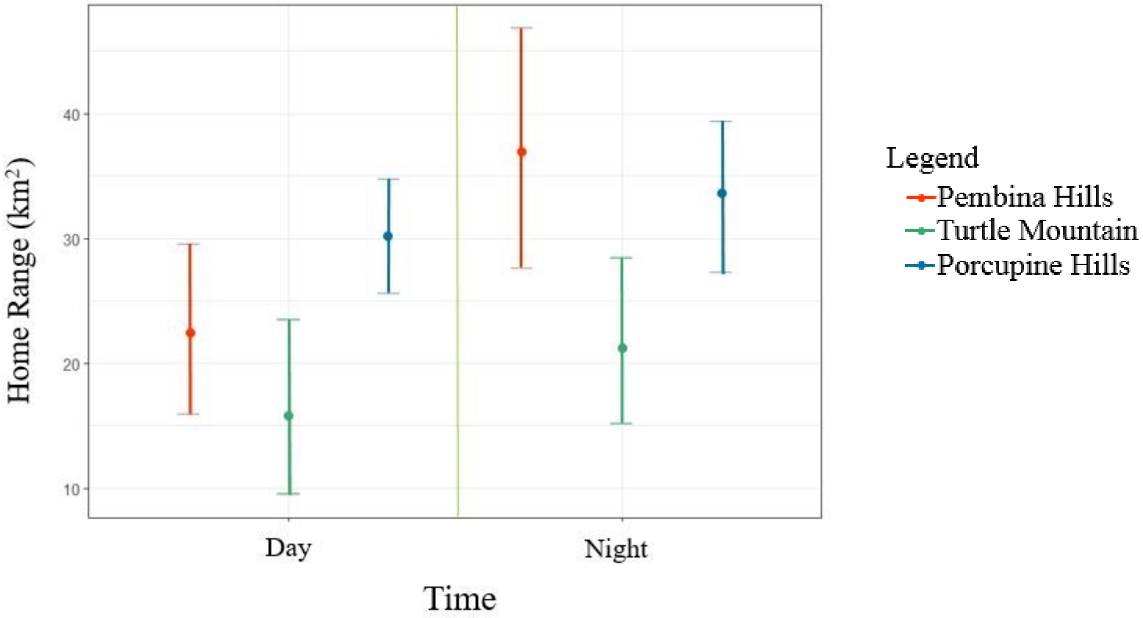
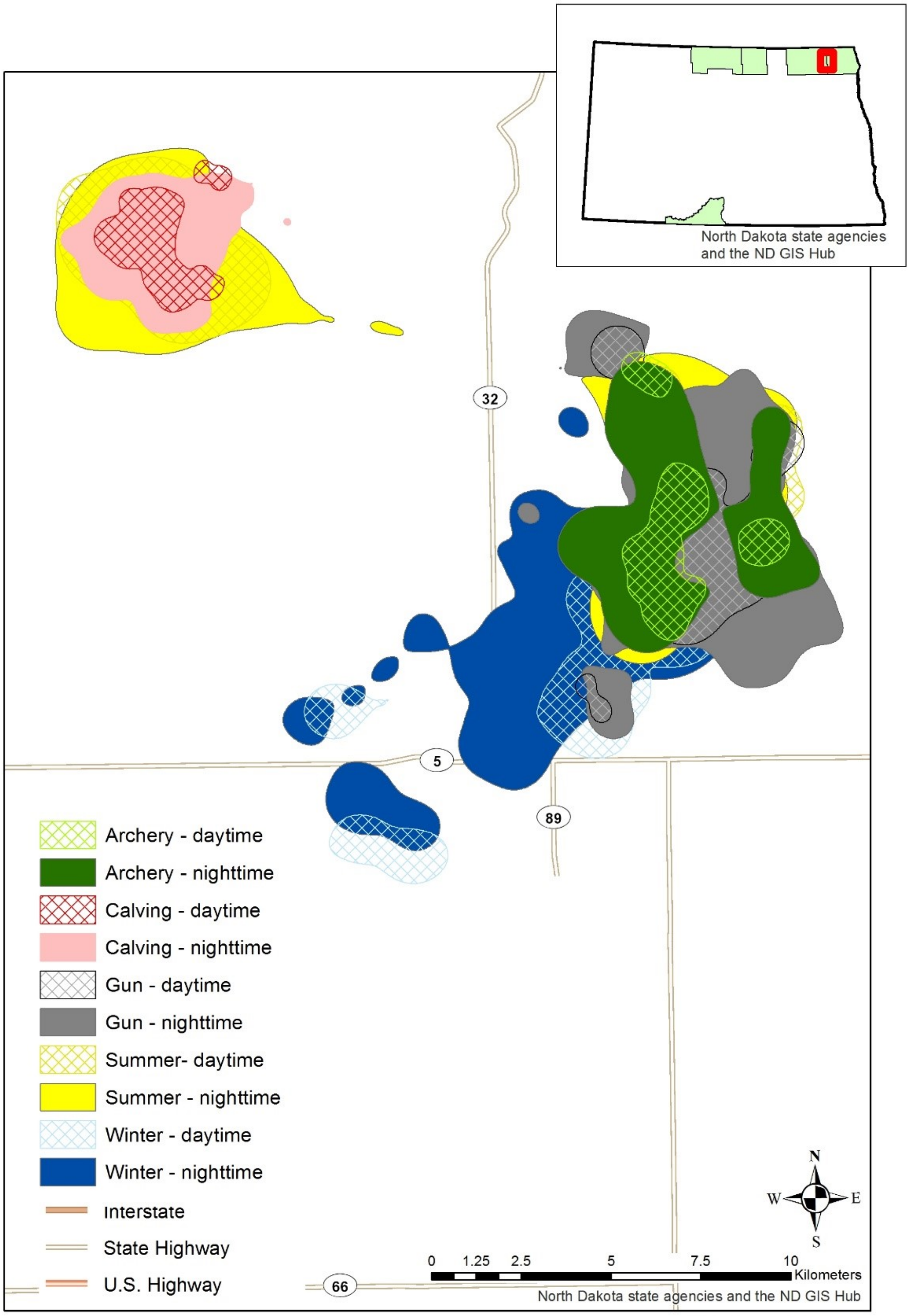


Figure 4. 95% confidence intervals and means of home range (km^2) distribution based on time and herd in Turtle Mountain, Pembina Hills, and Porcupine Hills, North Dakota, USA during 2016–2017.



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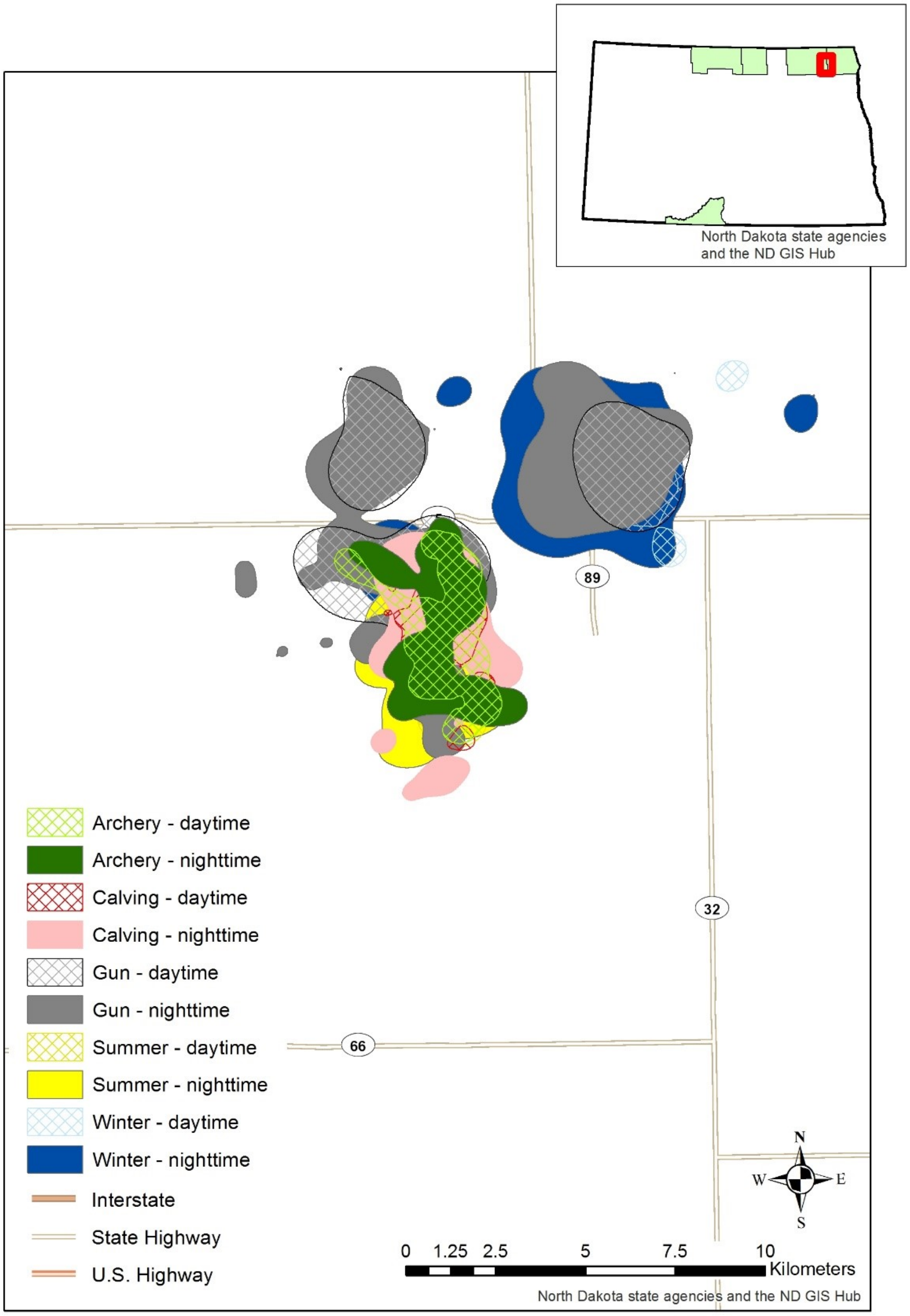
Author: Jacqueline Amor

Figure 5. Map overlay of Elk 1’s time of day and seasonal home ranges (km^2) in Pembina Hills herd, North Dakota, USA.



Author: Jacqueline Amor

Figure 6. Map overlay of Elk 2's time of day and seasonal home ranges (km^2) in Pembina Hills herd, North Dakota, USA.

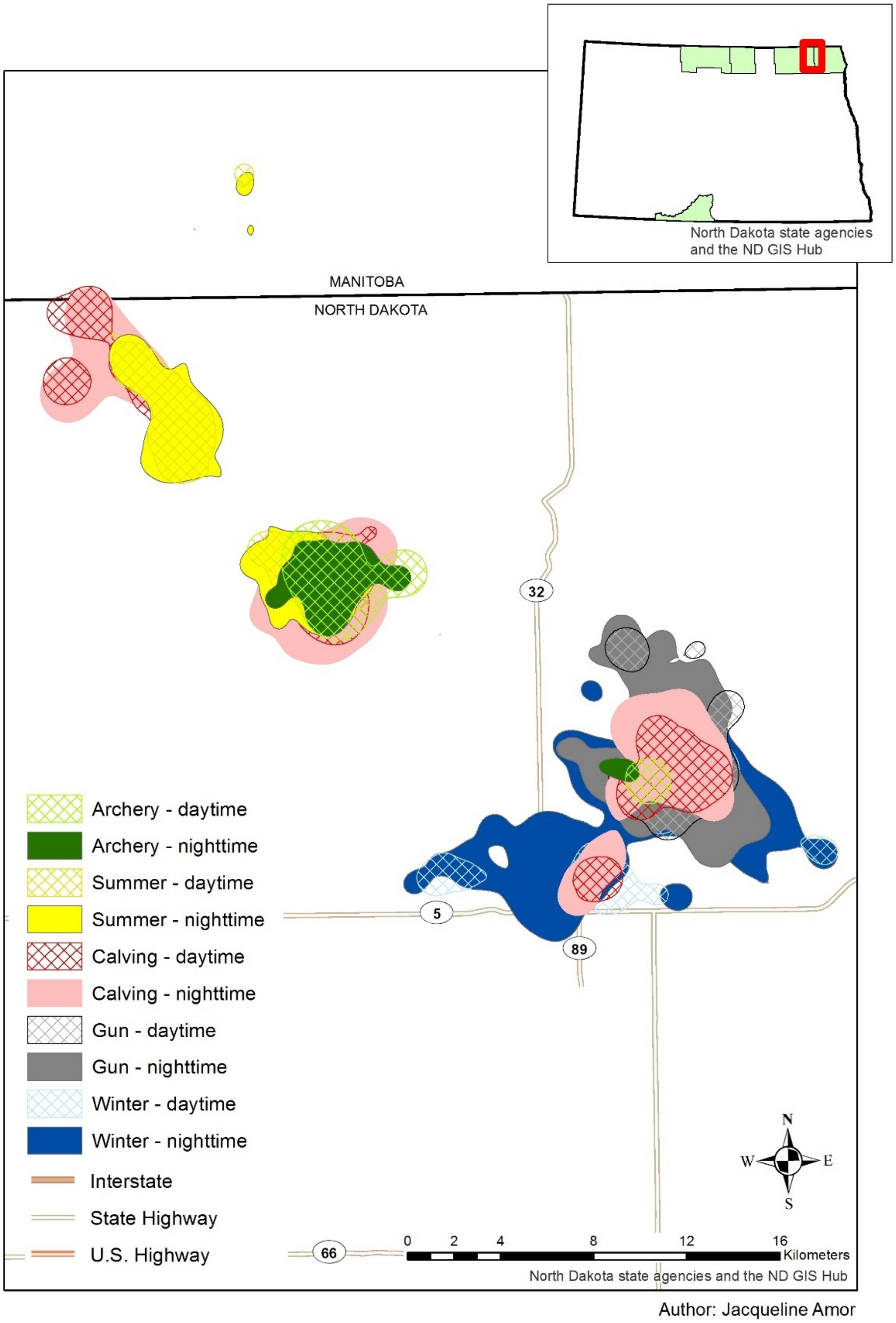


Figure 7. Map overlay of Elk 3's time of day and seasonal home ranges (km^2) in Pembina Hills herd, North Dakota, USA.

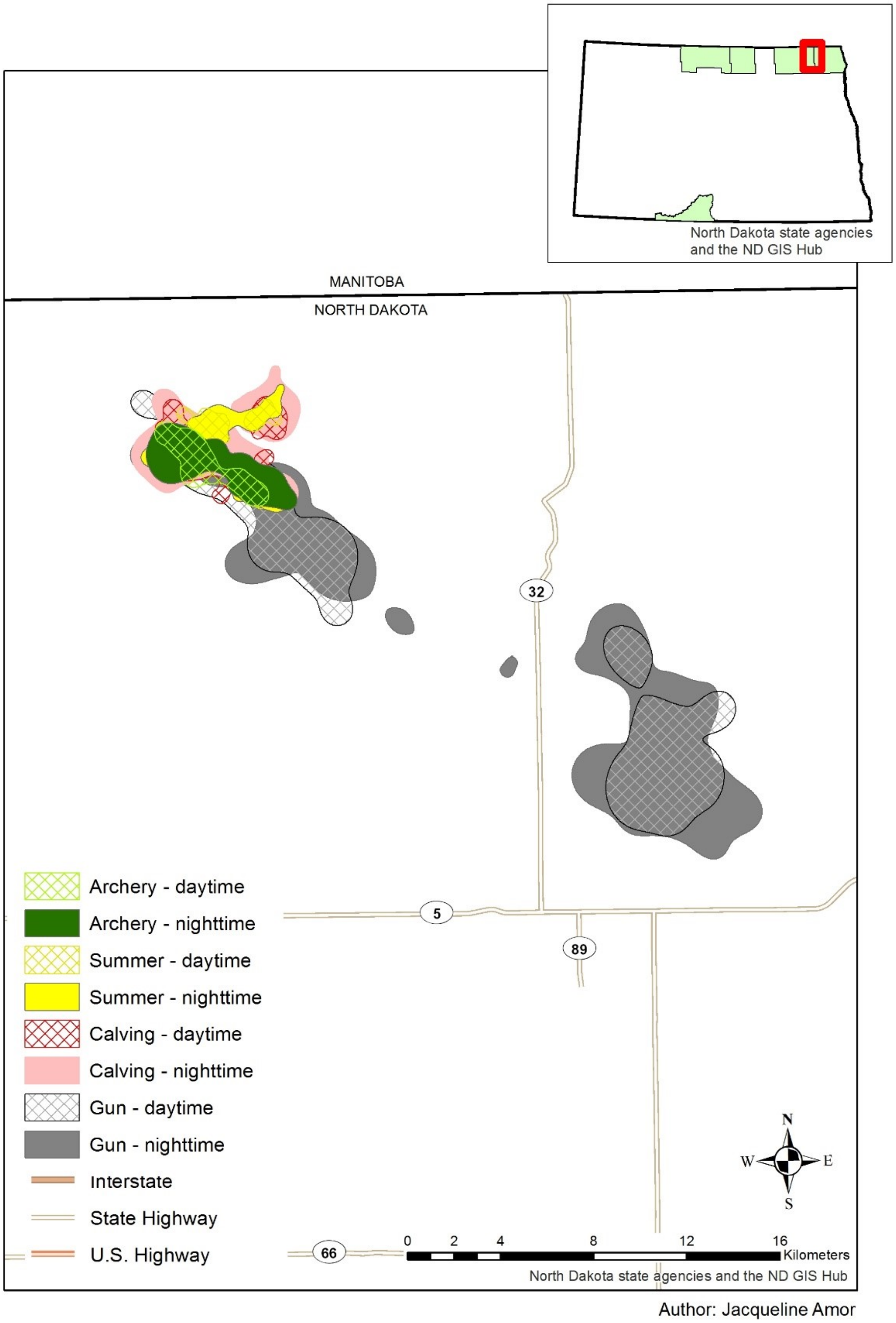
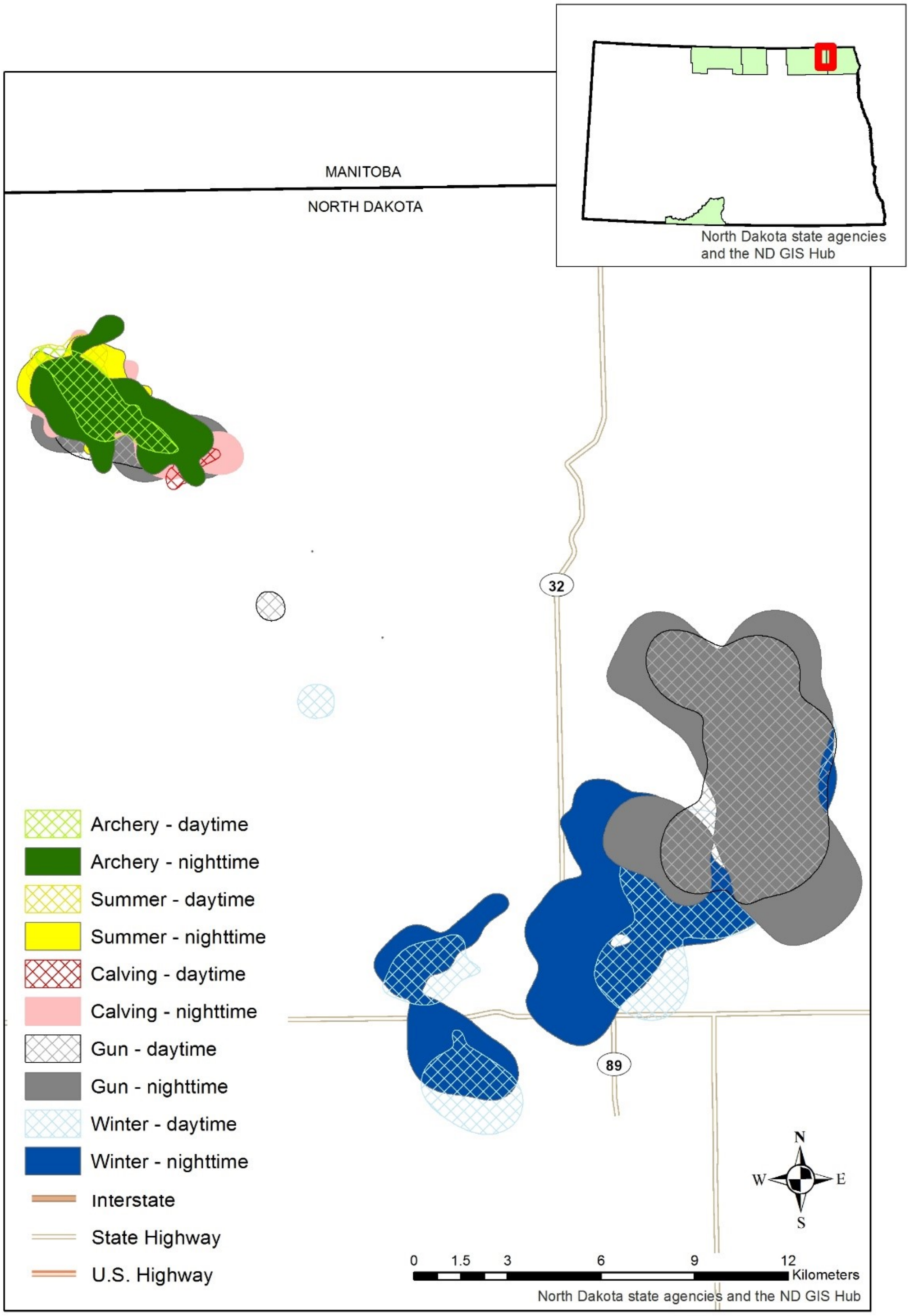


Figure 8. Map overlay of Elk 4's time of day and seasonal home ranges (km^2) in Pembina Hills herd, North Dakota, USA.



North Dakota state agencies and the ND GIS Hub

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Author: Jacqueline Amor

Figure 9. Map overlay of Elk 5's time of day and seasonal home ranges (km^2) in Pembina Hills herd, North Dakota, USA.

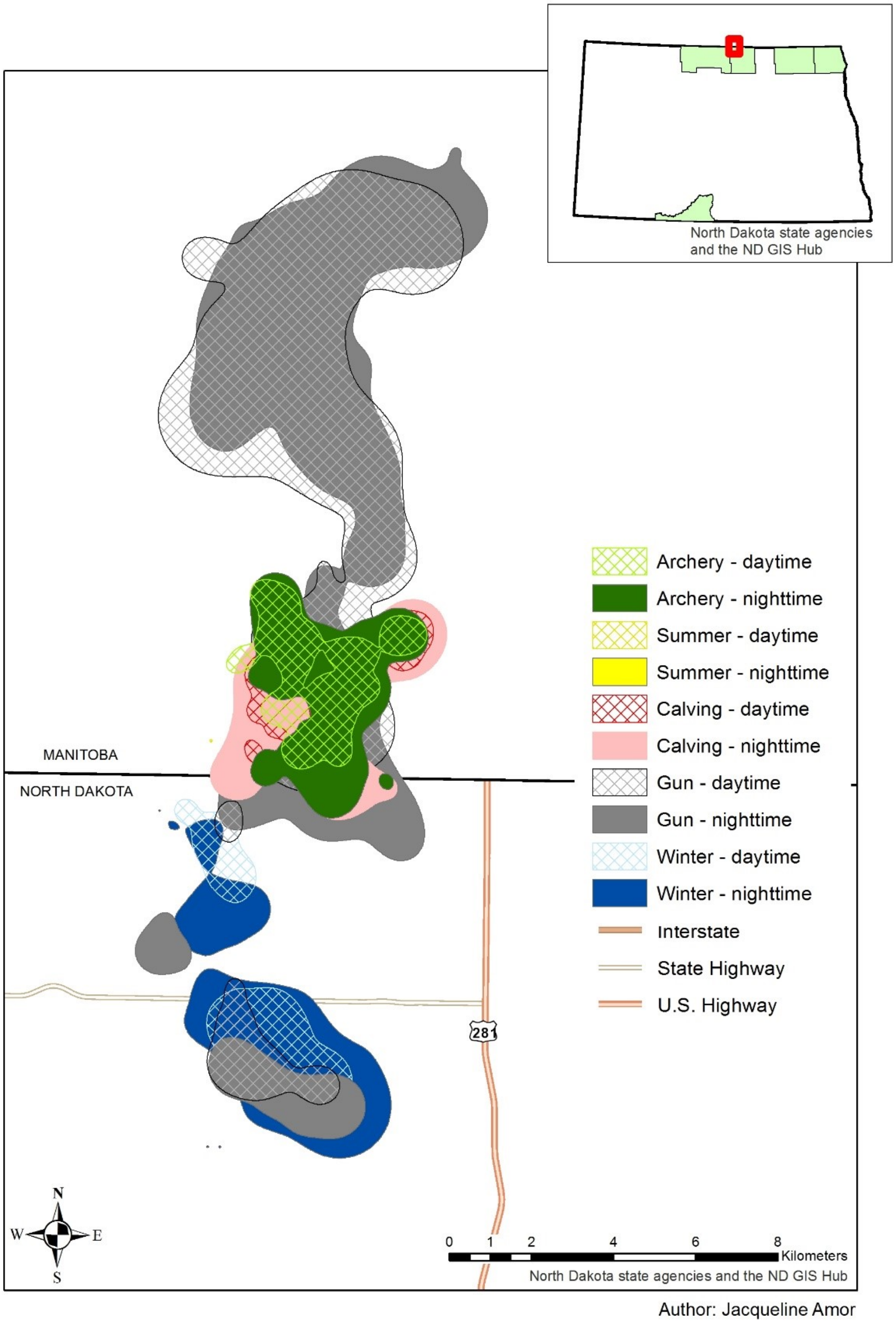


Figure 10. Map overlay of Elk 6’s time of day and seasonal home ranges (km^2) in Turtle Mountain herd, North Dakota, USA.

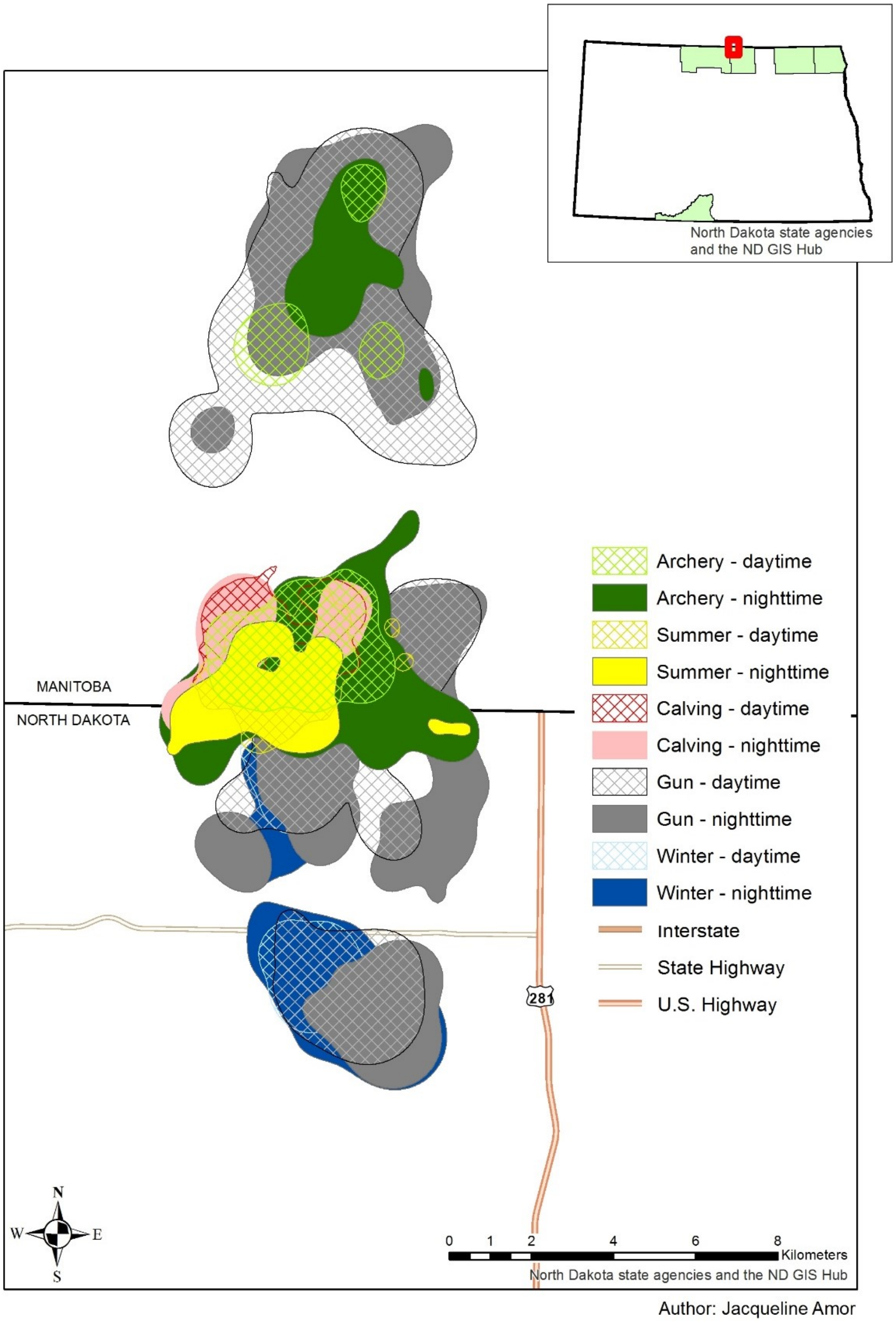
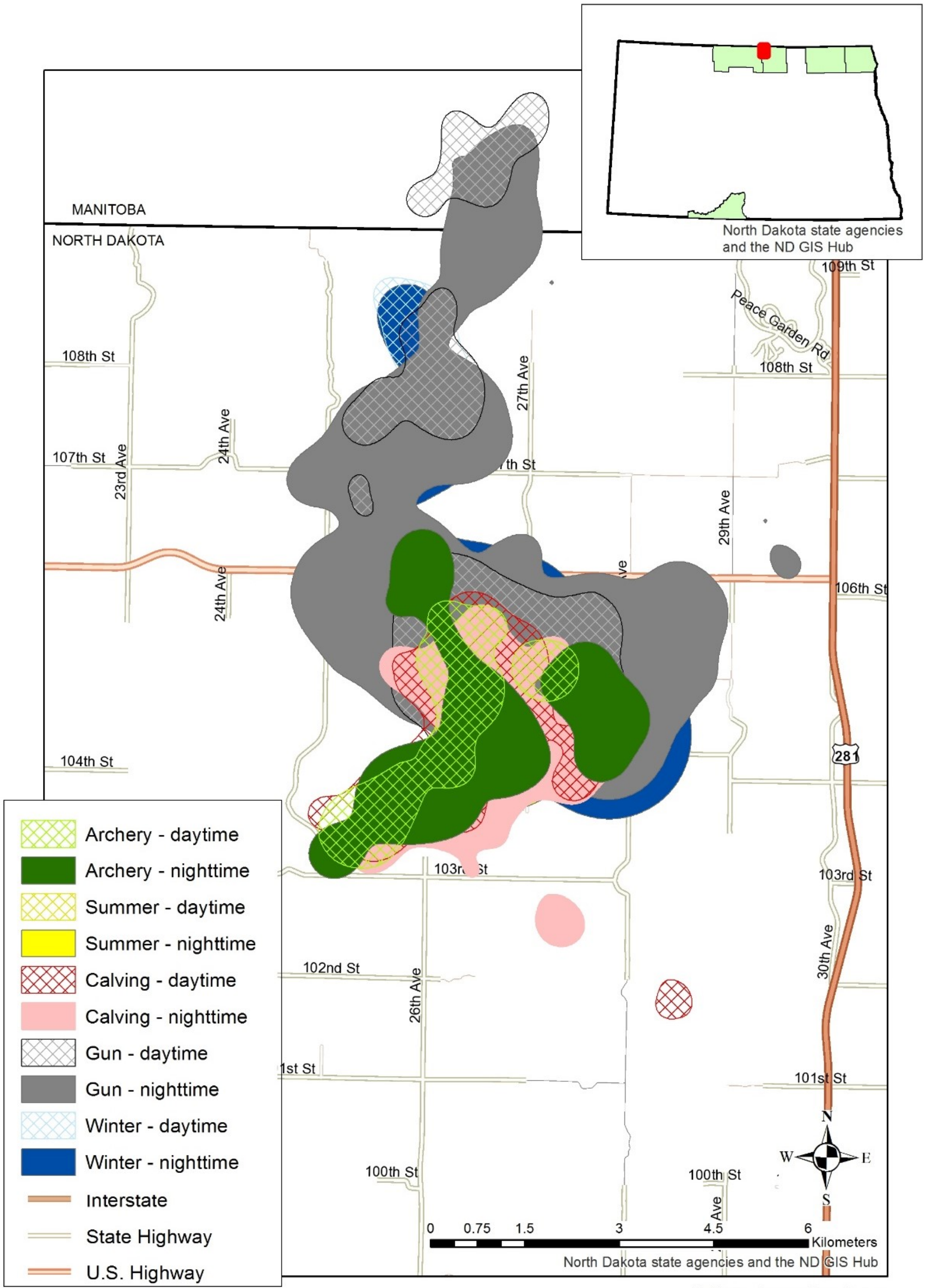


Figure 11. Map overlay of Elk 7’s time of day and seasonal home ranges (km^2) in Turtle Mountain herd, North Dakota, USA.



Author: Jacqueline Amor

Figure 12. Map overlay of Elk 8's time of day and seasonal home ranges (km^2) in Turtle Mountain herd, North Dakota, USA.

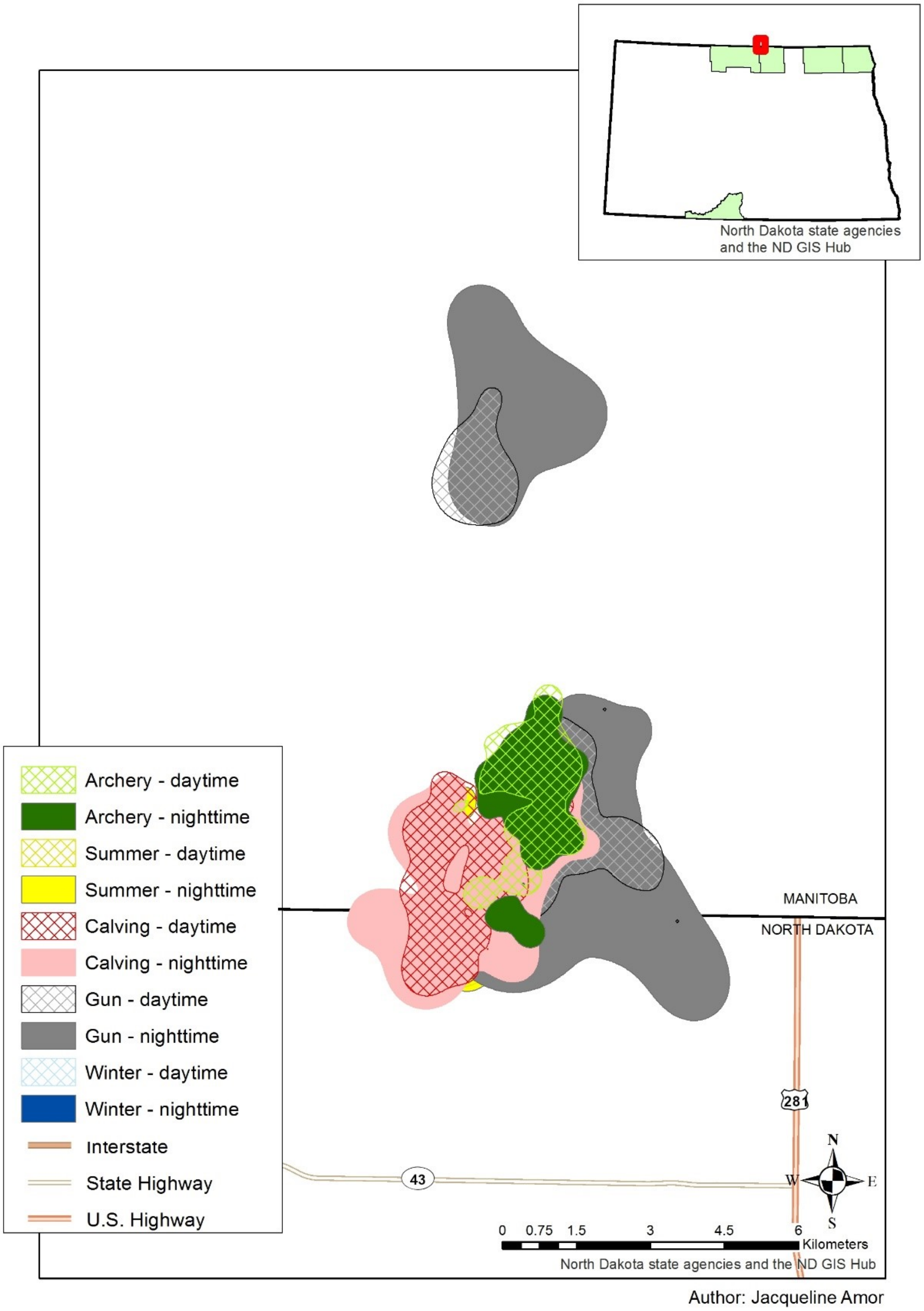


Figure 13. Map overlay of Elk 9's time of day and seasonal home ranges (km^2) in Turtle Mountain herd, North Dakota, USA.

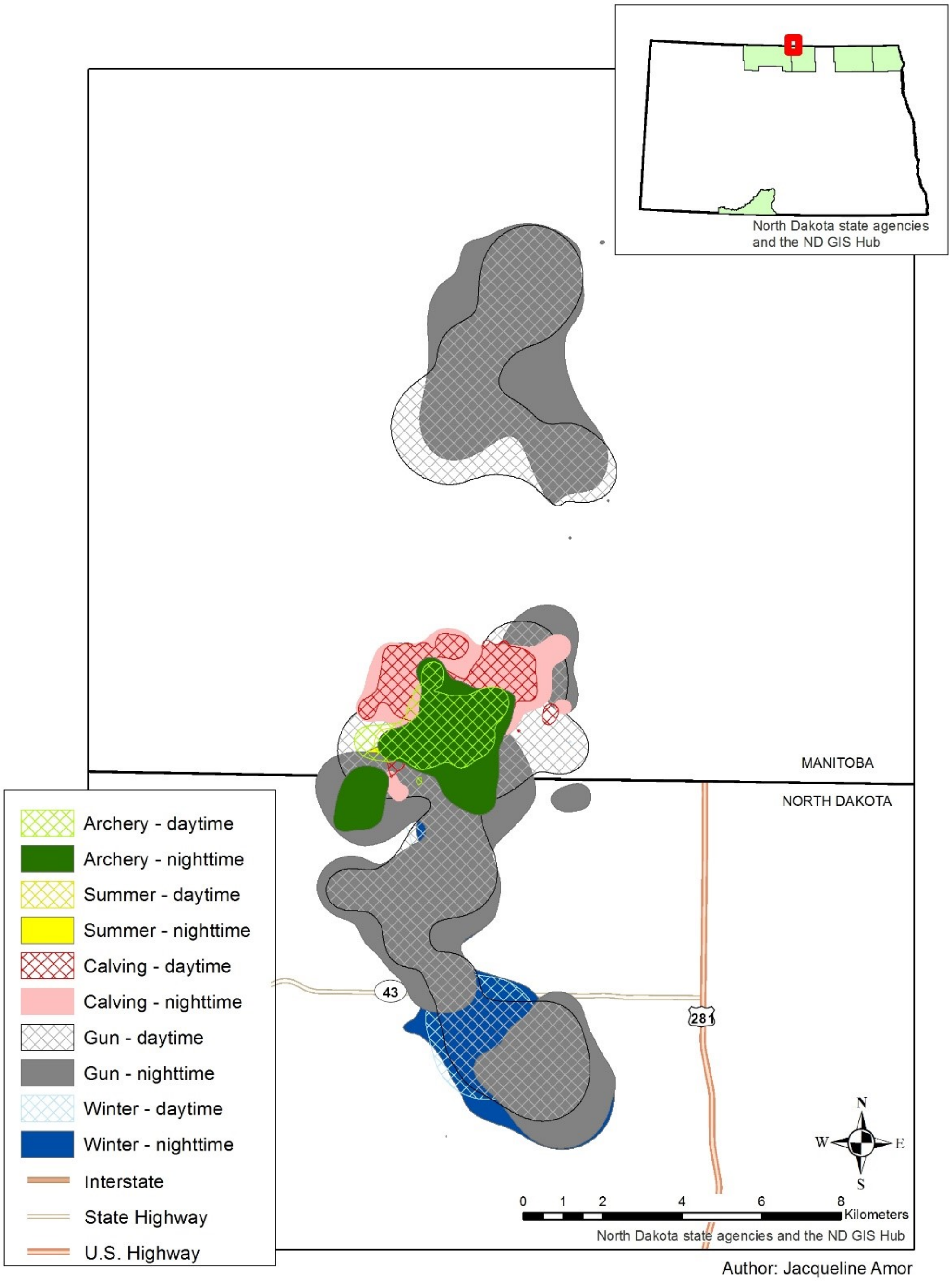


Figure 14. Map overlay of Elk 10's time of day and seasonal home ranges (km^2) in Turtle Mountain herd, North Dakota, USA.

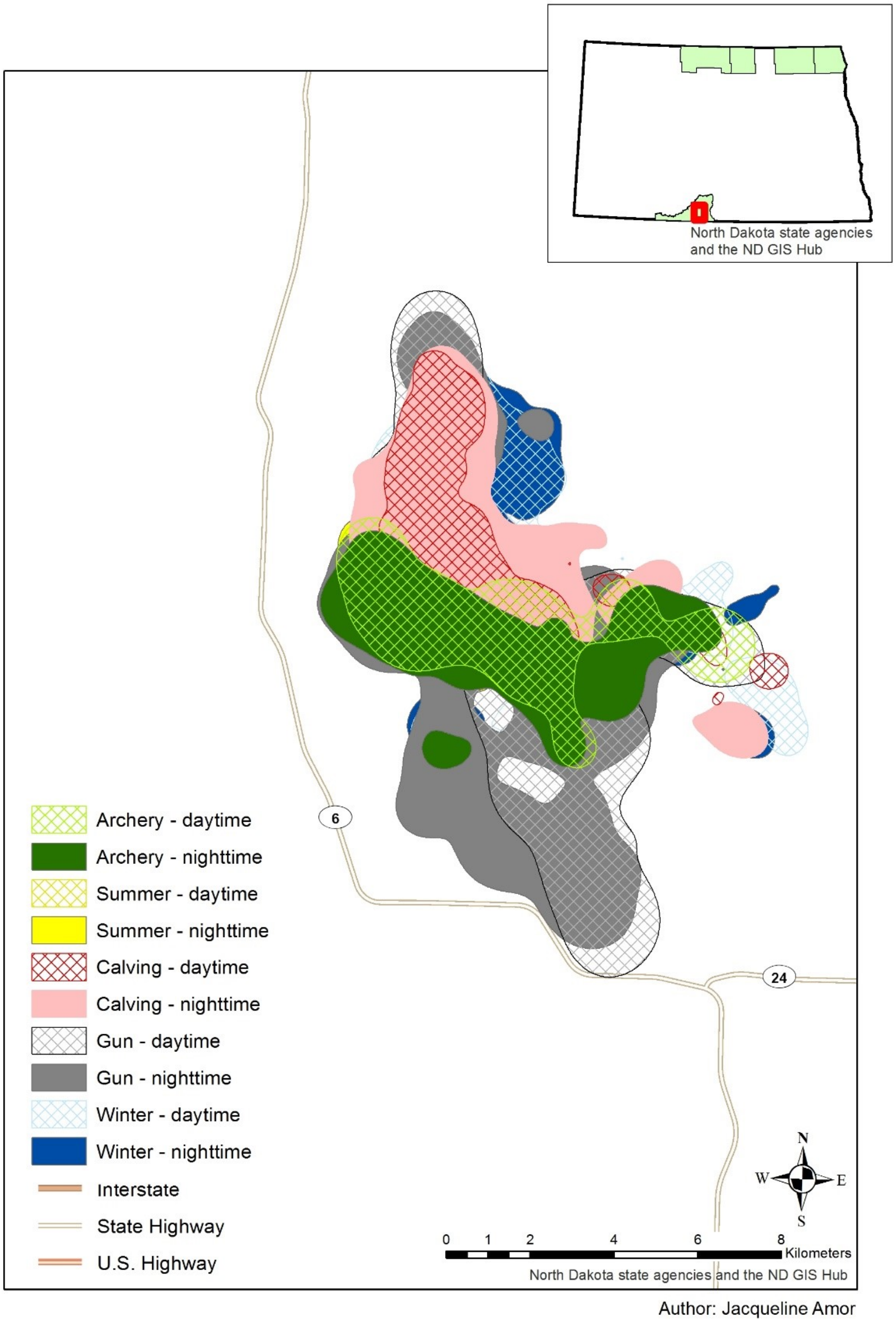


Figure 15. Map overlay of Elk 11's time of day and seasonal home ranges (km^2) in Porcupine Hills herd, North Dakota, USA.

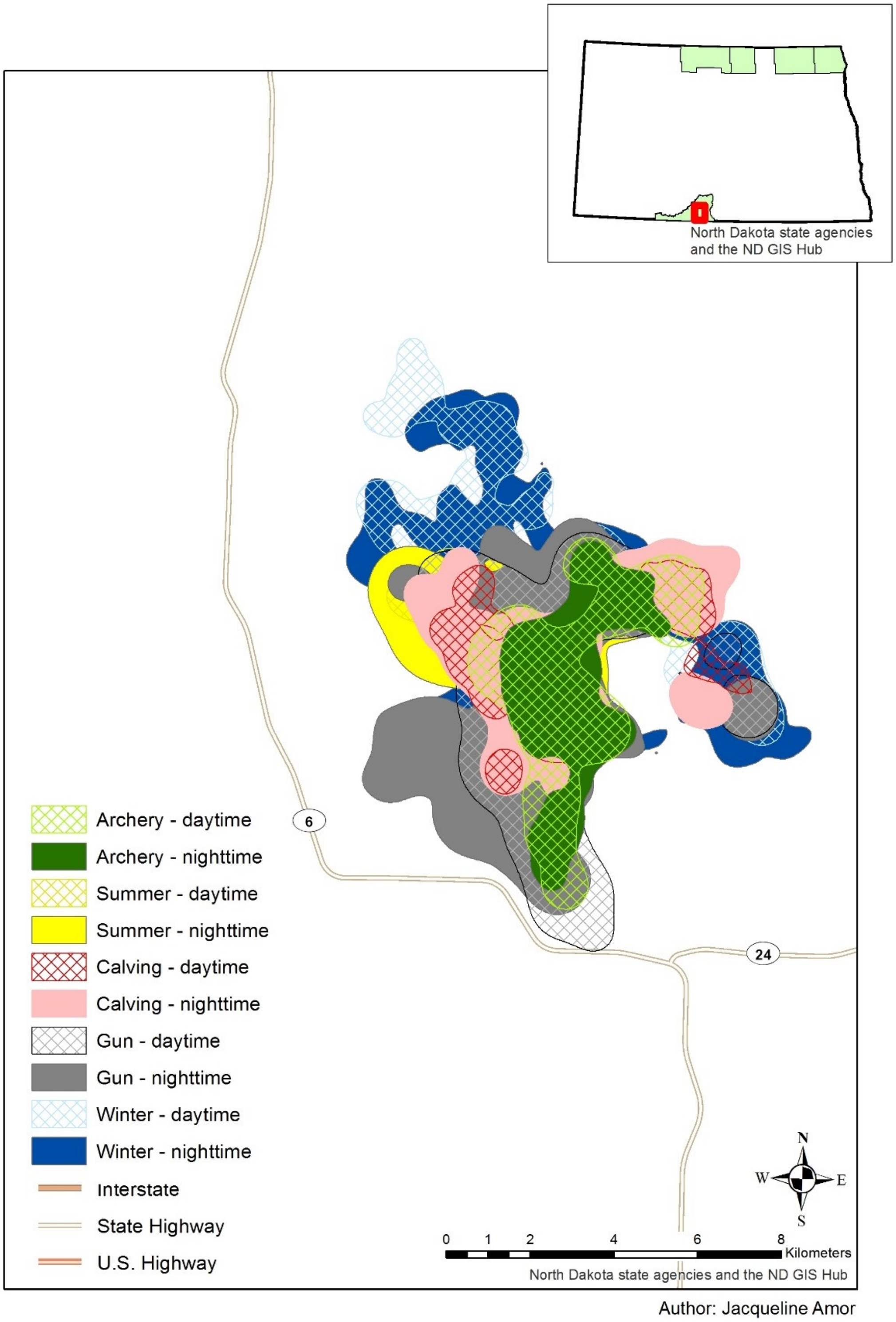


Figure 16. Map overlay of Elk 12's time of day and seasonal home ranges (km^2) in Porcupine Hills herd, North Dakota, USA.

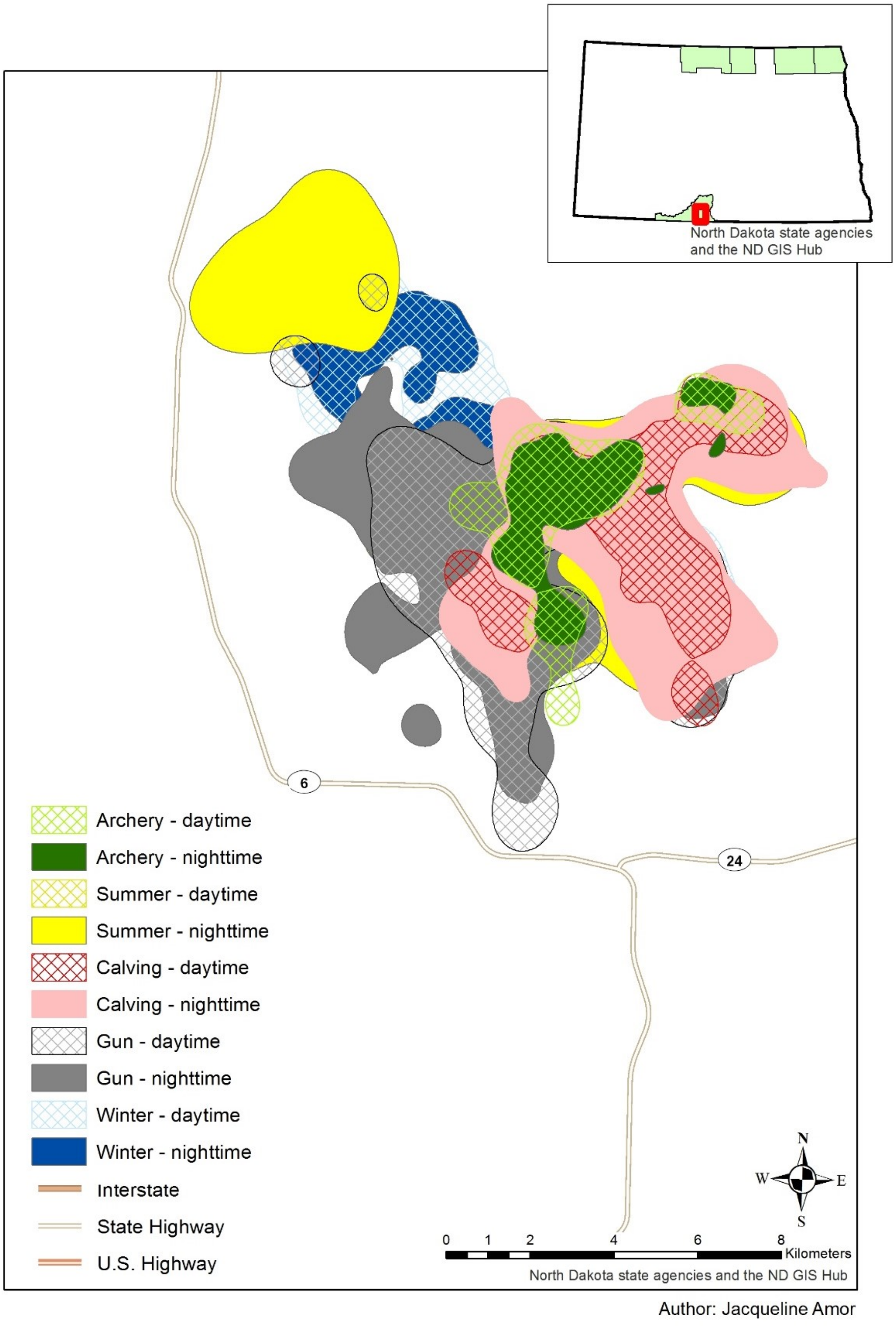


Figure 17. Map overlay of Elk 13's time of day and seasonal home ranges (km^2) in Porcupine Hills herd, North Dakota, USA.

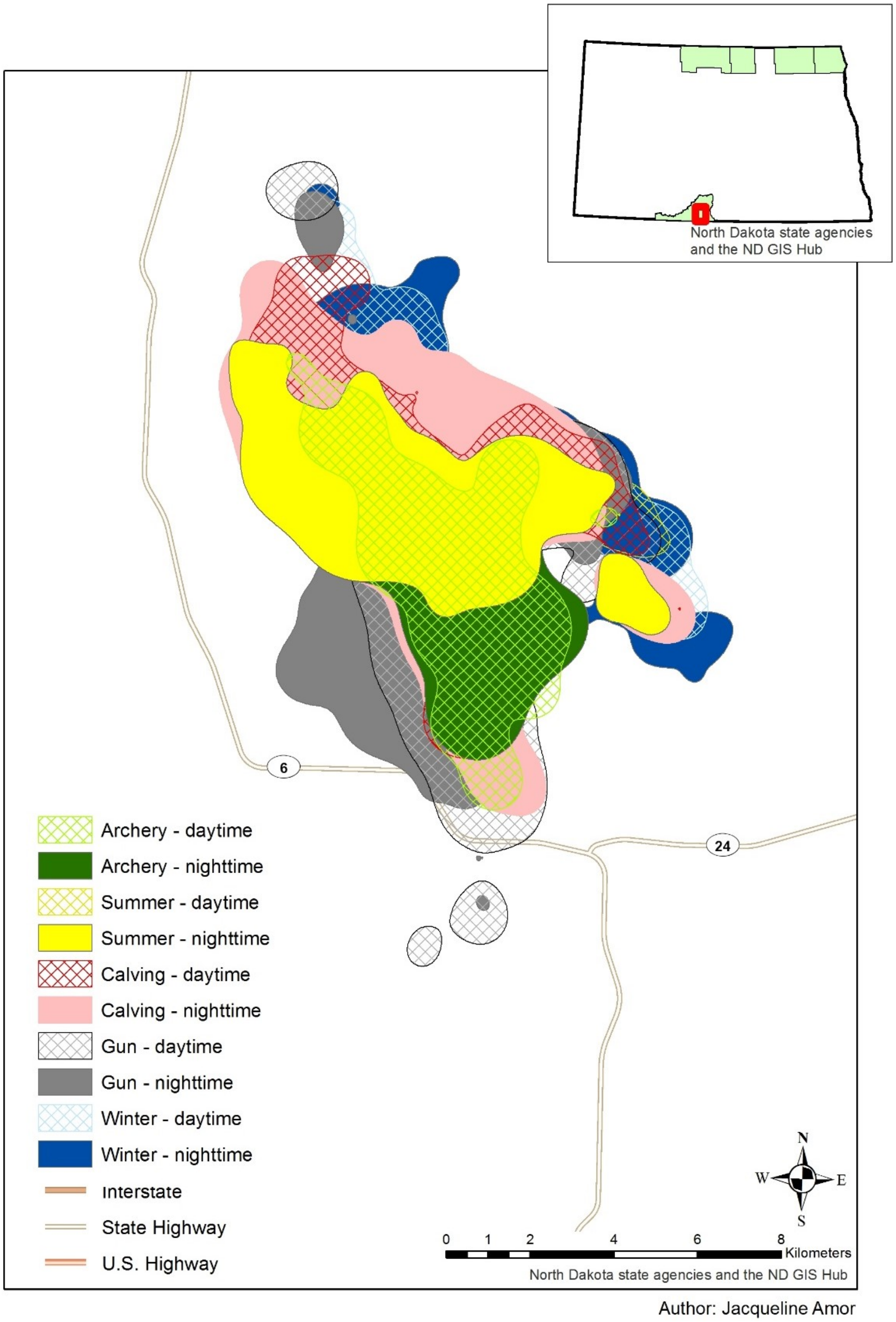
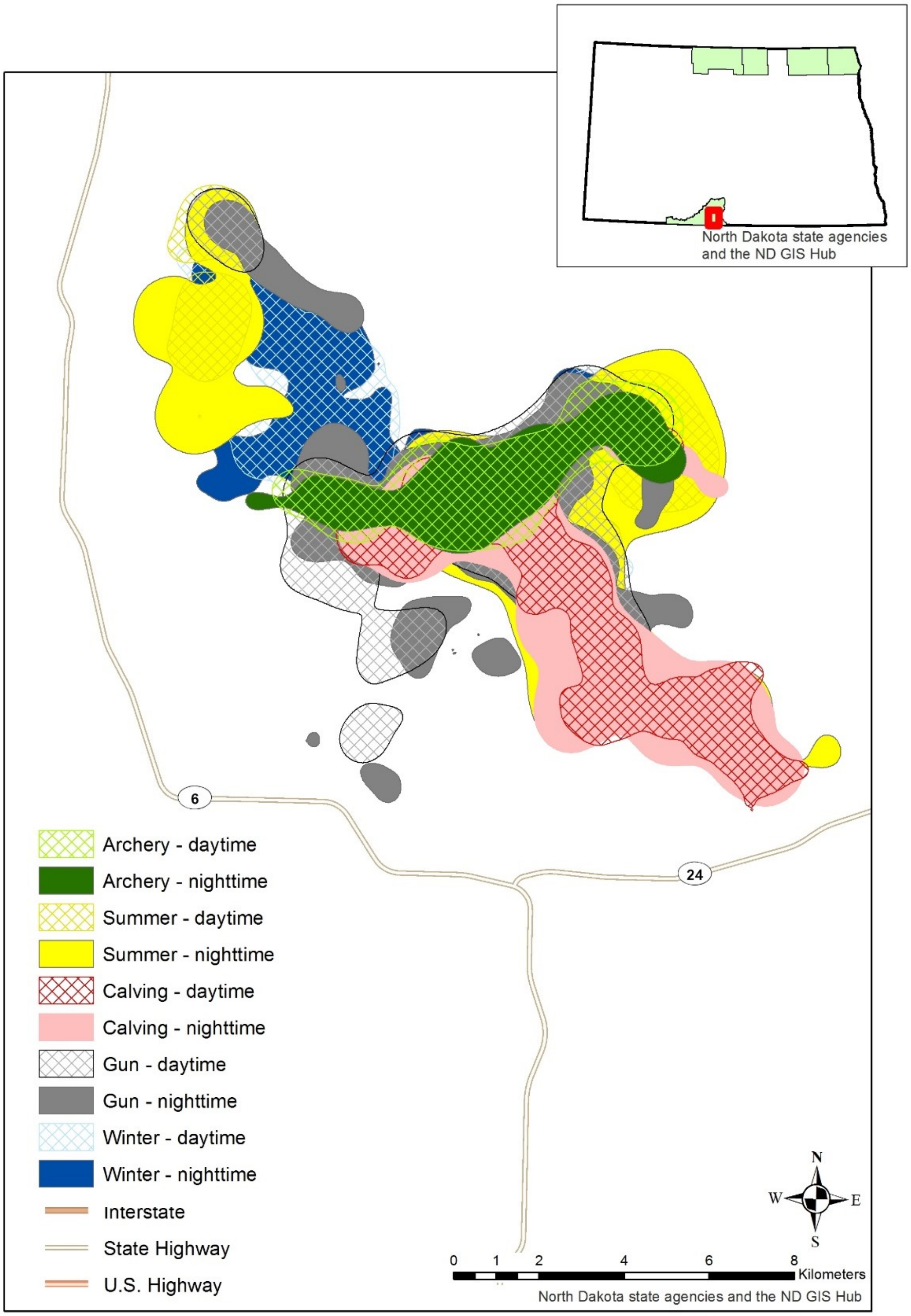


Figure 18. Map overlay of Elk 14's time of day and seasonal home ranges (km^2) in Porcupine Hills herd, North Dakota, USA.



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Author: Jacqueline Amor

Figure 19. Map overlay of Elk 15’s time of day and seasonal home ranges (km^2) in Porcupine Hills herd, North Dakota, USA.

Home Range Comparisons. – Our general linear mixed effects model on the $\log_{10}$ transformed data (Table 8) suggested significant differences. When compared to Pembina Hills, Turtle Mountain and Porcupine Hills elk home ranges were significantly smaller ($P < 0.05$) and larger ($P < 0.05$), respectively. Seasons that were significantly different from our baseline comparison were gun ($P < 0.01$) and winter ($P < 0.05$). Night ($P < 0.05$) was significantly different from day (our baseline). Two-way interactions that were significantly different from our baseline included the Turtle Mountain herd dependent on gun season ($P < 0.05$), the Porcupine Hills herd dependent on gun season ($P < 0.05$), the Porcupine Hills herd dependent on winter season ($P < 0.05$), and the Porcupine Hills herd dependent on nighttime ($P < 0.05$). From running multiple models to determine the best model for our questions, there was no statistical significance between time of day and season, which is why it is not included in this model.

Table 8. Linear mixed effects model using $\log_{10}$ transformed data on 95% home ranges.

	Estimate	SE	DF	t-value	p-value
(Intercept)	1.092	0.089	112	12.207	0
herdBott	-0.294	0.118	12	-2.500	0.0279
herdSioux	0.332	0.118	12	2.825	0.0153
seasonCalving	-0.067	0.104	112	-0.643	0.5217
seasonGun	0.477	0.104	112	4.589	0
seasonArchery	-0.096	0.104	112	-0.921	0.3593
seasonWinter	0.359	0.110	112	3.250	0.0015
timeNight	0.263	0.087	112	3.015	0.0032
herdBott:seasonCalving	0.152	0.127	112	1.195	0.2347
herdSioux:seasonCalving	0.035	0.127	112	0.273	0.7857
herdBott:seasonGun	0.277	0.127	112	2.182	0.0312
herdSioux:seasonGun	-0.292	0.127	112	-2.299	0.0234
herdBott:seasonArchery	0.216	0.127	112	1.699	0.092
herdSioux:seasonArchery	-0.051	0.127	112	-0.404	0.6868
herdBott:seasonWinter	-0.130	0.136	112	-0.957	0.3406
herdSioux:seasonWinter	-0.268	0.132	112	-2.033	0.0444
herdBott:timeNight	-0.051	0.082	112	-0.619	0.5374
herdSioux:timeNight	-0.216	0.081	112	-2.659	0.009
seasonCalving:timeNight	0.063	0.104	112	0.608	0.5444
seasonGun:timeNight	-0.110	0.104	112	-1.057	0.2926
seasonArchery:timeNight	-0.073	0.104	112	-0.702	0.4839
seasonWinter:timeNight	-0.003	0.108	112	-0.028	0.9778

DISCUSSION AND CONCLUSIONS

Our results provide a novel contribution to ungulate ecology in North Dakota and describe home range estimates for unstudied or newly colonized elk herds. We used a modern home range estimator, BBMM, to test differences among factor levels, which is useful for estimating space use by incorporating location data from each individual animal and conditional random walk models (Horne et al. 2007). BBMM treats movements between each observed location probabilistically, which allows researchers to quantify uncertainty in estimating actual paths by taking key factors into consideration such as time when location was taken, distance between locations, measurement error from the GPS equipment, and mobility of each individual animal (Horne et al. 2007). As hypothesized, we found differences in home ranges based on season, time of day, and herd, likely due to variation in forage and cover (Allen et al. 2016). For example, Porcupine Hills has more mixed and shortgrass prairie, possibly forcing elk to travel farther to find adequate cover. In contrast, the Turtle Mountains is heavily forested, potentially reducing the necessary travel distance (Seidel and Boyce 2016). Vegetation and landscape differences (Seabloom 2011) between our study areas may explain why all 3 elk herds differed in home range (Beck et al. 2013, Allen et al. 2016). It should be noted that Porcupine Hills was closed to all elk hunting during the Fall of 2016, however regular deer-gun hunting season occurred during this period and may have influenced elk movements in all three herd locations as well as elk hunting in permitted herd locations.

Home range size varied by season, and was significantly different during the gun and winter seasons. Each year, elk gun hunting season in North Dakota takes place from about October 1–December 31. Elk home range increased across all 3 elk herds during the gun season, and this is likely due to hunter pressure from both elk and deer-gun hunters, which displace elk from their usual habitat to seek alternative cover and forage (Ranglack et al. 2017, Thurfjell et al. 2017). During the winter season (January 1–April 30), reduced habitat quality, due to snow and cold temperatures may have forced elk to travel farther to seek adequate forage and cover (Allen et al. 2016). All herds were consistently distributed throughout the different seasons. Our data suggested a significant difference between nighttime home ranges and daytime home ranges. Herds had larger home ranges at nighttime than daytime (Figure 4). This is not surprising, given elk are known to forage in cover throughout the day and forage in open areas at night (Lone et al. 2017). Differences in home range for calving and archery seasons were less distinguishable, although there was consistency among average herd home range during each season there was no significant difference found between these seasons and our baseline. Home range movements during calving may have been influenced by pregnancy or calf presence but our model did not test for this hypothesis.

Based on model two-way interactions, each herd was significantly different than the other during gun season which shows variation in space use mainly driven by factors of hunting pressure variability (Thurfjell et al. 2017). It should be noted that there is no elk hunting season in Porcupine Hills in 2016 but seemed to still have higher home range movement like the other two herds during this time of year. In addition to hunting pressure, elk distributions may vary during hunting seasons due to habitat resource selection and dependence on available resources (Ranglack et al. 2017). In the latter case, our study herds had larger home ranges consistently, but significantly differed from each another during the gun hunting season. Our model emphasizes the importance of how individual elk movement and space use may vary across geographical range due to available cover in different habitat types (Allen et al. 2016).

In our study, home range size of Porcupine Hills elk differed from those in Pembina Hills during the winter season and by diel. In both cases, we calculated greater variation in the Pembina Hills elk herd. Our analysis demonstrates that all 3 herds have similarities across seasons but have different individual home ranges within each herd. The herds reacted as predicted to hunter pressure, climatic changes and habitat availability during seasonal changes, along with greater home range movement during night versus day. Forage availability must meet an animal's energy and nutritional requirements within a home range or the home range size must be increased, animals will have greater home ranges to encompass additional resources in order to meet their survival needs (Andersen et al. 2005).

Aerial surveys conducted that flew in transects without telemetry are important to conduct because this gives a better understanding of any surrounding elk herds that may not be included with our studied collared elk. This type of survey helps give a better understanding of population status and estimation. A combination of radio-collaring "Judas" elk in the sub herds, with flying transect surveys, may provide the best means for monitoring elk herds; particularly those along the Canadian border. We did find classification of elk from the air problematic, particularly when in forested cover. Completed snow cover appears essential for classification and counting elk.

Management Implications

Using BBMM to estimate home ranges for elk in this study allowed us to more precisely identify the probability of an area being utilized (Horne et al. 2007). Our analysis provides support for home range estimates for elk herds based on individual elk defined by season and diel. Studying individual elk movements allows us to gain insight into population distributions, important resources being used, dispersal strategies, social interactions, and general patterns of space use (Horne et al. 2007). Understanding elk movement during hunting seasons, allows us to recognize the difference in home range with high human presence and hunter avoidance. Since 2 elk populations border Canada, we can better understand how to manage an elk herd that has international range, future studies that elk collaring takes place should consider finding elk herds on both sides of the border for collaring. Ungulates are a widespread species that hold high economic value, and understanding their movements can help determine the impact on available forage and their response to natural and human disturbances could be key to estimating home range distributions in short and long-term periods of time (Seidel and Boyce 2016).

We suggest the following action items to be considered for future elk research in North Dakota (the following are potential questions to be raised):

1. Increase the number of collars to more than five per sub herd of elk.
2. Identify the location of sub herds prior to capture and distribute the collars accordingly.
3. Collect blood tests for pregnancy.
4. Consider the use of Vaginal Implant Transmitters (VIT) when capturing elk. The VIT comes out during the delivery of the fawn or calf and with the change in temperature, the VHS frequency changes and allows you to know when and where a birth has occurred. By using VITs and monitoring GPS movements, researchers could increase the frequency of locations and look at behavioral movement patterns just prior to parturition.
5. Use of cow elk movements that may suggest birthing dates and locations. This might still be done with these data.
6. The combination of monitoring elk movements and the use of VITs may provide insight into behavioral cues of the cow about calving habitat.
7. Concerns and suggestions with future use of the BBMM, such as only using BBMM for seasons that have enough GPS locations to create valid home range

estimates. Advantages from using this method is that it takes into consideration random walks taken in between GPS fixes but drawbacks could be that the random walks may be overestimated or underestimated depending on time of year.

8. Evaluation of GIS layers prior to the start of the study. Budget to ground truth GPS layers.

Further analysis should be conducted to understand elk habitat selection and foraging sites within our study areas, and this work is forthcoming. These analyses will allow more insight for understanding what elk choose to forage versus what is available. Furthermore, these techniques can inform understanding a population size in balance with biological and cultural carrying capacity.

APPENDIX A. DATA SHEETS FROM ALL FLIGHTS CONDUCTED 2016–2017

Table 9. Aerial observations of Porcupine Hills Elk, March 15, 2016.

Date: March 15, 2016 **Observer: Bill Jensen** **Pilot: Jeff Faught**
Comments: One group of 5 elk sighted 1 to 2 miles north of collared elk. Left Bismarck: 13:00 hrs. Landed: 14:30
Weather: Clear, 55F, Windy 24 MPH NW (difficult to hold position over the elk and observe)

Elk No.	Time Observed (DST)	Location	Bulls			Cows	Calves	Unknown
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
11	13:36	N46.05.748 W100.47.507						4 collared cows in two close groups of 17 & 22 elk. No antlered bulls seen. In trees.
12	13:44	N46.05.748 W100.47.507						4 collared cows in two close groups of 17 & 22 elk.
13	13:34	N46.05.729 W100.47.353				1 collared cow		4 collared cows in two close groups of 17 & 22 elk.
14	13:36	N46.05.748 W100.47.507						4 collared cows in two close groups of 17 & 22 elk.
15	13:41	N46.05.748 W100.47.507						4 collared cows in two close groups of 17 & 22 elk.

Table 10. Aerial observations of Porcupine Hills Elk April 1, 2016.

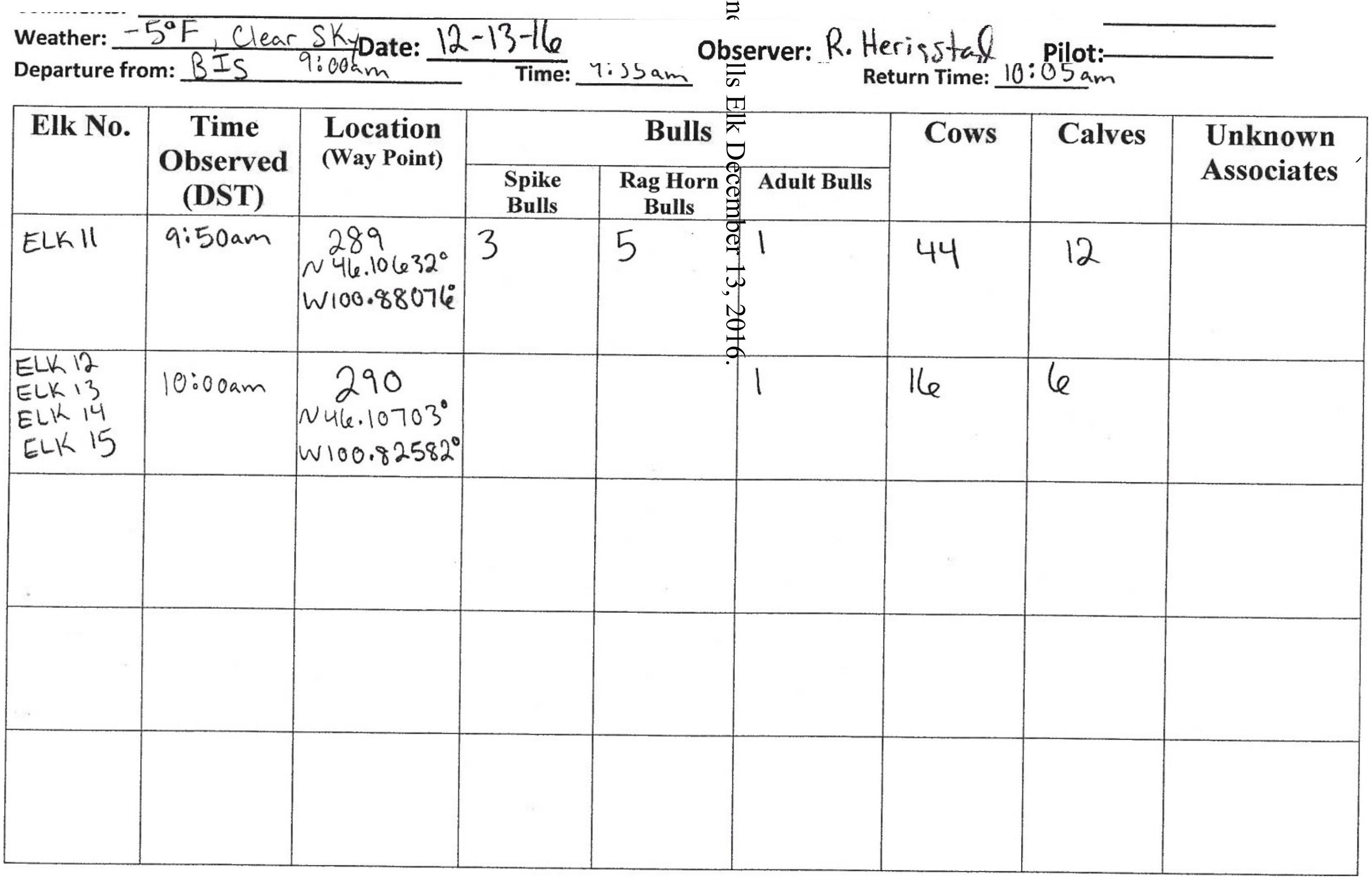
Date: 1 April 2016 Observer: Dale Repnow Pilot: Jeff Faught

Comments: One group of 5 elk sighted 1 to 2 miles north of collared elk. Left Bismarck: 8:15hrs. Landed: 10:02

Weather: 27° F, Mostly Cloudy, light skiff of snow on the ground from last night.

Elk No.	Time Observed (DST)	Location	Bulls			Cows	Calves	Unknown
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
11	0913	N46.08.537 W100.54.366	2			2 (Collared)		16
12	0929	N46.06.727 W100.50.258				2 (1 Collared)		
13	0905	N46.06.518 W100.51.887				1 (Collared)		1
14	0913	N46.08.537 W100.54.366	2			2 (Elk 11 and 14 Collared)		16
15	0920	N46.06.193 W100.52.220				4 (1 Collared)		

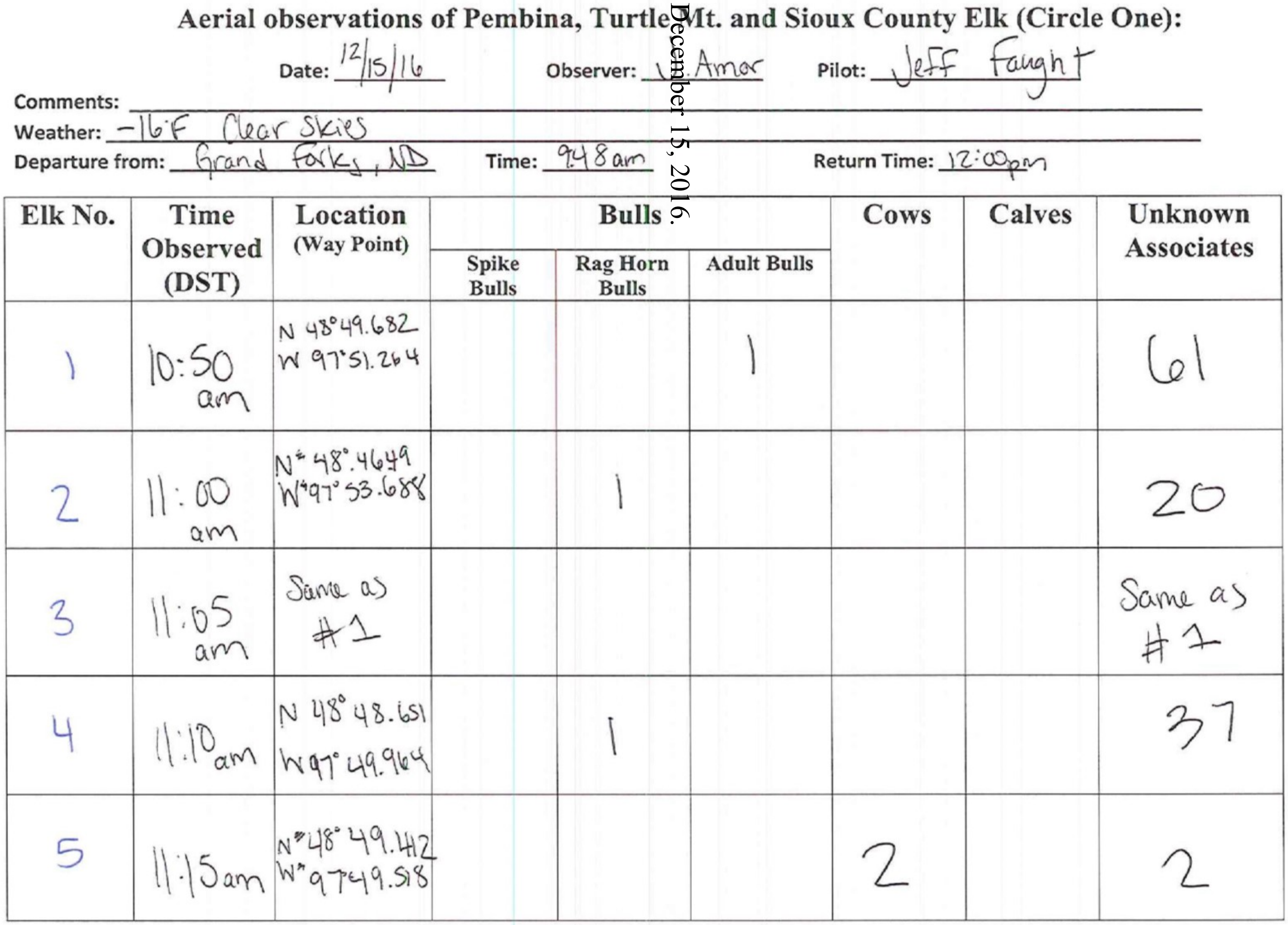
al Observations of Porcupine lls Elk December 13, 2016.



Weather: -5°F, Clear Sky Date: 12-13-16 Observer: R. Herigstad Pilot:

Departure from: BIS 9:00am Time: 9:55am Return Time: 10:05am

Elk No.	Time Observed (DST)	Location (Way Point)	Bulls			Cows	Calves	Unknown Associates
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
ELK 11	9:50am	289 N46.10632° W100.88076°	3	5	1	44	12	
ELK 12 ELK 13 ELK 14 ELK 15	10:00am	290 N46.10703° W100.82582°			1	16	6	



al Observations of Pembina Hills December 15, 2016.

Aerial observations of Pembina, Turtle Mt. and Sioux County Elk (Circle One):

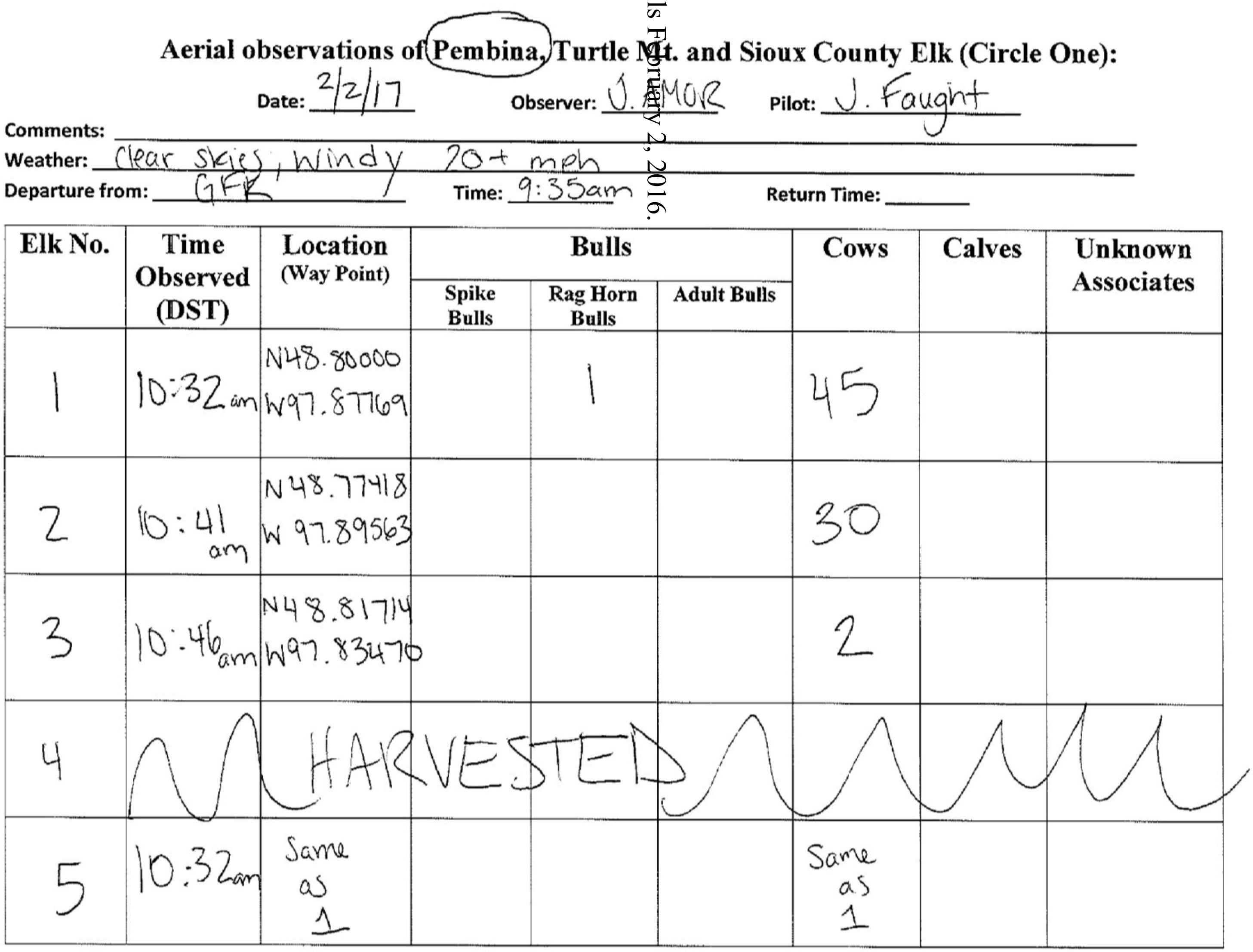
Date: 12/15/16 Observer: V. Amar Pilot: Jeff Faught

Comments:

Weather: -16°F Clear Skies

Departure from: Grand Forks, ND Time: 9:48 am Return Time: 12:00pm

Elk No.	Time Observed (DST)	Location (Way Point)	Bulls			Cows	Calves	Unknown Associates
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
1	10:50 am	N 48°49.682 W 97°51.264			1			61
2	11:00 am	N° 48°.4649 W° 97° 53.688		1				20
3	11:05 am	Same as #1						Same as #1
4	11:10 am	N 48° 48.651 W 97° 49.964		1				37
5	11:15 am	N° 48° 49.412 W° 97° 49.518				2		2



Aerial observations of [✓ Pembina,] Turtle Mt. and Sioux County Elk (Circle One):

Date: 2/2/17 Observer: J. AMOR Pilot: J. Faught

Comments:

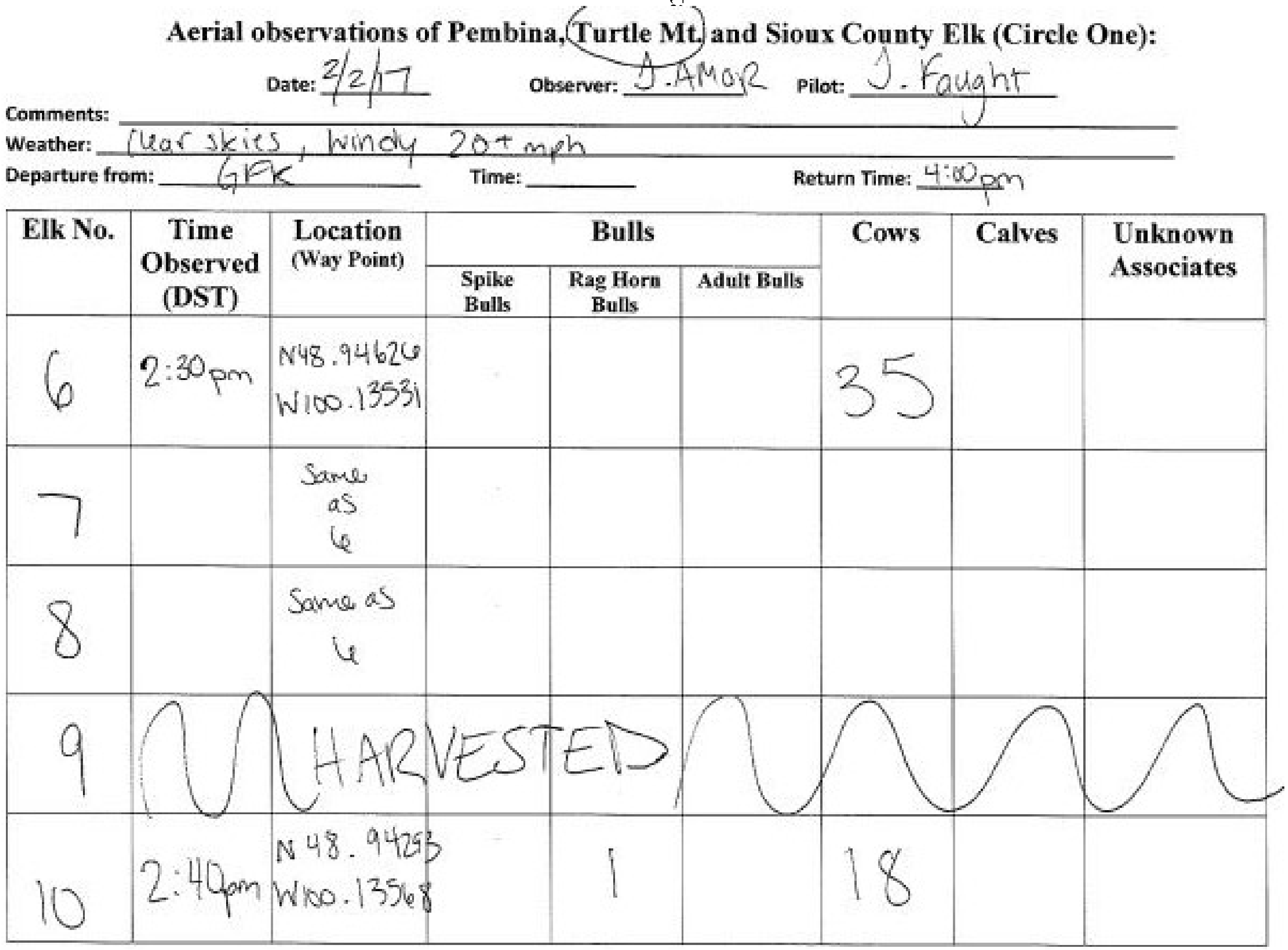
Weather: Clear skies, windy 20+ mph

Departure from: GFK Time: 9:35am Return Time:

Elk No.	Time Observed (DST)	Location (Way Point)	Bulls			Cows	Calves	Unknown Associates
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
1	10:32 am	N48.80000 W97.87769		1		45		
2	10:41 am	N48.77418 W 97.89563				30		
3	10:46 am	N48.81714 W97.83470				2		
4	HARVESTED							
5	10:32 am	Same as 1				Same as 1		

Aerial Observations of Pembina Hills February 2, 2016.

erial Observations of Turtle Mount



Aerial observations of Pembina, [✓ Turtle Mt.] and Sioux County Elk (Circle One):

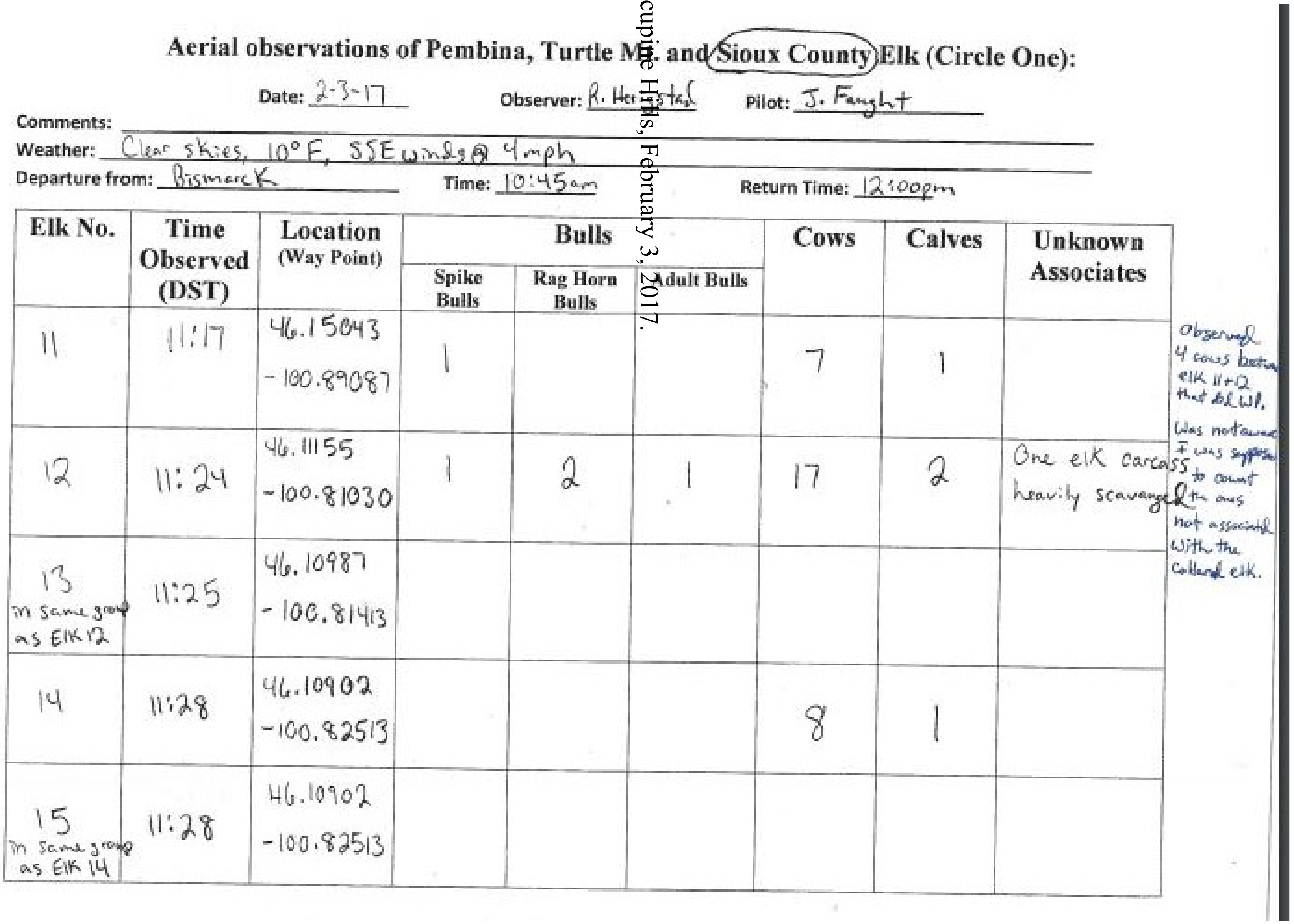
Date: 2/2/17 **Observer:** J. AMOR **Pilot:** J. Faught

Comments:

Weather: Clear skies, windy 20+ mph

Departure from: GFK **Time:** **Return Time:** 4:00pm

Elk No.	Time Observed (DST)	Location (Way Point)	Bulls			Cows	Calves	Unknown Associates
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
6	2:30pm	N48.94626 W100.13531				35		
7		Same as 6						
8		Same as 6						
9		HARVESTED						
10	2:40pm	N 48.94293 W100.13568		1		18		



ble 15. Aerial Observations of Porcupine Hills, February 3, 2017.

Aerial observations of Pembina, Turtle Mt. and [✓ Sioux County] Elk (Circle One):

Date: 2-3-17 Observer: R. Herstad Pilot: J. Faught

Comments:

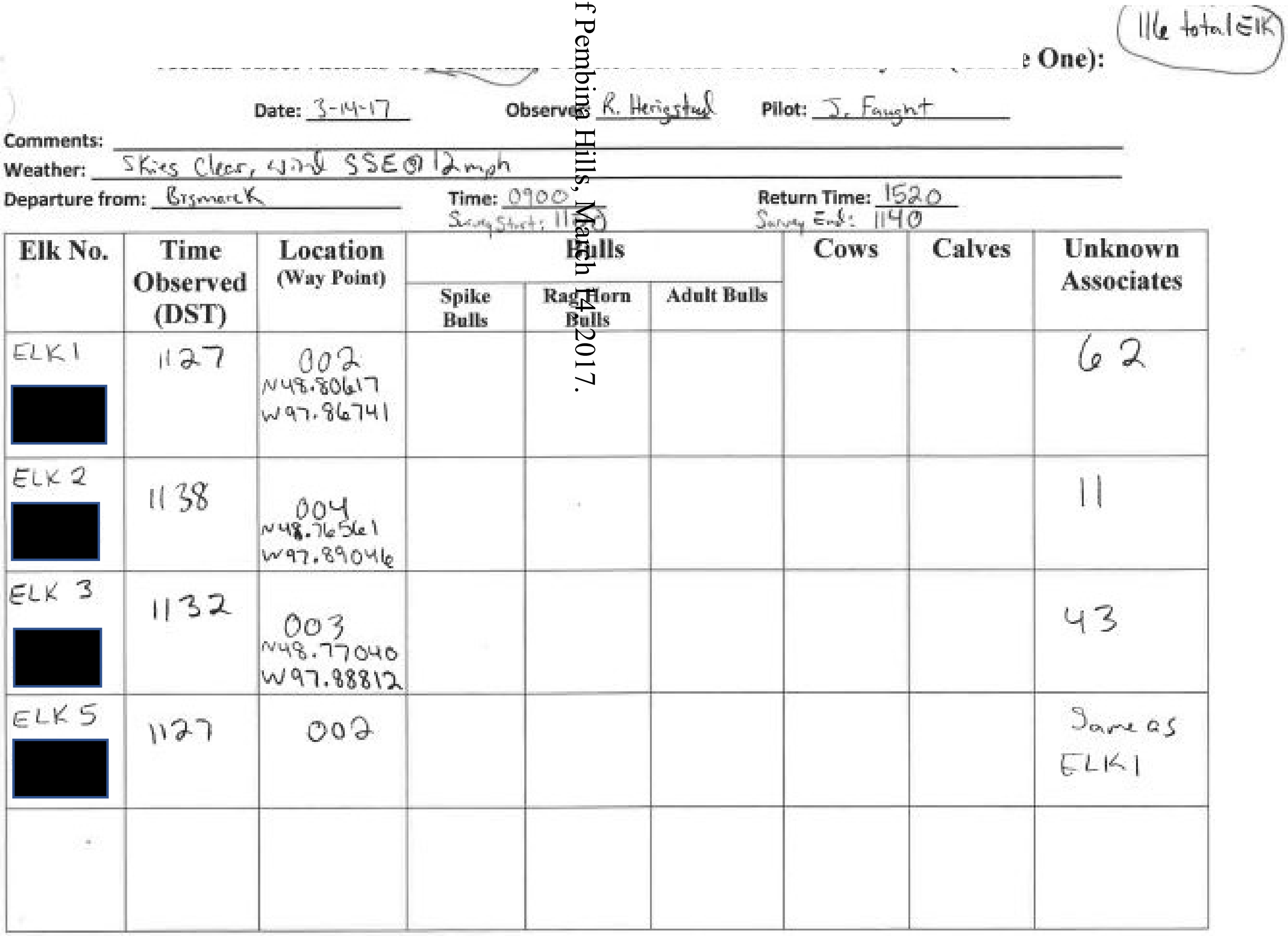
Weather: Clear skies, 10°F, SSE winds @ 4mph

Departure from: Bismarck Time: 10:45am Return Time: 12:00pm

Elk No.	Time Observed (DST)	Location (Way Point)	Bulls			Cows	Calves	Unknown Associates
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
11	11:17	46.15043 -100.89087	1			7	1	
12	11:24	46.11155 -100.81030	1	2	1	17	2	One elk carcass heavily scavenged
13 in same group as Elk 12	11:25	46.10987 -100.81413						
14	11:28	46.10902 -100.82513				8	1	
15 in same group as Elk 14	11:28	46.10902 -100.82513						

Observed
4 cows between
elk 11+12
that did WP.
Was not aware
I was supposed
to count
the ones
not associated
with the
collared elk.

. Aerial Observations of Pembina Hills, March 14 2017.



e One): 116 total Elk

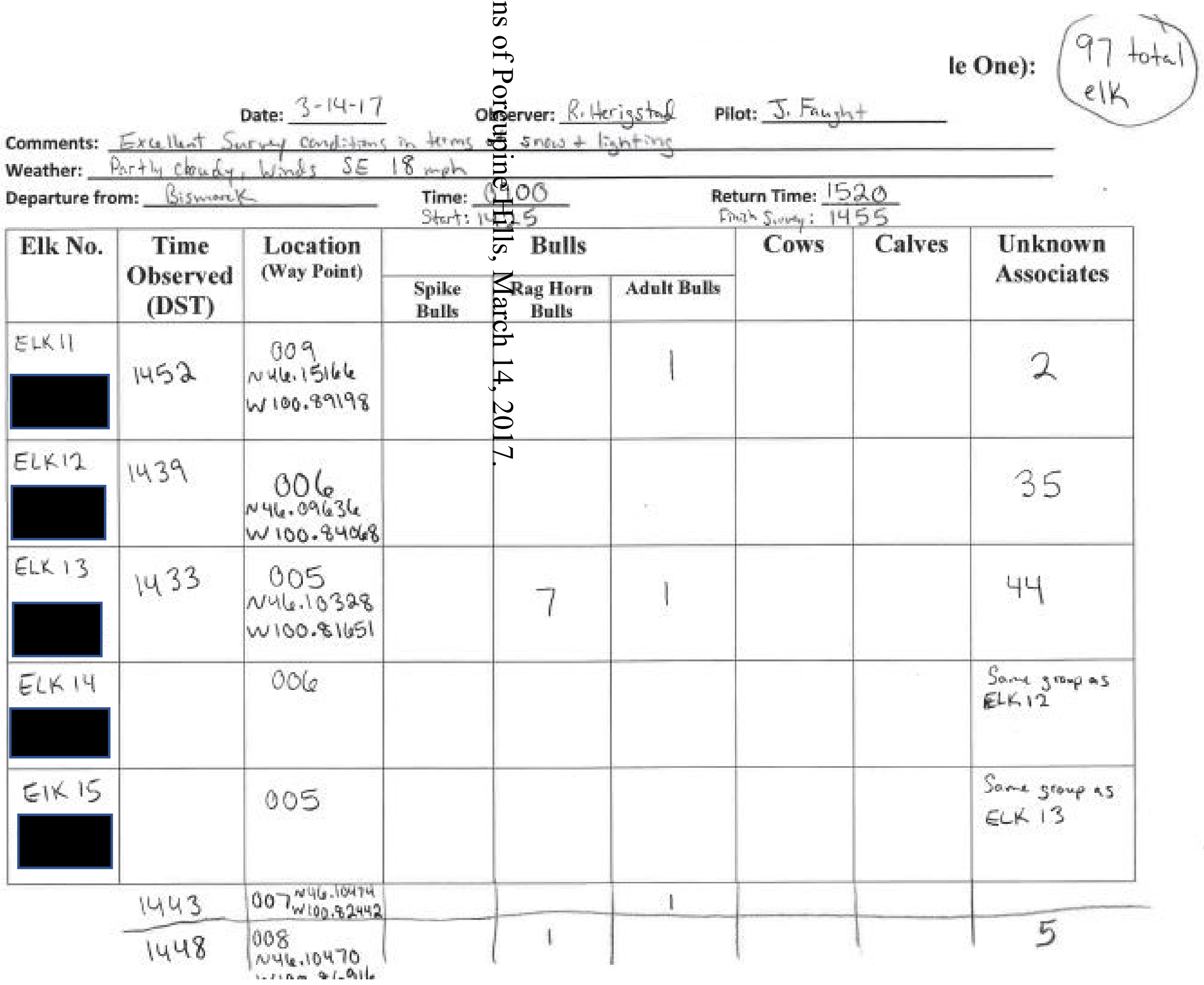
Date: 3-14-17 Observer: R. Herigstad Pilot: J. Faught

Comments:

Weather: Skies Clear, wind SSE @ 12 mph

Departure from: Bismarck Time: 0900 Survey Start: 1125 Return Time: 1520 Survey End: 1140

Elk No.	Time Observed (DST)	Location (Way Point)	Bulls			Cows	Calves	Unknown Associates
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
ELK 1 [redacted]	1127	002 N48.80617 W97.86741						62
ELK 2 [redacted]	1138	004 N48.76561 W97.89046						11
ELK 3 [redacted]	1132	003 N48.77040 W97.88812						43
ELK 5 [redacted]	1127	002						Same as ELK 1



le One): 97 total elk

Date: 3-14-17 Observer: R. Herigstad Pilot: J. Faught

Comments: Excellent Survey conditions in terms of snow + lighting

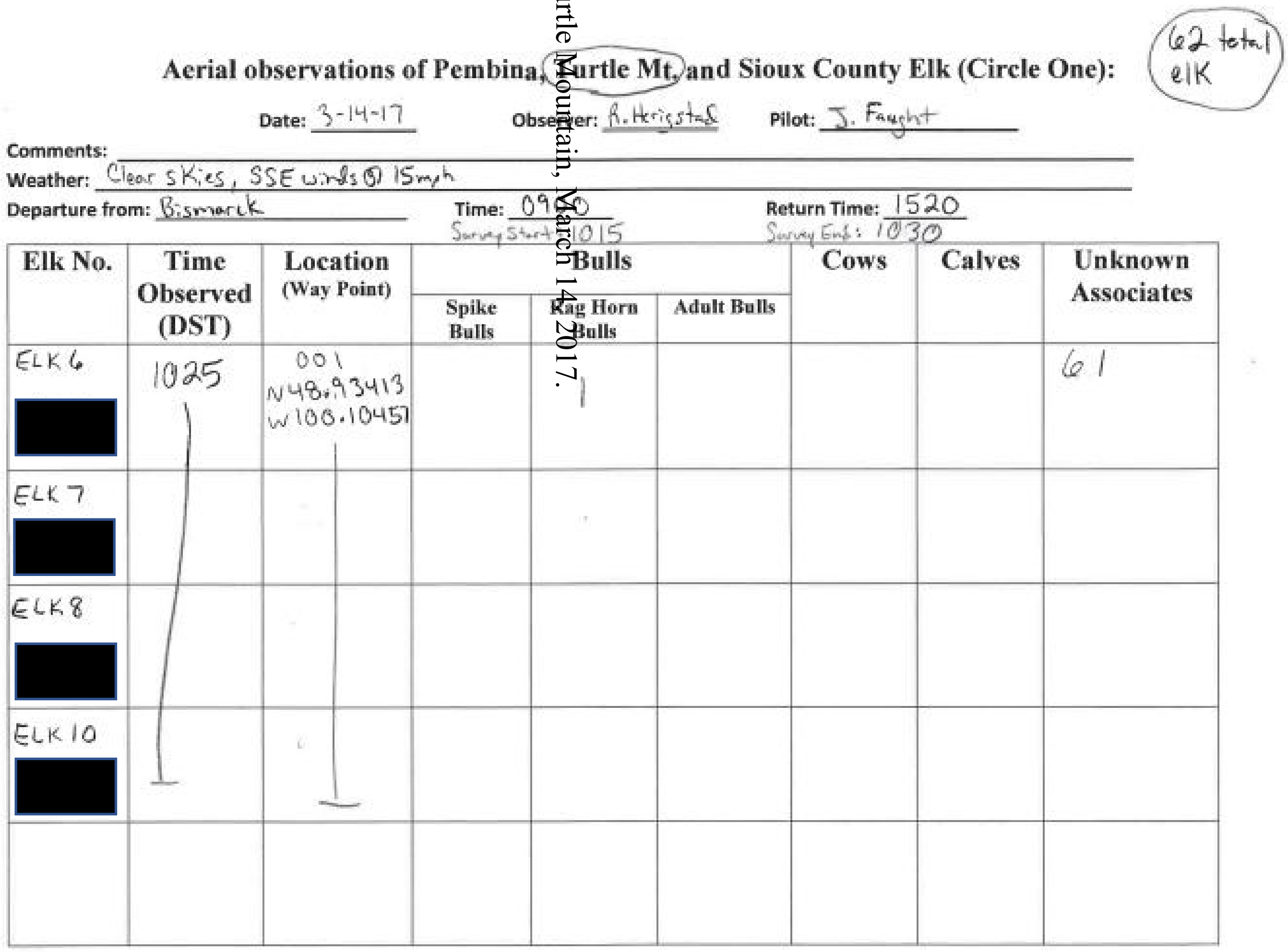
Weather: Partly cloudy, Winds SE 18 mph

Departure from: Bismarck Time: [illegible]00 Return Time: 1520

Start: 14[illegible]5 Finish Survey: 1455

Elk No.	Time Observed (DST)	Location (Way Point)	Bulls			Cows	Calves	Unknown Associates
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
ELK11 [redacted]	1452	009 N46.15166 W100.89198			1			2
ELK12 [redacted]	1439	006 N46.09636 W100.84068						35
ELK13 [redacted]	1433	005 N46.10328 W100.81651		7	1			44
ELK14 [redacted]		006						Same group as ELK12
ELK15 [redacted]		005						Same group as ELK13
	1443	007 N46.10474 W100.82442			1			
	1448	008 N46.10470		1				5

e 17. Aerial Observations of Porcupine Hills, March 14, 2017.



Aerial observations of Pembina, [✓ Turtle Mt.], and Sioux County Elk (Circle One):

62 total elK

Date: 3-14-17 Observer: R. Herigstad Pilot: J. Faught

Comments:

Weather: Clear sKies, SSE winds @ 15mph

Departure from: Bismarck Time: 09[illegible]0 Return Time: 1520

Survey Start: 1015 Survey End: 1030

Elk No.	Time Observed (DST)	Location (Way Point)	Bulls			Cows	Calves	Unknown Associates
			Spike Bulls	Rag Horn Bulls	Adult Bulls			
ELK 6 [redacted]	1025	001 N48.93413 W100.10457		1				61
ELK 7 [redacted]								
ELK 8 [redacted]								
ELK 10 [redacted]								

. Aerial Observations of Turtle Mountain, March 14, 2017.

APPENDIX B. TABLE OF ELK CAPTURE DATA

Table 19. Biological notes from capture of all elk collared & pregnancy tests for each

Animal ID	**Response in Test, OD**	**PSPB Range**	**Age**	**General Body Condition**	**General Tooth Condition**	**Parasites**	**Origin of Capture**	**Misc. Comments/Fate**
ELK1	0.045	Open	3	Good	Good	Ticks	Pembina	
ELK2	0.6103	Pregnant	2	Good			Pembina	
ELK3	0.045	Open	2	Good	Good	Ticks	Pembina	
ELK4	0.4417	Pregnant	3	Good			Pembina	Harvested 2016
ELK5	0.4947	Pregnant	2	Good			Pembina	
ELK6	0.6344	Pregnant	3+	Good	Good	Ticks	Turtle Mountain	
ELK7	0.5643	Pregnant	4+	Very Good	Good		Turtle Mountain	
ELK8	0.5125	Pregnant	4	Good			Turtle Mountain	
ELK9	0.9195	Pregnant	Mature	Good	Good		Turtle Mountain	Harvested 2016
ELK10	0.7369	Pregnant	4+	Below Average			Turtle Mountain	
ELK11	0.8299	Pregnant	Mature	Good			Sioux County	
ELK12	0.2634	Pregnant	Mature	Good	Minimal wear		Sioux County	No hair long
ELK13	0.7555	Pregnant	Mature	Good			Sioux County	
ELK14	0.045	Open	3	Average		Ticks	Sioux County	
ELK15	0.6107	Pregnant	4	Above Average	Good	Ticks	Sioux County	

APPENDIX C. R CODE USED FOR BBMM HOME RANGE ANALYSIS

R Code

```
#Appendix: Examples of R code used in the analysis.
#Software Dependencies:
#The R code uses the (freely available) adehabitatHR and caTools packages,
together
#with other packages on which they depend, as specified in the code.
#Note that R code for the LoCoH routine is already published on line at
#http://locoh.cnr.berkeley.edu/rtutorial.
#Code to run the MKDE routine, display maps, and estimate AUC values
# 1.0. Working directory and upload of packages
rm(list=ls())
date()
library(adehabitatHR)
library(adehabitatMA)
library(raster)
library(caTools)
library(bitops)
library(sp)
library(rgdal)
library(maptools)
library(chron)
library(plyr)
#setwd("U:/JAMOR")
#setwd("~/GIS/Elk Collars")
#Use this section of code to import and merge numerous separate files that are
located in the same
#folder. Be sure to not place anything else in this folder or it will also be added to
your dataset
# setwd("D:\\Walter\\SpatialDatabases\\02_PAdeerHomeRange\\Files")
# alldeer = ldply(list.files(pattern = ".csv"), function(fname) {
#   dum = read.csv(fname,sep=",")#stringsAsFactors=FALSE)#Note:
stringAsFactors may be needed
#   dum$fname = fname  # adds the filename it was read from as a column
#   return(dum)
# })
# head(alldeer)
# str(alldeer)
# wtdeer <- alldeer
#setwd("D:\\Walter\\SpatialDatabases\\02_PAdeerHomeRange")
#Or if a single csv file use:
wtdeer<-read.csv("elkcollars_nightday2.csv", header=T, sep=",")
str(wtdeer)
wtdeer$x <- wtdeer$UTMe
wtdeer$y <- wtdeer$UTMn
```

```
#wtdeer$ID <- as.factor(wtdeer$individual.local.identifier)
wtdeer$ID <- as.factor(wtdeer$COLLARID)
#Remove outlier locations
#newwtdeer <-subset(wtdeer, wtdeer$Long > -110.50 & wtdeer$Lat > 37.3 &
wtdeer$Long < -107)
#wtdeer <- newwtdeer
#wtdeer <- subset(wtdeer, !is.na(wtdeer$GPS.Latitude))
#Make a spatial data frame of locations after removing outliers
#summary of x,y to make sure no N/As
coords<-data.frame(x = wtdeer$x, y = wtdeer$y)
#REPLACE WITH UTM NAD 14N
#Albers.crs <-"+proj=aea +lat_1=29.5 +lat_2=45.5 +lat_0=23 +lon_0=-96
+x_0=0 +y_0=0 +ellps=GRS80 +towgs84=0,0,0,0,0,0,0 +units=m +no_defs"
utm.crs <-"+proj=utm +zone=14 +datum=NAD83 +units=m +no_defs
+ellps=GRS80 +towgs84=0,0,0"
head(coords)
plot(coords)
deer.spdf <- SpatialPointsDataFrame(coords= coords, data = wtdeer, proj4string =
CRS(utm.crs))
head(deer.spdf)
class(deer.spdf)
proj4string(deer.spdf)
plot(deer.spdf,col=deer.spdf$ID)
#NOTE: First I changed timestamp to Date - Military time by formatting cells and
copy/paste
#into timestamp2 before reading in csv IN EXCEL
#MAKE SURE DATE IS THE SAME FORMAT for R to read DATE
wtdeer$NewDate<-as.POSIXct(wtdeer$timestamp2, format="%m/%d/%Y
%H:%M", origin="1970-01-01")
#Remove all with missing dates
wtdeer$NewDate
wtdeer$timestamp2
wtdeer <- subset(wtdeer, !is.na(wtdeer$NewDate))
summary(wtdeer$NewDate)#should be no NAs
#TIME DIFF NECESSARY IN BBMM CODE
#timediff<-wtdeer$timediff
#timediff <- diff(wtdeer$NewDate)
# remove first entry without any difference
#wtdeer <- wtdeer$ID[-1,]
#wtdeer$timelag <-as.numeric(abs(timediff))
#summary(wtdeer$timelag)
#timediff is timelag in this dataset
summary(wtdeer$timediff)
#Remove locations greater than 24 hours apart in time
wtdeer$timediff<0
summary(wtdeer$timediff<0)
```

```
#However, this sample size represents multiple years of data so causes errors in
running
#some home range estimators. Therefore, let's separate each deer into the years
data
#are available with the name 048_2006 for example
#wtdeer$Year <- format(wtdeer$NewDate, "%Y")
#wtdeer$Year <- as.factor(wtdeer$Year)
#wtdeer <- subset(wtdeer, wtdeer$Year != "NA")
#wtdeer$YearBurst <- c(paste(wtdeer$id,wtdeer$Year,sep="_"))
#wtdeer$YearBurst <- as.factor(wtdeer$YearBurst)
#str(wtdeer)
#summary(wtdeer$YearBurst)
#Or define YEAR based on biology of study animal by predefined dates
wtdeer$Season <- NULL
wtdeer$Season[wtdeer$NewDate >= "2016-09-01 00:01:00" & wtdeer$NewDate
<="2016-09-30 20:01:00"] <- "Archery"
wtdeer$Season[wtdeer$NewDate >= "2016-10-01 00:01:00" & wtdeer$NewDate
<= "2016-12-31 20:01:00"] <- "Gun"
#wtdeer$Season[wtdeer$NewDate >= "2016-02-20 00:01:00" &
wtdeer$NewDate <= "2016-04-30 20:01:00"|wtdeer$NewDate >= "2017-01-01
00:01:00" & wtdeer$NewDate <= "2017-04-01 20:01:00"] <- "Winter"
wtdeer$Season[wtdeer$NewDate >= "2016-03-01 00:01:00" & wtdeer$NewDate
<= "2016-04-30 20:01:00"]<- "Winter2016"
wtdeer$Season[wtdeer$NewDate >= "2017-01-01 00:01:00" & wtdeer$NewDate
<= "2017-04-01 20:01:00"] <- "Winter2017"
wtdeer$Season[wtdeer$NewDate >= "2016-05-01 00:01:00" & wtdeer$NewDate
<= "2016-06-30 20:01:00"] <- "Calving"
wtdeer$Season[wtdeer$NewDate >= "2016-07-01 00:01:00" & wtdeer$NewDate
<= "2016-08-31 20:01:00"] <- "Summer"
wtdeer$Season <- as.factor(wtdeer$Season)
wtdeer<-subset(wtdeer,!is.na(wtdeer$Season))
wtdeer<-subset(wtdeer,wtdeer$Season !="Winter2016")#remove if need 2016
winter
wtdeer$Season<-droplevels(wtdeer$Season)#remove if remove line above
#NEW ID FOR SEASON & ELK
wtdeer$SeasonBurst <- c(paste(wtdeer$ID,wtdeer$Season,wtdeer$Diel,sep="_"))
#might need to remove "c", add subset for teh date
wtdeer$SeasonBurst <- as.factor(wtdeer$SeasonBurst)
wtdeer$SeasonBurst<-droplevels(wtdeer$SeasonBurst)
# table(wtdeer$YearBurst)
# #Remove any deer without a suitable number of locations if needed
#YOU DONT WANT TO USE ELK THAT DONT HAVE ENOUGH
LOCATIONS this uses more than the number you have
#wtdeer <- subset(wtdeer, table(wtdeer$YearBurst)[wtdeer$YearBurst] > 100)
# #wtdeer$YearBurst <- factor(wtdeer$YearBurst)
# wtdeer <- wtdeer[c(-1)]
```

```
# wtdeer$X<- wtdeer$GPS.UTM.Northing
# wtdeer$Y <- wtdeer$GPS.UTM.Easting
# crs<-"+proj=utm +zone=12 +datum=WGS84"
d1 <- wtdeer
str(d1)
#Code separate each animal into a shapefile or text file to use as "List" in
Cumming and Cornelis
# get input file
indata <- d1
innames <- unique(d1$SeasonBurst)# base off code above for seasonal choice
innames <- innames[59:87]#needs to be number of unique IDs *150 factors look
in environments* 176 from factors when running all
outnames <- innames
# begin loop to separate each deer into it's own file
for (i in 1:length(innames)){
  data <- indata[which(indata$SeasonBurst==innames[i]),]
  if(dim(data)[1] != 0){
    #data <-data[c(-21)]
    # export the point data into a shp file
    data.xy = data[c("x", "y")]
    coordinates(data.xy) <- ~x+y
    sppt <- SpatialPointsDataFrame(coordinates(data.xy),data)
    #proj4string(sppt) <- CRS("+proj=utm +zone=12 +datum=WGS84")
    #writePointsShape(sppt,fn=paste(outnames[i],sep="/"),factor2char=TRUE)
    #sppt <-data[c(-22,-23)]
    write.table(sppt, paste(outnames[i],"txt",sep="."), sep="\t", quote=FALSE,
row.names=FALSE)
    write.table(paste(outnames[i],"txt",sep="."), sep="\t", quote=FALSE,
row.names=FALSE, col.names=FALSE, "In_list87.txt", append=TRUE)
    #The write.table line above should only be run once to create the In_list.txt file
otherwise it writes all deer each time }}
#############################
################################################################
#################################################################
#Brownian Bridge Movement Model (BBMM)
#
#################################################################
# 6.1 Working directory and upload of packages
library(adehabitatHR)
library(adehabitatMA)
library(maptools)
library(sp)
library(BBMM)
library(rgdal)
library(PBSmapping)
library(raster)
```

```
library(caTools)
library(bitops)
date()
# 6.2. Reads and prepares the data
# 6.2.2. Reads the List file of GPS datasets
List<-read.table("In_list58.txt",sep="\t",header=F)
head(List) #List contains the filenames deer datasets
# Generation of results vectors
LOCNB<- rep(0,nrow(List))
AUC <- rep(0,nrow(List))
HR50 <- rep(0,nrow(List))#HOME RANGE SIZE IN SQUARE KILOMETERS
HR80 <- rep(0,nrow(List))
HR95 <- rep(0,nrow(List))
ROWNB <- rep(0,nrow(List))
COLNB <- rep(0,nrow(List))
TIMEIN <- rep(0,nrow(List))
TIMEOUT <- rep(0,nrow(List))
#  6.3 BBMM computation start of loop
#i=1 (use to test code before doing full run)
for(i in 1:nrow(List)) {
  coords<-read.table(as.character(List[i,]),sep="\t",header=T)
  head(coords)
  LOCNB[i]<-nrow(coords)
  loc<-coords[,c("x", "y")] #CHANGE TO UTMN and UTME
  coordinates(loc) = c("x", "y") # conversion to format SpatialPointsDataFrame
(necessary for count.cells)
  #Coordinate system info may not be needed CHANGE TO NAD UTM 14N
  proj4string(loc) = CRS("+proj=utm +zone=14 +datum=NAD83 +units=m
+no_defs +ellps=GRS80 +towgs84=0,0,0")
  # 6.4. Generation of a reference grid around the location data
  # 6.4.1. Reference grid : input parameters
  RESO <- 30 # grid resolution (m)
  BUFF <- 5000 # grid extent (m) (buffer around location extremes)
  XMIN <- RESO*(round(((min(coords$x)-BUFF)/RESO),0))#CHANGE to
UTMn and UTMe
  YMIN <- RESO*(round(((min(coords$y)-BUFF)/RESO),0))
  XMAX <- XMIN+RESO*(round(((max(coords$x)+BUFF-XMIN)/RESO),0))
  YMAX <- YMIN+RESO*(round(((max(coords$y)+BUFF-YMIN)/RESO),0))
  NRW <- ((YMAX-YMIN)/RESO)
  NCL <- ((XMAX-XMIN)/RESO)
  # 6.4.2. Generation of refgrid
  refgrid<-raster(nrows=NRW, ncols=NCL, xmn=XMIN, xmx=XMAX,
ymn=YMIN, ymx=YMAX)
  ##Get the center points of the mask raster with values set to 1
  refgrid <- xyFromCell(refgrid, 1:ncell(refgrid))
  # 6.5. BBMM computation
```

```
  TIMEIN[i]<-date()
  BBMM <- brownian.bridge(x=coords$x, y=coords$y, time.lag=coords$timediff,
area.grid=refgrid, location.error=3, max.lag=1440) #check to make sure to
seconds or minutes try 24 hours to minutes
  TIMEOUT[i]<-date()
  # Volume contours computation
  # Create a data frame from x,y,z values
  BBMM.df <-
data.frame("x"=BBMM$x,"y"=BBMM$y,"z"=BBMM$probability)
  ##Make a raster from the x, y, z values, assign projection from above, match the
resolution to that of the
  #raster mask, note 100 is the cell resolution defined in evalPoints above
  bbmm.raster <- rasterFromXYZ(BBMM.df, res=c(30,30), crs=proj4string(loc))
  #crs=proj4string, digits=5)
  ##Cast the data over to an adehabitatHR estUD
  bbmm.px <- as(bbmm.raster, "SpatialPixelsDataFrame")
  image(bbmm.px)
  bbmm.ud <- new("estUD",bbmm.px)
  bbmm.ud@vol = FALSE
  bbmm.ud@h$meth = "BBMM"
  ##Convert the raw UD values to volume
  udvol <- getvolumeUD(bbmm.ud, standardize=TRUE)
  proj4string(udvol) = CRS("+proj=utm +zone=14 +datum=NAD83 +units=m
+no_defs +ellps=GRS80 +towgs84=0,0,0")#CHANGE TO UTM
  bbmm.50vol <- getverticeshr(bbmm.ud, percent = 50,ida = NULL, unin = "m",
unout = "km2", standardize=TRUE)#units out are km2
  bbmm.80vol <- getverticeshr(bbmm.ud, percent = 80,ida = NULL, unin = "m",
unout = "km2", standardize=TRUE)
  bbmm.95vol <- getverticeshr(bbmm.ud, percent = 95,ida = NULL, unin = "m",
unout = "km2", standardize=TRUE)
  #write.table(paste(round(bbmm.95vol$area)), sep="\t", quote=FALSE,
row.names=FALSE, col.names=FALSE, "BBMM_95.txt", append=TRUE)
  writeOGR(bbmm.50vol, dsn = ".", layer=paste(substr(List[i,],1,24),"50bbmm"),
driver = "ESRI Shapefile")
  writeOGR(bbmm.80vol, dsn = ".", layer=paste(substr(List[i,],1,24),"80bbmm"),
driver = "ESRI Shapefile")
  writeOGR(bbmm.95vol, dsn = ".", layer=paste(substr(List[i,],1,24),"95bbmm"),
driver = "ESRI Shapefile")
  HR50[i] <- round(bbmm.50vol$area, digits=4)
  HR80[i] <- round(bbmm.80vol$area, digits=4)
  HR95[i] <- round(bbmm.95vol$area, digits=4)
  # 6.6. AUC computation using caTools and bitops package installed
  # Number of points per raster cell
  nlocrast<-count.points(loc,udvol)
  #image(nlocrast,col=myPal(64))
```

```
  kerneldata <- udvol@data$n # vector containing volume contour (= predicted)
values
  pointdata <- nlocrast@data$x
  pointdata <- ifelse(pointdata>=1,1,0) # vector containing location (= actual)
values
  AUC[i] <- colAUC(kerneldata, pointdata, plotROC=FALSE,
alg=c("Wilcoxon","ROC"))
  ROWNB[i] <- udvol@grid@cells.dim[1]
  COLNB[i] <- udvol@grid@cells.dim[2]
  # 6.6.1. Graphs
  filename<-paste(substr(List[i,],1,24),"BBMM","png", sep=".")
  #NOTE:Numbers after "List[i,] need to encompass possible lengths of output
name (i.e.,   D19.txt is 6 characters)
  png(filename,height=20,width=30,units="cm",res=300)
  par(mar=c(6,6,3,3))
  nf<- layout(mat=matrix(c(1,1,2,1,1,3),nrow=2,ncol=3,byrow=T),respect=TRUE)
  #layout.show(nf)
  # 6.6.2. Plot
  myPal <- colorRampPalette( c("red","orange","yellow"))
  udvoltmp<-udvol
  udvoltmp@data$n<-ifelse(udvoltmp@data$n>=99.9,NA,udvoltmp@data$n)
  udvoltmp<-raster(udvoltmp)
  image(udvoltmp,col=myPal(64),frame.plot=FALSE)
  points(coords[,c("x","y")],pch=3,cex=0.2)
  title(main=paste("BBMM",substr(List[i,],1,24), sep="."),line=0,cex.main=1)
  # 6.6.3. Colorbar
  ncolors<-64
  rangev <- (0:(ncolors - 1))/(ncolors - 1)
  rangebar <- matrix(rangev, nrow = 2, ncol = 64, byrow = TRUE)
  image(z = rangebar, axes = FALSE, col = myPal(64), frame.plot = TRUE)
  axis(side = 2, (0:5)/5, labels = c("0", "", "", "", "","100"))
  title(ylab=expression("Volume contours [%]"),line=2, cex.lab=1)

  # 6.6.4. Graph AUC
  #NOTE:Run code once to get figures then turn these on if separate ROC graphs
are needed
  #filename<-paste("AUC",substr(List[i,],1,9),"png", sep=".")
  #png(filename, bg = "white", restoreConsole = TRUE)
  colAUC(kerneldata, pointdata, plotROC=TRUE, alg=c("Wilcoxon","ROC"))
  dev.off()
}
# 6.7 Results and output table
AUC<-as.data.frame(AUC)
RESULT<-
cbind(List,LOCNB,AUC,HR50,HR80,HR95,ROWNB,COLNB,TIMEIN,TIMEO
UT)
```

```
colnames(RESULT)<-
c("ID","NBLOCS","AUC","HR50","HR80","HR95","NBROWS","NBCOLS","T
IMEIN","TIMEOUT")
RESULT
write.table(RESULT,"OUT_AUC_BBMM.txt", sep="\t")
date()
```

APPENDIX D. TABLE OF ALL ELK HOME RANGES ESTIMATED USING BBMM

Table 20. 95% and 50% mean home ranges for each elk by herd, season, and time of day, km^2.

Herd	#	**Season**	#	**Time**	#	**HR95**
Bottineau	1	archery	1	Day	0	km^2
Pembina	2	calving	2	Night	1	
Sioux	3	gun	3			
		summer	4			
		winter	5			

elk #	herd	season	time	HR50	HR95
1	2	1	0	1.66	9.82
1	2	1	1	5.31	28.28
1	2	2	0	1.27	7.02
1	2	2	1	3.93	15.85
1	2	3	0	3.22	21.37
1	2	3	1	8.75	48.11
1	2	4	0	6.16	44.68
1	2	4	1	10.21	62.06
1	2	5	0	3.61	27.78
1	2	5	1	4.5	48.15
2	2	1	0	1.95	10.61
2	2	1	1	1.51	12.46
2	2	2	0	0.9	5.77
2	2	2	1	1.65	13.86
2	2	3	0	3.69	33.52
2	2	3	1	5.82	44.33
2	2	4	0	2.51	9.7
2	2	4	1	3.05	18.36
2	2	5	0	1.12	13.47
2	2	5	1	4.55	34.38
3	2	1	0	3.32	22.6
3	2	1	1	1.82	15.3
3	2	2	0	6.43	51.72
3	2	2	1	12.22	83.74
3	2	3	0	4.22	24.74
3	2	3	1	9.93	49.47
3	2	4	0	4.88	27.23
3	2	4	1	5.29	35.58
3	2	5	0	4.73	32.84
3	2	5	1	11.9	73.82
4	2	1	0	1.11	6.56
4	2	1	1	1.74	11.65
4	2	2	0	1.75	10.99
4	2	2	1	3.83	23.15
4	2	3	0	8.64	57.43
4	2	3	1	13.86	78.42
4	2	4	0	1.59	7.76
4	2	4	1	2.1	11.53
4	2	5	0	NA	NA
4	2	5	1	NA	NA

5	2	1	0	0.97	6.08
5	2	1	1	1.18	13.9
5	2	2	0	1.21	5.95
5	2	2	1	2.33	13.08
5	2	3	0	8.54	47.7
5	2	3	1	12.15	70.22
5	2	4	0	1.07	5.17
5	2	4	1	1.61	7.75
5	2	5	0	6.43	48.04
5	2	5	1	8.04	71.34
6	1	1	0	2.09	9.55
6	1	1	1	2.92	14.2
6	1	2	0	1.67	8.79
6	1	2	1	3.18	16.63
6	1	3	0	9.09	60.68
6	1	3	1	8.87	61.41
6	1	4	0	1.69	7.01
6	1	4	1	2.79	12.64
6	1	5	0	1.87	10.02
6	1	5	1	2.17	17.95
7	1	1	0	3.68	17.12
7	1	1	1	6.39	33.16
7	1	2	0	1.02	8.18
7	1	2	1	1.46	11.02
7	1	3	0	8.14	66.49
7	1	3	1	8.59	59.83
7	1	4	0	2.43	10.02
7	1	4	1	1.11	9.57
7	1	5	0	1.98	9.78
7	1	5	1	2.28	18.23
8	1	1	0	0.91	5.79
8	1	1	1	0.95	10.05
8	1	2	0	1.76	9.68
8	1	2	1	1.78	10.74
8	1	3	0	2.12	14.81
8	1	3	1	6.18	31.78
8	1	4	0	0.38	2.33
8	1	4	1	0.95	6.19
8	1	5	0	1.86	9.69
8	1	5	1	2.56	18.3
9	1	1	0	0.88	5.59

9	1	1	1	1.39	5.71
9	1	2	0	2.22	10.16
9	1	2	1	3.75	15.43
9	1	3	0	2.24	12.84
9	1	3	1	4.88	32.76
9	1	4	0	1.84	8.56
9	1	4	1	1.66	11.43
9	1	5	0	NA	NA
9	1	5	1	NA	NA
10	1	1	0	1.44	5.65
10	1	1	1	2.31	9.31
10	1	2	0	1.24	6.93
10	1	2	1	1.64	10.73
10	1	3	0	8.66	58.33
10	1	3	1	10.76	62.06
10	1	4	0	1.63	7.26
10	1	4	1	2.75	12.47
10	1	5	0	2.14	12.75
10	1	5	1	2.53	20.05
11	3	1	0	2.84	20.95
11	3	1	1	3.27	22.82
11	3	2	0	3.37	18.31
11	3	2	1	5.62	30.87
11	3	3	0	11.39	57.47
11	3	3	1	10.52	59.23
11	3	4	0	3.25	16.96
11	3	4	1	2.37	16.62
11	3	5	0	7.11	37.41
11	3	5	1	6.24	33.89
12	3	1	0	3.14	19.22
12	3	1	1	2.5	14.67
12	3	2	0	1.51	13.18
12	3	2	1	4.16	24.08
12	3	3	0	5.81	31.92
12	3	3	1	7.94	39.84
12	3	4	0	3.03	13.25
12	3	4	1	3.77	21.23
12	3	5	0	5.41	29.33
12	3	5	1	3.9	30.29
13	3	1	0	1.84	14.66
13	3	1	1	1.08	9.18

13	3	2	0	3.5	20.43
13	3	2	1	8.39	40.72
13	3	3	0	7.96	47.15
13	3	3	1	8.57	5.55
13	3	4	0	5.51	34.24
13	3	4	1	9.49	55.19
13	3	5	0	5.62	35.03
13	3	5	1	3.85	29.76
14	3	1	0	4.76	30.82
14	3	1	1	5.82	30.09
14	3	2	0	7.84	38.51
14	3	2	1	15.66	62.12
14	3	3	0	9.47	50.99
14	3	3	1	11.56	55.17
14	3	4	0	3.4	25.81
14	3	4	1	4.35	34.18
14	3	5	0	7.3	34.33
14	3	5	1	5.08	39.39
15	3	1	0	2.61	17.69
15	3	1	1	1.6	14.74
15	3	2	0	5.19	24.71
15	3	2	1	7.93	33.59
15	3	3	0	6.25	45.51
15	3	3	1	3.6	40.58
15	3	4	0	5.11	38.52
15	3	4	1	6.55	58.88
15	3	5	0	7.62	39.6
15	3	5	1	5.68	37.27

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