Analyzing winter migration fidelity and movement of the wild Taimyr reindeer herd, Rangifer T. tarandus

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ANALYZING WINTER MIGRATION FIDELITY AND MOVEMENT OF THE WILD TAIMYR REINDEER HERD, RANGIFER T. TARANDUS

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

Emily T. Francis

University of Northern Iowa

May, 2016
ABSTRACT

The Taimyr Reindeer Herd (TRH) is the largest wild reindeer population in the world, and is located in the northern central region of Arctic Russia. Previous detailed research on the spatiotemporal dynamics of this herd have been conducted involving aerial population censuses for two of the three seasons for reindeer: calving (Meerdink, 2012) and summer (Cooney, 2014). The first part of this study continues with the methods of the previous studies, analyzing the spatiotemporal fidelity of the TRH in the winter season. This was completed using geospatial analysis of digitized historical aerial census data of reindeer locations, and analyzing areas of repeated reoccurrence by the herd. Findings included evidence of four regions of high reoccurrence within the winter range: three plateaus, two of similar latitude and one located to the northeast, and an outlier area in close proximity to human development. Using NASA’s remote sensed Modern-Era Retrospective Analysis for Research and Applications (MERRA) meteorological dataset for three chosen winter census years, a statistical analysis of the conditions and patterns of usage by reindeer for the areas of high fidelity were assessed. Results of this analysis suggest that weather variables, low surface temperatures, high total precipitation (snow) and snow depth, are deterrents for reindeer presence in specific areas of their wintering grounds. The second study within this thesis used data from the first ever satellite biotelemetry collaring of the TRH. By employing Argos collars, almost 11 months of location data was collected during the fall migration, winter season and spring migration of 2013-2014. These efforts produced
data for eleven successfully monitored reindeer. A subset of reindeer within this sample were analyzed further to determine behavior of seasonal movements and migration distance. Analyses produced clear evidence of patterned fall and spring migration, as well as winter seasonal behavior. The subset of reindeer provided data regarding potential categorization of different sexes between reindeer by movement patterns alone. The results from both parts of the thesis were utilized to better understand site selection for the TRH’s winter season and migrations, giving clues to understanding the activities and survival of the herd during the extreme Siberian winter.
This Study by: Emily T. Francis

Entitled: ANALYZING WINTER MIGRATION FIDELITY AND MOVEMENT OF THE TAIMYR REINDEER HERD, RANGIFER T. TARANDUS

has been approved as meeting the thesis requirement for the

Degree of Master of Arts

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Date Dr. Kavita Dhanwada, Dean, Graduate College
Dedicated to:
Barbara M. Francis

For encouraging your
daughter and granddaughters
to accomplish what you never
had an opportunity to achieve.
I would first and foremost like to acknowledge my advisor and friend, Dr. Andrey N. Petrov, for his continued help and support through the research process. I am grateful for his guidance and wealth of excitement for Arctic research, which I will continue in my career. A thank you to the international team of researchers including Leonid K. Kolpashchikov, the Joint Directorate of the Taimyr Nature Reserves, Pavel Kochkarev, of the Central Siberian Nature Preserve, and University of Northern Iowa Geography “Reindeer alumni”: Susan Meerdink, Anna Pestereva, Matthew Cooney, and Michael Madsen is well deserved. Also, a big thank you to John DeGroote and associates at the UNI GeoTREE Center who provided assistance in data processing. My gratitude is also extended to the University of Northern Iowa Department of Geography faculty, staff and students, as well as my thesis committee, for supporting and nurturing this stage in my academic career. I would like to thank Arctic-FROST for funding and support of wonderful and life changing opportunities I have been afforded during this degree and research experience. Finally, I thank my parents and brother for the long distance encouragement, love and late-night phone calls that it took to accomplish this goal. This research was supported by NSF #EPS-1101284 and #PLR-1504934.
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CHAPTER 1

INTRODUCTION

As the effects of global climate change become increasingly pronounced, it is essential for researchers to gain understandings of the current complex environmental relationships with nature. This is especially true of reindeer, *Rangifer tarandus* L., which has been a keystone species in the Arctic terrestrial ecosystem for around two million years, and has been the “socioecological cornerstone of circumpolar indigenous cultures” for thousands of years (Forbes & Kumpula, 2009; Vors & Boyce, 2009, p. 2626). The human relationship with reindeer extends from prehistoric times to today, and as anthropologist and author Dr. Piers Vitebsky states, “in the Arctic, the Age of Reindeer is not over” (Vitebsky, 2006, p. 17). Arctic scientists and researchers have studied reindeer biology, ecology and relationship to humans since the 1700s, when the taxonomic class Mammalia and species of *R. tarandus*, our modern reindeer, were described in 1758 by Linnaeus (ITIS, 2016).

The lives of Arctic inhabitants still revolve around the great migration patterns of wild and domestic migratory herds in countries of Canada, the United States, Norway, Greenland, Russia and other Arctic nations. However, as humans have and continue to expand development into the Arctic regions, as changing climate forcefully evolves Arctic seasons with rising temperatures, and as many as 80% of current wild reindeer herds are in decline, the future for “the Age of Reindeer” is grim at best (Russell et al.,
With the threat of deadly expanding diseases, like Chronic Wasting Disease, which in 2016 reportedly reached European reindeer, reindeer researchers have great cause for concern as loss of life will affect more than the species alone (Reitehaug, 2016). Decline of a cornerstone species disrupts the balance between all levels of their ecosystems, which in the Arctic is especially fragile (Manseau, Huot, & Crete, 1996; Olofsson, Stark, & Oksanen, 2004; Vors & Boyce, 2009).

Research indicates that rising global temperatures, which are already between 2 to 4 degrees Celsius warmer in the Arctic over the last 60 years, are influencing a number of dangerous environmental changes to reindeer habitat (Fig.1; ACIA, 2004). Increased temperatures provide expanded habitats for biting insects, including mosquitos and parasitic and biting flies, whose harassment of reindeer has been linked to distress and slower summer weight gain, which can reduce winter survival rates (Gunn & Skogland, 1997; Klien, 1999; Makeev, Klokov, Kolpashchikov, & Mikhailov, 2014; Vors & Boyce, 2009; Weladji, Holand, & Almøy, 2003). Earlier snow and ice melt has been recorded to effect spring migration to calving and summer grounds, causing mortality of new born calves who must cross flowing rivers, which in previous years would still be frozen during this migration (Kolpashchikov, & Mikhailov, 2011; Kolpashchikov, Mikhailov, & Mukhachev, 2011; Maklakov & Malygina, 2016). Reindeer dig through snow to reach lichen heaths as an important source of winter forage. Increases in snow depth, time and severity of snowfall and changes in winter
precipitation, i.e. layering of rain and snow, have been indicated as potentially dangerous changes to winter habitat conditions and could increase reindeer winter mortality (Heggberget, Gaare, & Ball, 2002; Klein, 1991; Miller & Gunn, 2003; Tyler, 2010). These are just a few effects of changing climate and increased global temperatures to the species of reindeer as a whole.

![Image of temperature changes to the Northern Hemisphere between 1954 to 2003.](image)

*Figure 1. Temperature changes to the Northern Hemisphere between 1954 to 2003. Image from ACIA 2004. (Chapman & Walsh, 2003).*

The direct effects of human development in the Arctic regions are also harmful to reindeer survival. Over-harvesting of wild reindeer herds is a long time concern for herd management, but the more recent and potentially detrimental human propelled changes are linked to extractive industries in the Arctic (Kolpashchikov, Makhailov, &
Various studies have indicated that disturbances from pipelines, mines, clear-cuts and roads severely imped and disrupt essential migration routes and grounds, which reindeer depend on for survival (Boulanger, Poole, Gunn, & Wierzchowski, 2012; Dyer, O'Neill, Wasel, & Boutin, 2001; Weir, Mahoney, McLaren, & Ferguson, 2007). In some cases, increased wild predation on herds has been linked to industrial disturbances, due to changing access routes to reindeer habitat (Latham, Latham, Boyce, & Boutin, 2011).

The Arctic also continues to open through changes in environment; previously wild and inaccessible land and sea is becoming attractive for future development and industry (Hovelsrud, Poppel, van Oort, & Reist, 2011; Humpert & Raspotnik, 2012; Sander et al., 2015). However, disruption of hundreds of years of reindeer migration has a potentially cataclysmic result to not only reindeer, but the humans living in these remote areas. Traditional subsistence hunting and herd lifestyles are intertwined with the survival of reindeer, in culture, livelihood and basic necessities like food and clothing. Loss of reindeer is loss of identity and increases food insecurity for indigenous people in the circumpolar Arctic (Vitebsky, 2005; Vors & Boyce, 2009).

The Taimyr reindeer herd (TRH) in Siberia is the largest herd in the world, and is in decline (Petrov, Pestereva, Kolpashchikov, & Mikhailov, 2012). Populations have fluctuated dramatically during the past 60 years, mainly due to human involvement by state controlled herd management for meat production. Unfortunately, there is a lack
of research about the TRH, compared to other herds around the world. While some, like the Porcupine Caribou Herd in Alaska and the Cape Bathurst Herd in Canada have decades of telemetry, population and ecological data, the small amount data for the TRH has only very recently been digitized (Fancy, Whitten, & Russell, 1994; Gunn, Russell, & Eamer, 2011; Nagy, Wright, Slack, & Veitch, 2005; Russell, Kofinas & Griffith, 2002; Walsh, Fancy, McCabe, & Pank, 1992; Whitten, 1996). There is a desperate need to study the TRH for the sake of the worldwide species, the humans that depend on it, as well as the herd itself. Without increased monitoring and analysis of current conditions for the world’s largest reindeer herd, there will continue to be loss of information of the effects of current and future climate change. Without scientific knowledge of the actual lands this herd uses, there is no way to protect and conserve this invaluable herd. Thus it is imperative for the research community to turn its gaze to the Arctic and to the TRH. Without this herd and the species of reindeer as a whole, a huge piece to human and environmental history, will be lost.

Therefore, the goal of this thesis is to improve understanding of winter migration patterns of the Taimyr Reindeer Herd, to increase the depth of knowledge about the largest wild reindeer herd in the world. My specific research objectives:

1. to identify the TRH’s winter range and the spatiotemporal dynamics of TRH’s distribution during the winter season TRH using 10 years of data collected during aerial population censuses;
2. to examine annual changes in wintering range location and relationship to climatic factors including, temperature and precipitation, with the use of the National Aeronautics and Space Administration’s (NASA’s) Modern-Era Retrospective Analysis for Research and Applications (MERRA) dataset;

3. to analyze spatiotemporal migration patterns of 12 individuals of the TRH tracked using Argos satellite telemetry collars for a maximum of 11 months between 2013 and 2014.

The structure of this thesis differs from the traditional narrative of introduction, literature review, methods, results, etc. This thesis is written in the format of two papers as separate chapters, each containing a smaller version of the thesis structure, ending with a conclusion chapter, tying together both studies.

**Study Area**

The TRH is the migratory subspecies of *R. tarandus*: the *Rangifer tarandus tarandus*, which lives in the continental tundra of Russia (Flagstad & Røed, 2003). The Taimyr region of Russia is located in the north central Siberian peninsula and is bordered by the Kara Sea to the northwest and the Laptev Sea to the northeast (Fig. 2). This land area is 67° to 78°N and 77° to 113°E, with a range of about 1.5 million square kilometers (Cooney, 2014). There are a number of physical geographic features including the Byrranga Mountains near the northern coast, the Anabar Plateau to the east, and the
Putorana Plateau, which is east of the city of Norilsk and Dudinka, along the western border of Taimyr (Fig. 2). The land is permafrost and there are many bodies of water including Lake Taimyr, which the Upper Taimyra River flows into, and is west of the Khatanga Bay. The Khatanga River flows south through the Anabar Plateau in the eastern side of the region. On the western side is the Yenisei Gulf, which the Yenisei River flows into reaching the Arctic Ocean. This river is of huge importance for Siberia and is one of the largest Russia. The Lower Tunguska River serves as a rough southern physical border to the Taimyr region.
Figure 2. Taimyr Peninsula physical geography map (Cooney, 2014).
CHAPTER 2

SPATIAL AND ENVIRONMENTAL ANALYSIS OF MIGRATION AND WINTER LOCATION FIDELITY

Introduction

In an effort to understand the ecology of the largest wild reindeer herd on Earth, researchers from various research institutions have joined to analyze historical and current data collected on the Taimyr Reindeer Herd (TRH). A dataset of aerial census data of the TRH, was collected by the Extreme North Agricultural Research Institute, in Russia. This data collection started in the late 1950s and has continued into the 2000s, and has been utilized in various research (Cooney, 2014; Kolpashchikov, Yakushkin, & Kokorev, 2003; Meerdink, 2012; Pavlov, Kolpashchikov, & Zyryanov, 1996; Petrov et al., 2012). This study is a continuation to analyze the three seasons of the TRH: calving, summer and winter, borrowing methods used in previous analyses of both calving season by Meerdink (2012) and the summer season by Cooney (2014). The focus of this study is on the winter migration season, which is the last to be analyzed. The objectives for this study are:

1. to identify areas of fidelity in the winter range using ten years of aerial census data;
2. to identify the relationship between winter habitat and selected climatic variables.
Literature Review

This section reviews literature involving the *Rangifer tarandus* species, subspecies, and specifically, the Taimyr Reindeer Herd’s (TRH) seasonal migration, population history and trends.

*Rangifer tarandus*

*R. tarandus*, commonly known as reindeer in Eurasia and caribou in North America, exists in the world’s harsh Arctic environments in three ecoregions: high arctic islands, tundra, and boreal forest (Flagstad & Røed, 2003). Living in herds from less than one hundred to hundreds of thousands, reindeer migrate vast distances and have one of the largest migratory ranges of any mammal in the world. Crowning the top of the globe, 23 wild herds live on the land masses surrounding the Arctic Ocean including the countries of the United States, Canada, Russia, Iceland, Norway, Sweden, Finland and Greenland (Fig. 3; Kutz et al., 2013; Russell, Gunn, & White, 2015; Russell et al. 2013). In these countries both wild and human-managed domestic herds intersect with the boundaries of numerous indigenous, and non-indigenous peoples, as well as each other.

Subspecies

Within the three ecoregions, modern day reindeer are split into three ecological variations: high arctic island, continental tundra, and woodland (Flagstad & Røed, 2003). To further categorize the species, there are eight commonly acknowledged
subspecies of *R. tarandus* based on genetic similarity. These include *R. tarandus caribou, eogroenlandicus, fennicus, grantii, groenlandicus, pearyi, platyrhyncus, and tarandus* (Flagstad & Røed, 2003). *R. tarandus grantii, groenlandicus* and *tarandus* all live in the continental tundra ecoregion, which correspond to the countries of United States, Canada, Greenland and Russia (Fig. 3). The *caribou* and *fennicus* subspecies both live in the woodland ecoregion, also referred to as boreal forest, which lies within Finland, Russia and Canada. Finally, *eogroenlandicus, pearyi*, and *platyrhyncus* are all high arctic island subspecies, which reside within the political boundaries of Greenland, Canada, and Svalbard.

The history of *Rangifer’s* existence goes beyond the last major glacial period. One hypothesis about the evolution of *Rangifer* subspecies is that differences among subspecies evolved during periods of population isolation during the last glacial era in North America, the Wisconsin Age. Flagstad and Røed (2003) concluded that, “a combination of glacial and interglacial effects have been important in shaping the recent evolutionary history of reindeer” (Flagstad & Røed, 2003, p. 668-669). However, it has been concluded that the differences in subspecies were not from physical or herd separation during glacial advances, but have come about since the end of glacial age as evolutionary adaptive responses to the environment (Flagstad & Røed, 2003). Therefore, subspecies have been evolving in response to environmental changes as the climate has changed from the end of the Wisconsin Age to modern time, highlighting potential ability for subspecies resilience to future environmental changes.
Figure 3. Subspecies distribution of *R. tarandus* across Arctic region (Russell et al., 2015).

**Taimyr Reindeer Herd**

The TRH lives on the continental tundra of northern central Siberian Russia and is part of the *R. t. tarandus* subspecies, (Fig. 3 & 4). An example of a female *R. t. tarandus* can be seen in Figure 5. The TRH is the largest wild reindeer herd in the world, with between 650,000 to 700,000 individuals (Kolpashchikov et al., 2015). Their overall range extends from the northern coast of the Taimyr Peninsula of Krasnoyarsk Krai,
west into the Sakha Republic of the Far East, and south into the northwestern border of Irkutsk Oblast, and is roughly 1.5 million square kilometers (Cooney, 2014).

Figure 4. Taimyr reindeer seasonal distribution.
Figure 5. A female *R. t. tarandus* from the captive herd at the Large Animal Research Station at the University Alaska Fairbanks. Image by Emily Francis.

**Seasonal Migration**

The TRH annual cycle can be divided into roughly three major seasons with major two migration periods throughout the year (Kolpashchikov, 2000; Syroechkovski, 1984). The three seasons in annual order are: calving, summer and winter, with spring and fall being the migration periods (Fig. 4). Spring migration starts by leaving the winter grounds and heading northwest to the calving grounds and then on to the summer range, which can reach the coast of the Kara Sea (Fig. 4). The calving range
starts roughly two thirds of the way north between the winter and summer range, and overlaps the summer range in some areas. These areas are where the pregnant female cows have historically given birth, as noted from ENARI aerial censuses of calving season (Meerdink, 2012). The range where reindeer spend calving season are much smaller than the summer and winter ranges (Fig. 4; Meerdink, 2012). As the calves become strong enough to migrate, cows and calves continue north to the seasonal summer area where the climate is cooler and reindeer can forage on plentiful vascular and nutrient high plants.

The summer season is spent eating, gaining weight and avoiding harassing insects, the latter of which plays an important role in herd dynamics and individual behavior, especially for new calves (Gunn & Skogland, 1997; Hagemoen & Reimers, 2002; Helle & Tarvainen, 1984; Skarin, Danell, Bergström, & Moen, 2004; Weladji et al., 2003). Reindeer move north to avoid hot summer temperatures in the wintering grounds, however they become targets for biting and stinging insects, particularly flies. This is a cause of stress for reindeer, and can be overwhelming for young calves. Skarin et al. (2004) found that the harassment of insects can so overpowering that a $R. \text{t.}$ tarandus herd in Långfjället, Sweden will increase likelihood of contact with humans if it means peace from the constant onslaught. This is unusual as herds tend to avoid human contact.

Fall migration includes movement from the summer range to winter grounds and rut/mating. Distances between the northern summer and southern winter ranges can
be around 1,500 kilometers (Syroechkovski, 2000). The rut is extremely strenuous on males and can be deadly if a male does not conserve energy. In winters with exceptionally high amounts of snow and ice, males that have overworked themselves during rut can die of starvation and/or exposure from lacking the strength to dig through the snow and ice for lichen heaths (Episode 2: Plains, 2015; Miller & Gunn, 2003). There are certain groups of indigenous herders, like the Sami of northern Scandinavia, who castrate chosen males to prevent them from taking part in the rut. This way there are males in winter that are strong enough to dig through deep snow to help keep the herd alive (Episode 2: Plains, 2015). It is unknown if Russian herders practice the technique.

The winter migration is especially difficult because of the lack of food in the form of vascular plants that reindeer depend on in summer. Up to 80% of winter foraging diets come from lichen, which can only provide limited nutrients (Heggberget et al., 2002). Reindeer have to survive off of the fat stores, which they amassed during the summer season. This is especially difficult for pregnant cows, who will give birth during calving season on the way to the summer grounds.

Population History and Trends

Compared to the North American herds, the TRH has been understudied (Gunn, Russell, Daniel, White, & Kofinas, 2013). Existing data was collected by the Extreme North Agricultural Research Institute (ENARI), and ranges from the 1960s to the 2000s. Due to constraints from weather conditions and funding, there were only ten years of
censuses collected for the winter seasons during that time period. The winter census data was collected during the following years: 1980, 1982, 1984, 1985, 1986, 1989, 1990, 1993, 1999 and 2000 (Fig. 6). These surveys were completed using small aircrafts with trained observers counting reindeer from the air and taking aerial photographs for later analysis (Baskin, 2003; Kolpashchikov et al., 2008; Pavlov, Kuksov, & Savelev, 1976; Petrov et al., 2012). Figure 7 illustrates the estimated total herd population for each census year, which was an estimation as not every season had a completed three season census for each year (Baskin, 2003; Pavlov et al., 1976; Kolpashchikov et al., 2008).

The initial census in 1959 estimated that the TRH had less than 200,000 individuals and reached a peak population in 2000 with around one million reindeer (Fig. 7). A decline began at the start of the 21st century with over 800,000 in 2003 and between 700,000 and 800,000 in 2009 (Fig. 7). In the 1980s, it was believed that the carrying capacity for Taimyr was around 850,000 reindeer and yet about one million lived in the early 2000s (Kolpashchikov et al., 2015). This population increase and subsequent decrease is directly correlated with human management. The spike in population corresponds with Soviet Union management regulations on both commercial TRH hunting and wolf management in the TRH range, as well as the fall of the Soviet government (Kolpashchikov et al., 2015). Commercial hunting started in 1971 by the Taimyr State Hunting Enterprise and lasted until 1991, with largest harvest in 1988 when around 120,000 reindeer were harvested (Fig. 8). It is estimated that 700,000
were harvested in wintering grounds in and around the southern border of Taimyr between the years of 1971-1981 (Syroechkovski, 2000).

During the time of the Taimyr State Hunting Enterprise, wolves, reindeer’s main predator, were controlled through a quota-based hunting system, reducing the number of predators for the TRH (Syroechkovski, 2000). Once the Soviet Union fell, the Taimyr State Hunting Enterprise program ended, and with it the commercialization of reindeer hunting causing a decrease in TRH harvest numbers. Without government support to commercially harvest reindeer, (i.e. subsidized transport of harvested reindeer from remote areas, etc.), and no money to support population censuses, there was also no funds for aerial census counts, hence the census gap in the 1990s (Fig. 7). There was little control over hunting regulations of any kind resulting in loss of quotas and increased poaching (Kolpashchikov et al., 2015; Syroechkovski, 2000). According to Syroechkovski (2000), “Ecological and economic control over ... [the TRH] has been lost in recent years. None but the wolves and poachers hunt there now ... [Herd] collapse is possible,” (Syroechkovski, 2000, p. 123). At the time there was concern not only for herd collapse from overgrazing, but from diseases and infections from substances such as anthrax that had been buried with dead semi-domestic deer. Transmission of anthrax was possible due to permafrost conditions, as well as burying rather than burning dead reindeer, which can allow anthrax to be lethal even after a body is buried (Syroechkovski, 2000).
The decreased wolf population due to hunting quotas during the Taimyr State Hunting Enterprise, combined with a complete loss in commercial reindeer hunting after the end of the USSR, allowed increases in both reindeer and wolf populations (Syroechkovski, 2000). Once hunting regulations were removed from the wolf species, the population became to rise, which in turn affected the reindeer. The disturbance of the wolf-reindeer ecological system increased the TRH to a population of one million individuals in 2000. Recorded harvest numbers of TRH increased in 2002, when installation of reindeer hunting regulations and quotas began again (Fig. 8). The TRH population in Figure 7 was also influenced by the increase in the wolf population, which reached about 3,000-3,500 wolves in 2000 (Syroechkovski, 2000). The current Russian government has once again funded researching the TRH, along with implementing hunting quotas. The herd has been declining to a population which may bring it closer to its numbers before Soviet management. However, the TRH is still much larger than the population in 1959, when formal censuses started.
Figure 6. ENARI three season population censuses of TRH, 1960s to 2003 (Petrov et al., 2012).
Figure 7. Population of TRH for each year of aerial surveys (Kolpashchikov et al., 2015).

Figure 8. Number of harvested individuals from the TRH, 1959 to 2009 (Kolpashchikov et al., 2015).
**Methods**

**Historical Census Data and Herd Fidelity to Wintering Grounds**

**Methodology.** The historical aerial census data from the ENARI was used by both Meerdink (2012) and Cooney (2014) to analyze the spatial fidelity of TRH to the calving and summer grounds. This data has also been used for this study, focusing on the wintering grounds. The original census data was collected and recorded as typewritten reports and paper maps, which have recently been digitized into GIS shapefiles, allowing digital analysis to be performed. In both Meerdink’s (2012) and Cooney’s (2014) studies, the fidelity analyses involved analysis of: *range overlap, concentration of range, standard distance* and *temporal variation*. Using the shapefile locations of reindeer locations and census collection for each year allowed for the computation of these reindeer range analyses. Each of these four parts were computed using ArcGIS 10.3 Desktop. This GIS software provided the platform and tools necessary for analysis.

The flowchart in Figure 9 outlines the methods used to create the analysis of historical spatial fidelity and range concentration used by Cooney (2014). The workflow was completed by first using the digitized polygon shapefiles that were created from the aerial census paper maps and converting them into raster files by year with the Polygon to Raster tool. The Reclassify tool applied a reclassification to each year for discernibility when joined into one layer using Raster Calculator. The output created a map of areas where reindeer were located in during all the winter aerial
censuses. Thus, highlighting areas of high fidelity, where reindeer were congregating during census flyovers.

Figure 9. The methods for historical fidelity mapping for range shift and concentration analysis.

*Range overlap* was quantified by the sum of the total area of each year’s polygon shapefiles and subtracted by the area overlapping from the next year. Gunn, Russell, White, and Kofinas (2009) proposed the equation, which Cooney (2014) used for TRH summer range overlap:

\[
\text{Range overlap} = \frac{(2 \times \text{Area of Intersection}) \times 100}{\text{Area of polygon x} + \text{Area of polygon y}}
\]

The equation was applied to computing the winter range.
The Geographic Mean tool was used to create central points of each year’s mean location, essentially, the center longitude and latitude coordinates of the census range (Cooney, 2014). The Geographic Mean Centers, GMCs, were calculated for each winter census year, as well as an overall GMC for all the years. The mapped output of these GMCs were the *concentration of range* analyses. Once all of the GMCs were mapped, the *standard distances* of each geographic mean centers were calculated using the Measure tool. Distances were calculated between chronological GMCs, and from each year to the overall GMC. These calculations provided a measure of variance between each year and the overall mean centroid (Cooney, 2014).

The final spatial assessment by Cooney (2014) was to measure *temporal variation*. The analysis looked specifically at temporal frequency and spatial patterns of range usage. This was created by layering the 10 years of winter census data to provide a hotspot map which highlight the areas that were repeatedly visited by the TRH throughout the census. The output map from the concentration of range provided the base for analysis, which emphasized areas that were revisited most during the years of winter censuses. The result provided a scale of temporal fidelity for each winter.

**Analysis of Climatic Migration Factors**

The data used to assess climate factors influencing TRH winter range use was a subset of years (1980, 1990, and 2000) from the Modern-Era Retrospective Analysis for Research and Applications, or MERRA, produced by NASA. The particular product used for this study is the MERRA-Land which focused on land-based measurements, however,
for the purposes of this study, was be referred to as MERRA (Reichle, 2012). There were 50 variables available in this MERRA dataset, and 6 were chosen for this analysis. The six variables are: TSURF, TSNOW, PRECSNO, PRECTOT, SNOMASS, and SNODP (Table 1). Each of these were chosen for their relation to reindeer winter habitat and were variables that were believed could determine and affect where reindeer chose to overwinter (Kolpashchikov & Mikhailov, 2011; Maklakov & Malygina, 2016).

Table 1. Description of MERRA variables (Reichle, 2012).

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSURF</td>
<td>Mean lane surface temperature (including snow)</td>
<td>K (Kelvin)</td>
</tr>
<tr>
<td>TSNOW</td>
<td>Top snow layer temperature</td>
<td>K (Kelvin)</td>
</tr>
<tr>
<td>PRECSNO</td>
<td>Surface snowfall</td>
<td>kg m(^{-2}) s(^{-1})</td>
</tr>
<tr>
<td>PRECTOT</td>
<td>Total surface precipitation</td>
<td>kg m(^{-2}) s(^{-1})</td>
</tr>
<tr>
<td>SNOMASS</td>
<td>Snow mass</td>
<td>kg m(^{-2})</td>
</tr>
<tr>
<td>SNODP</td>
<td>Snow depth</td>
<td>m (meters)</td>
</tr>
</tbody>
</table>

This analysis required presence vs. absence data, where reindeer were located during a specific winter and where they were not, using the aerial census data. There were no data assigning locations to each individual reindeer within the herd in the ENARI census dataset, therefore, presence and absence points were generated for analysis. Using winter aerial shapefile ranges for 1980, 1990 and 2000, random points were assigned within each year, 100 points for each polygon. These were assigned as points of “presence.” To represent absence, three shapefiles were created, each with all of the wintering ground boundaries, except for one of the years to be analyzed, and
were populated with random points. These points represented where reindeer were not found during a specific year, but had been seen in other census years.

MERRA data was stored in a netCDF, Network Common Data Form, and was converted to the chosen final format of ArcGIS shapefiles, where cells held the climatic data. The cells had a resolution of 2/3 a degree longitude and 1/2 a degree latitude (Reichle, 2012). Data was clipped to the cells, which overlapped the outline of the TRH wintering ground footprint, creating a boundary which fit the area for analysis, which were also held in CSV files. There were 386 cells covering the outline of the recorded TRH range. The MERRA dataset contained climate data from 1979 to present and covered the entire globe. As many other climatic datasets do not thoroughly cover the Arctic, MERRA was the best choice for this research (Reichle, 2012).

The chosen years for this analysis were 1980, 1990 and 2000. This was because of the decadal spread over the course of the ENARI surveys, as well and representing the population changes between each decade. A dataset of shapefiles was created for each of the 6 climate variables for each year. The timeframe for each shapefile contained the average value for each variable per month of analysis for each individual cell within the wintering ground outline, divided into the chosen years. As the analysis was for the winter season only, the months of November, December, January and February were used. Therefore, for the winter of 1980, the data was averaged from November and December, 1980 and January and February 1981. The same format was used from 1990 and 2000.
The MERRA variable cells were overlaid with the absence vs. presence point shapefiles. The points were assigned to underlying cells, which provided footprints of areas reindeer were located for each winter. If there were more presence than absence points within one cell, the cell was considered a presence cell. If there were equal number of presence and absence points within a cell, the cell was considered a presence. This data was included in the attributes tables for each variable and was exported into CSV files for each of the selected years.

**Statistical Data Analysis.** CSV files of each year containing presence data were imported into SPSS statistical software where they were analyzed using logistic regression analysis. Each of the MERRA climatic variables, TSURF, TPSNOW, PRECSNO, PRECTOT, SNOMASS and SNODP, for each year, 1980, 1990 and 2000, were used to provide a decadal analysis. As recommended by Field (2005), to eliminate collinearity, collinear diagnostics had to be tested using the OLS method, which allowed removal of collinear variables. For each year, the binary logistic regression model used the presence field for each MERRA cell as the dependent, and the variables listed above. Therefore, the test was comprised of the reduced variables for a logistic regression using non-collinear variables, and the Backward: Wald data entry process was applied (Field, 2005). A model summary was also produced for each set of tests.
Results

GIS Analysis of Wintering Ground Fidelity

Range Overlap. The percent winter habitat overlap between years when a full census was conducted provided insight into the migration and choice of wintering habitat for the TRH, as well as a wintering ground shifts overtime. Figure 10 indicated that there was a downward trend in overlap percentages from 1980-1982, 1982-1984, and 1984-1985, which were all between 15% to 20% overlap. There was an increase with an almost 30% overlap between the years 1985-1986, and a reduction in 1986-1989 to about 25% overlap. Another very large increase from 1989-1990, which was also the largest overlap percentage at just under 35%. Similar to the first three intervals of decreasing overlap, the last three intervals experienced steady decreases within 25 to 30%.
Concentration of Range. Winter range for the GMCs were longitudinally clustered relatively tightly around the overall geographic mean (Fig. 11). All GMCs were located within 2 standard deviations of the overall GMC. The first standard deviation contains 60% of the GMCs, including: 1982, 1985, 1986, 1990, 1993, and 2000. The second standard deviation contained GMCs for: 1980, 1984, 1989 and 1999. All of the GMCs from the years 1980 to 1989 are at or below the latitude of the geographic mean of all the years, but three of the four years after 1989 are north of the overall GMC. Not all of the GMCs fell within the winter range footprint.

The chronological geographic shifts throughout the time of the winter census data is represented in Figure 12. The two years with the furthest distance north to
south was 2000 and 1985, which were separated by 198.3 kilometers. The furthest east to west distance was between 1999 and 1984, which was 404.9 kilometers. Overall, the geographic means created an “S” pattern from 1980 to 1986. From 1989 to 2000, there is a Sigma “Σ” shape slightly overlapping the “S.” Overall, the GMCs have shifted northeast from 1980 to 2000.

**Standard Distance.** Figure 13 represents the distances in kilometers between the GMCs of each consecutive winter census. There was an overall descending trend across the nine intervals, with three dips from years with the shortest distances. The 1982-1984 range was the largest distance between two consecutive years: 323 kilometers. The distance was compared to all others in Figure 12. This was a 16% increase from the next largest distance, the preceding range 1980-1982, which was 271 kilometers between the two GMCs. The smallest distance was between the censuses in 1990-1993 with measure of 57 kilometers. These GMCs were also the closest of any to the overall GMC.
Figure 11. Spatial Concentration of Range representing the standard deviations and locations of the GMCs for each winter census.
Figure 12. GMC shifts from 1980 to 2000.
Figure 13. Distance between sequential census year’s GMCs.

Figure 14 represented another set of results from the GMC distance measurements, which were the distance from each year’s GMC to the overall GMC. There was no clear overall trend line in this set of data, however, there were consistencies with previously stated findings; namely that 1990 and 1993 have the smallest distances from the overall GMC, 28 and 34 kilometers. The year with the largest distance were 1984 with 209 kilometers, which may highlight the 1982-1984 and 1984-1985 ranges in Figure 13, which were the first and third largest distances from each GMC. In Figure 14, 1999 had the largest distance from the GMC, with a distance of 203 kilometers. This negated the ability to suggest a downward trend for this set of results. However, without the two largest distances, there would be a slight decreasing trend in this data. It is important to note that gaps between years have potential effects
on data. The largest temporal gap were 6 years between 1993 and 1999. These two years also has the largest difference in distances from each year’s GMC to the overall GMC. The year 1993 was 34 kilometers away from the overall GMC, and 1990 was 203 kilometers, the second largest distance between a year and the overall GMC; a difference of 169 kilometers.

**Figure 14.** Distance between individual year's GMCs and the overall GMC.

**Temporal Variation.** Four areas were identified with the highest TRH fidelity during wintering range (Fig. 15). The areas with the darkest colors on the map were regions indicating highest fidelity. Starting from east to west, the areas were categorized by physical geographic markers located in those regions. The first region, Northern Putorana Plateau, was the largest in overall size and centered on the northern
half of the Putorana Plateau. The color scale representing the number of overlapping years indicated that parts of this region had reindeer present 7 of the 9 census years. The majority of the area was categorized as 5 and 6 reoccurrences.

The second region, the Anabar Plateau, was southwest of the first region and was located on the Anabar Plateau, east of the Central Siberian Plateau and the Verkhoyansk Mountains. Only one very small area had 6 reoccurrences. There were larger areas with 4 and 5 reoccurrences, which related, compared to the surroundings. There is a pattern of areas that are clearly favored over others, evident in the visible sliver of 2 reoccurrences in the center of the region.

The third area, Vilyuy Plateau was west of the Anabar Plateau, and west of the Verkhoyansk. This had a much more consistent boundary of reoccurrence then any of the other areas. Seen as an oblong oval over the Vilyuy Plateau, focusing northwest to southeast, the area has clear significance to the TRH due to its continued reoccurrence (Fig. 15). According to the scale, parts of this area had 9 reoccurrences, which was the highest on the map scale, meaning that parts of the herd returned to this area every year a census was conducted.

The fourth and final area of high fidelity, Southbank of Yenisei River region, was also the smallest, located along the southwest bank of the Yenisei River, northwest of the third area. Even though the highest reoccurrence was 5, it was clearly an area of importance in winter migration. The fourth area's distance and size compared to the
other regions highlights its uniqueness, and could be considered an outlier. It was also interesting because of the proximity to human development, specifically to Norilsk, the largest city in the province and the location of the largest nickel mine in the world, as well as the smaller city of Dudinka. Both cities were on the eastern shore of the Yenisei River, but reindeer would have to travel around these settled areas to reach the fourth area of high wintering ground fidelity.

**Overall Fidelity Patterns.** The GIS analysis of ENARI census data and the wintering grounds of the TRH has provided four areas of high fidelity where reindeer have returned at least four of the ten years. These four separate and distinct areas are spread across the wintering ground range and across varying physical topography. Between each year there is at least a 15% overlap of range from the census year before, and almost 30% for the winters of 1989 to 1990. All of the GMCs fall within two standard deviations of the GMC range. Six of the ten years fall within the first standard deviation. The overall GMC has shifted over the course of the ten censuses, resting north east of all of the GMCs for the final year of 2000.
Figure 15. The results of Temporal Variation analysis. Area 1: Vilyuy Plateau region; Area 2: Anabar Plateau region; Area 3: Northern Putorana Plateau; Area 4: Southbank of Yenisei River.

Analysis of Climatic Migration Factors

A preliminary binary logistic regression model for the 1980 data was able to classify 83.5% of reindeer presence for all cases. With this result, a linear regression test, including collinear diagnostics was performed (Table 2a). The VIF collinearity statistic values highlight that there was collinearity between the three related pairs: SNODP and SNOMASS, TPSNOW and TSURF, and PRECTOT and PRECSNO. For this
reason, SNOMASS, TPSNOW and PRECSNO were removed for the reduced logistic regression analysis (Table 2b).

Table 2. Collinearity statistics, logistic regression results and model summary: 1980.

<table>
<thead>
<tr>
<th>a. Collinearity Statistics</th>
<th>B</th>
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<table>
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<th>c. Model Summary</th>
<th>Step</th>
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<td></td>
<td>2</td>
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<td>.325</td>
<td>.472</td>
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Table 2b represents the three chosen, non-collinear variables: SNODP, TSURF, and PRECTOT. This reduced logistic regression ran a Backward: Wald method. Step 2 of the analysis removed SNODP for statistical insignificance. The significance values of TSURF and PRECTOT were very strong, as well as negative B values, indicating that the
variables negatively impact reindeer presence in a specific MERRA cell. This was also seen in Exp(B), as each of the values were less than 1, meaning the probability of presence decreased due to these variables. The model summary (Table 2c) indicated both Cox & Snell R Squared and Nagelkerke R Squared values for analysis in Table 2b were within an acceptable range to support the logistic regression results.

The preliminary 1990 logistic regression model was able to correctly classify 79.4% of reindeer presence for all cases. The collinearity statistics test provided VIF values to analyze collinear variables (Table 3a). All variables had an acceptable VIF range of above 10, accept for PRECTOT, which had a value of 1.037. These results further supported the elimination of collinear variables, SNOMASS, TPSNOW and PRESNO for a reduced logistic regression using the Backward: Wald method.

The three chosen, non-collinear variables for 1990 were: SNODP, TSURF, and PRECTOT, which were the same for 1980. As with the 1980 results, the test removed SNODP. Also similar with 1980, both TSURF’s and PRECTOT’s B, Sig and Exp(B) values were at same ends of the negative range. Thus meaning, both years had similar conditions, areas with low surface temperature and high (snow) precipitation, to which the reindeer avoided during those winter seasons. Table 3c highlights the Cox & Snell R Squared and the Nagelkerke R Squared as being statistically significant, but less strong compared to 1980’s results.
Table 3. Collinearity statistics, logistic regression results and model summary: 1990.

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>Standard Error</th>
<th>Beta</th>
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<th>Significance</th>
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<tr>
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The final year for analysis was 2000, which was the last year a winter TRH census was reported. The preliminary logistic regression results for the 2000 model were able to classify 70.9% of reindeer presence for all cases, the lowest percentage of all three years. PRECTOT was removed from further analysis after the preliminary logistic regression model because its data for the entire four months of winter were the same as PRECSNO values. This had not been discovered until these results. Therefore, only the remaining five variables were included in the collinearity statistics model (Table 4a).
The collinear diagnostics provided results for the three of the variables which fell within the acceptable VIF value: TPSNOW, TSURF and PRECSNO. Both SNODP and SNOMASS have very high VIF collinear values, and were not included in the logistic regression with Backward: Wald model.


<table>
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<tr>
<th>Variables</th>
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<td>.793</td>
<td>1.260</td>
</tr>
</tbody>
</table>

b. Logistic Regression

<table>
<thead>
<tr>
<th>Step 3</th>
<th>B</th>
<th>S. E.</th>
<th>Backward: Wald</th>
<th>df</th>
<th>Significance</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>.242</td>
<td>.497</td>
<td>.236</td>
<td>1</td>
<td>.627</td>
<td>1.273</td>
</tr>
<tr>
<td>snodp</td>
<td>-3.689</td>
<td>1.854</td>
<td>3.957</td>
<td>1</td>
<td>.047</td>
<td>.025</td>
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</tbody>
</table>

c. Model Summary

<table>
<thead>
<tr>
<th>Step</th>
<th>-2 Log Likelihood</th>
<th>Cox &amp; Snell R Square</th>
<th>Nagelkerke R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>363.896</td>
<td>.015</td>
<td>.021</td>
</tr>
<tr>
<td>2</td>
<td>363.900</td>
<td>.015</td>
<td>.021</td>
</tr>
<tr>
<td>3</td>
<td>364.207</td>
<td>.014</td>
<td>.020</td>
</tr>
</tbody>
</table>

Unlike the previously analyzed years, there were three steps in the logistic regression results, as the test removed two of the three variables, all of which were the same from the previous year’s tests: SNODP, TSURF, and PRECTOT (Table 4b). The final
variable in Step 3 was SNODP with very weak B, Sig and Exp(B) values. The model summary reveals that both the Cox & Snell R Squared and the Nagelkerke R Squared had very low values for this model (Table 4c). The final result of 2000 is that none of the variables were highly significant in location of presence vs. absence, accept for SNODP. However, SNODP was statistically weak, revealing that SNODP slightly impacted reindeer presence, but was not overly significant.

Discussion and Conclusions

Discussion

The most important observation about these results was the potential influence of herd size on choice of winter grounds and winter migration. In 1980, the herd population was around 500,000 individuals, and increased to around 650,000 by 1990. By 2000, the population had increased to 1,000,000 individuals due to lack of managed harvest following the dissolution of the USSR (Fig. 7 & 8). The 20-year difference between 1980 and 2000 was huge change to herd dynamics and could have affected winter food availability for such large numbers. Without census data for each year, it is impossible to know which areas can accommodate the most reindeer. However, the movement of the GMC to the northeast may be an indication that larger herd numbers effected the spreading to different wintering grounds which may not have been favored previously for winter forage. Therefore, the climatic variables for 2000 wintering grounds may have been statistically insignificant because the boost in population forced
reindeer to use grounds that were unsuitable due to overcrowding. Without wintering
census data for any years since 2000, it is impossible to know the effects the larger herd
number had on the environment, or locations used in subsequent years. However,
these results could provide future research the baseline data for studying extreme
changes in herd population and winter habitat use.

Limitations

While the ENARI data provides opportunity to analyze the TRH, which without
this study could not be possible, but there are still serious limitations to the aerial
census data. There are many reasons for gaps between censuses: expense of pilots,
fuel, airplanes, trained researchers, etc., and especially the change in government has
affected the amount of aerial data which has been collect for this herd. However, the
biggest issue has been the temporal range, as the last winter census was conducted in
2000. Essentially, there has now been a sixteen-year gap in winter data, making analysis
of future populations and herd dynamics, extremely difficult, if not impossible. These
assessments and analyses are crucial as climatic changes in the Arctic effect the herd.

A second issue with data is the precision of the climate variables. The cell size
for MERRA was very large, which caused the data to be averaged many times over to
produce the values for the areas used in this study. This changing of data may mask
significant variations and patterns, which are indiscernible when looking at such large
areas. The data used in this study has provided a baseline for the winter migration
seasons. However, with more data and developments in technology, much more can be learned of this herd in the future.

Conclusions

The two objectives for the study were: (1) to identify areas of fidelity in the winter range using ten years of aerial census data, and (2) to identify the relationship between winter habitat and selected climatic variables. The four areas of highest fidelity were easily discernable for the winter range: Vilyuy Plateau region, Anabar Plateau region, Northern Putorana Plateau, and the Southbank of Yenisei River. The first three regions are physically different from areas of fidelity for calving and summer seasons, each being plateaus (Cooney, 2014; Meerdink 2012). The Southbank location is an outlier because of its location to human settlements, particularly, Norilsk and Dudinka. The most interesting of these locations was the defined oblong edges of the Northern Putorana Plateau.

The distance between the consecutive years Geographic Mean Centers has had a declining distance trend over the course of the census dataset. However, the distance between each year’s GMC to the overall GMC has no distinct trend. The variation between each year’s footprint changed each year with no two years with the exact same outlines. Overall, the size, shape and distribution of each year’s wintering grounds changed, but overlap between the years’ highlight areas where reindeer are almost always recorded as having presence. These hotspots are areas that may have been
returned to for generations of reindeer and have importance to herd survival and historical land usage.

The second objective was addressed in the second half of the study, focusing on the results of the logistic regression analyses involving historic presence of reindeer and corresponding climatic variables. The results provided insight into climatic conditions effecting reindeer land usage during the winter seasons. In 1980, there was strong statistical evidence that reindeer tended to avoid low surface temperatures and areas of high snowfall (precipitation). The results were similar in 1990, with the most statistically significant variables, mean surface temperature and total surface precipitation, being negative drivers for reindeer presence. In 2000, however, snow depth was the only significant variable, albeit weak. In general, the results for 2000 were not helpful in determining what influenced reindeer presence. Overall, it was discovered the least collinear variables with the most influence on reindeer wintering grounds were mean surface temperature, total precipitation and snow depth. However, these were the results by relying on the logistic regression tests which were chosen. There may have been other patterns which included correlated variables that were removed during the collinearity analysis.

The joining of these objectives, identifying wintering range fidelity and the relationships between winter habitat and climatic variable, provides insight into where reindeer of the TRH choose to winter and why. Having created fidelity maps provide
locations for ground-truthing and vegetation analysis, increasing understanding of forage habits. Understanding presence and absence locations to climatic variables provide statistical evidence to reindeer wintering preferences, i.e., warm surface temperatures and low total surface snowfall. These details can facilitate forecasts for changing climate effects on the TRH and reindeer worldwide, as well as land management and protection of herd lands.
CHAPTER 3
WILD TAIMYR REINDEER (*Rangifer t. tarandus*) HERD: SATELLITE BIOTELEMETRY
MOVEMENT AND WINTER MIGRATION ANALYSIS

**Introduction**

The invention and use of telemetry, sending information by radio waves, has proven over the last century to be an excellent method of tracking and analyzing animal movement. Biotelemetry is an exciting avenue of study that has created boundless opportunities for scientific discovery (Cagnacci, Boitani, Powell, & Boyce, 2010; Cooke et al., 2004; Fancy, Pank, Whitten, & Regelin, 1989; Hay & Nebel, 2012; Werber, 1970). The harnessing of radio waves and launching of satellites revolutionized the research fields of animal ecology and biogeography in the 20th century. Specifically, since the invention of satellites and Global Positioning Systems (GPS), telemetry has advanced from the short distance of radio capabilities to the long range transmissions of satellites. Thus allowing animals which cover great distances to be tracked and studied like never before. This research technique has given an advantage to those with knowledge of Geographic Information Systems and Sciences (GIS), which innately work with GPS location data recorded from satellites.

As the field of biotelemetry and its technology has expanded, new techniques for attaching transmitters to wildlife has changed. Due to the size of the transmitters in the early stages, large animals were chosen for analysis because of their size and ability to carry bulky, cumbersome equipment (Cagnacci et al., 2010; Casper, 2009). One such
animal is the *Rangifer tarandus*, which is called the reindeer in Europe and Russia, and the caribou in North America. In their natural habitat, reindeer are large herbivorous mammals which migrate annually across extreme tracks of land in the Arctic. Reindeer have essential relationships to the environment of the tundra biome, as well as with the humans that live there, both as wild and domesticated creatures (Hummel & Ray, 2008).

With the impending and existing impact of changing climate, monitoring reindeer as a global natural resource has become an international effort. Biotelemetry provides a monitoring technique which allows researchers to study migration remotely in order to understand animal behavior and identify short- and long-term migration patterns and trends. Thirteen individuals of the wild Taimyr Reindeer Herd (TRH) in the northern central area of Taimyr, Russia were collared and monitored from 2013 to 2014. This is the first study to monitor and analyze the world’s largest wild reindeer herd, the TRH, with satellite telemetry and one of the first satellite telemetry projects to be conducted on reindeer in Russia. The goal of monitoring the TRH was to research the currently understudied migratory behaviors of individual Russian wild reindeer over fine-timescales with the objectives to:

1. measure key characteristics of reindeer mobility: average distances and speeds over the temporal range of winter migration for both individuals and the collared cohort;
2. complete an in-depth analysis of seasonal, monthly and daily mobility patterns for a subset of reindeer with highest quality data (day vs. night movement, destination vs. localized mobility).

**Literature Review**

Scientific Animal Tracking

Within satellite biotelemetry there are three subdivisions: GPS, satellite, and GPS/satellite (Farve, 2012). Like radio telemetry, an animal must be tagged with a transmitter, however, the method of data collection is different. With GPS telemetry, utilizing only GPS satellites, the transmitters on the ground must have three or more satellites to triangulate location to create a two or three-dimensional coordinate for longitude, latitude and/or elevation (Farve, 2012). Retrieving the data depends on the type of transmitter system being used. Certain transmitters must be recaptured to download data, others can only be downloaded on a handheld receiver, lastly, some allow data to be downloaded via the internet (Farve, 2012).

Satellite biotelemetry research uses Argos satellites. The Argos system is comprised of six Polar Orbiting Environmental Satellites: NOAA-N, NOAA-15 and 18 are US owned, METOP-A and B are Eumetsat owned, and most recently launched, SARAL, which is owned by the Indian Space Research Organization (Argos User Manual, 2016). However, the fewer number of Argos satellites, compared to number of GPS satellites, can limit the accuracy of identifying locations using triangulation causing
larger error radii. Argos counters this by using the Doppler Effect to improve accuracy of location data while the satellites are passing over a transmitter (Argos User Manual, 2016). According to Argos documentation, “at the poles, the satellites see each transmitter on every pass, approximately 14 times a day,” (Argos User Manual, 2016). Lastly, GPS/satellite telemetry expands usage options by utilizes both GPS satellites and Argos satellites to capitalize on GPS triangulation and Doppler Effect, in essence to increase accuracy. In this case the transmitter is more technologically advanced, collecting GPS data at chosen intervals by the researcher and uploads to an Argos satellite every few days (Argos User Manual, 2016). Therefore, the goal of using a more integrated system of satellites is to be have higher precision and accuracy, specifically for polar regions. Once GPS/satellite data is collected it can be downloaded to a computer and analyzed.

Data coming from satellites must be downloaded to one of the more than 60 receiving centers positioned all over the globe and transferred to an Argos processing center (Fig. 16). From the three Argos processing centers, data is further transferred to one of regional reception stations. Data can be stored with Argos in two ways, either the whole dataset is made accessible for download during the study, or it must be downloaded in specific intervals. The latter is where the data is only available during a certain time window, after which is no longer available without requesting and paying to retrieve data. Choosing between these two options is a matter of cost.
Satellite telemetry has advantages and disadvantages. Firstly, satellite transmitters have the ability to collect much larger datasets, sometimes 10 to 100 times larger than radio counterparts (Moorcroft, 2012). By utilizing satellites, this type of telemetry can monitor animals with expansive migration and global ranges. The datasets can also include other location factors that are not capable with radio. One of which is the elevation of the animal at their location. This is very useful in studies in mountainous and deep marine environments. However, the number one disadvantage of this technology is the cost. When studying large, migratory animals there is a high cost of accessing the location of the animal, then to capture and mark the
individual. Also, animals that are very large require more manpower in the tagging process. The transmitters and systems used to record the data are also very expensive, along with the trained people and software needed to organize and analyze the subsequent collected data. For these reasons, it is very important for researchers to understand what the objectives of their collaring study require. If the study ultimately needs satellite telemetry, then the high cost may be worth it.

The idea of location tracking via satellite was popularized in the late 1960s and early 1970s. Buechner, Craighead Jr., Craighead, and Cote (1971) in particular, discussed the unique possibilities this technology would bring and how it would change wildlife research. Moving to the present, telemetry has brought forth many of the advancements that Buechner et al. (1971) had hoped for. To date telemetry has assisted researchers in studies published on identifying methods of resource selection analysis, the influences of animal movement, animal memory, behavior, seasonal migration patterns, herd dynamics, and predator and forage influences, among many other topics (Avgar, Mosser, Brown, & Fryxell, 2013; Bechtel et al., 2004; Buechner et al., 1971; Cagnacci et al., 2010; Cristescu, Stenhouse, & Boyce, 2014; Hillis, Mallory, Dalton, & Smiegielski, 1998; Moortcroft, 2012; Penin, Adrados, Mann, & Janeau, 2004).

Due to the newness of the technology and its rapid development over the last 20 years, both methods of use and analysis are still being tested and expanded. This has spurred by widespread implementation of GIS, which innately works with GPS data (Bissonette, Sherburne & Ramsey, 1994; Wynn, Songer & Hurst, 1990). GIS analysts
often work with very large datasets, common in satellite tracking data, as GPS transmitters can record huge volumes of data for extended periods of time and need to be filtered and analyzed (Moorcroft, 2012). Therefore, GIS is an excellent method to analyze animal movement data collected from biotelemetry studies on animals of almost any size.

*R. tarandus* Tracking

North American caribou herds have been monitored using radio and satellite collars since the mid to late 1980s. The CircumArctic *Rangifer* Monitoring and Assessment network, CARMA, holds data from more than 22 wild migratory *Rangifer* herds, and 13 of these herds have had telemetric collar studies (Fig. 17). These herds are: Bathhurst (1996-2009), Ahaik (2001-2010), Cape Bathurst (1996-2010), Bluenose West and Bluenose East (1996-2010), Dolphin and Union (1996-2006), Western Arctic (1987-2010), Central Arctic (1986-2006), Porcupine (1985-2010), Kangerlussuaq-Sisimiut (1998-1999), Akia-Maniitsoq (1997-1999), and the Iceland herd (2006-2008; Russell et al., 2013). Notably, not one of these herds are located in Eurasia. The collar data for these 13 herds have been used in many studies ranging from seasonal migration variation and climate change, influences on winter distribution, studying home ranges, factors of animal movement, mapping habitat use, and comparing satellite imagery reflectance to collar data (Avgar et al., 2012; Bechtel et al., 2004; Hillis et al., 1998; Joly, 2011; McNeil, Russell, Griffith, Gunn, & Kofinas, 2005; Rasiulis, Schemlzer, & Wright,
These studies have provided an excellent methodological framework for analyzing *Rangifer* spatial ecology using biotelemetry.

Figure 17. CARMA *Rangifer* herds (Conservation of Arctic Flora and Fauna, n.d.; Russell et al., 2013). Map by Emily Francis.

This study is one of the first studies to use satellite telemetry on wild reindeer in Russia, and the first ever for the TRH (Kolpashchikov et al., 2015; Petrov et al., 2012). Fifteen individuals from the TRH were collared in September of 2013, and the last collar ceased to transmit data in August of 2014. This short study duration and limited sample only 15 reindeer are not sufficient for a full understanding of the TRH
and its migration behaviors (Cagnacci et al., 2010). However, the utilization of modern satellite telemetry will substantially advance our knowledge of this important species, especially as the global climate change increases its effect on the Arctic.

**Methods**

**Collaring and Argos Preprocessing**

In October 2013, 15 reindeer from the eastern branch of the TRH were collared near the Khatanga village, in Russia. The Russian technique of collaring reindeer, used in this study, involved approaching the individual while it was swimming, usually from a small watercraft, grabbing hold of the antlers and securing the collar around the animal's neck. Reindeer were preoccupied while swimming, usually remaining in a calm “stupor” and would continue treading while waylaid in the water (ITN Source, 2014). After the collar was secured, a magnetic pin was pulled to activate satellite communication and transmission recording. The individual was released to continue swimming. The collars were programmed to record each reindeer’s location once every 15 minutes. All of the functional collars started recording locations on October 13 or 14, 2013.

As the collars transmitted to overpassing Argos satellites, the data recorded was downloaded to receiving centers and sent to processing centers before being accessible through the Argos online platform. Data was available on the online platform to be downloaded at intervals of every 10 to 20 days. If left undownloaded longer than the
interval time allotted data would be removed from the Argos server. At each time interval, data were downloaded as Excel files by time frame. A specific interval file contained each reindeer that had been recorded and all of its location recordings from the beginning of the current interval. The final interval download was in August 2014, when the last collar stopped transmitting data.

Even though the data had initial preprocessing applied before being available to Argos users, further processing and filtering was conducted. These steps involved reorganizing the data from time interval collection to the specific individual identification numbers generically assigned by Argos. This reorganization of data was completed using ArcPy scripting language, a Python sublanguage to be used with ArcGIS. These scripts converted the Excel files of time intervals from Argos into CSV files, created a file geodatabase and thirteen datasets. Of the 15 collars deployed, only 12 successfully transmitted data. Within each of the datasets field names and attributes tables were created, data was imported and the coordinate system was set. Each dataset consisted of feature classes holding each of the downloading time intervals, which were corrected by looping through feature classes, adding corrected attribute tables and finalizing a new dataset, with a separate feature class for each reindeer.

The reindeer were given names to distinguish them without using the numeric identification numbers provided by Argos. These names were given purely for differentiation and were not meant to describe individuals in anyway or indicate sex. These names and identification numbers can be found in Table 5 in the Results section.
Filtering Outliers

Once data was organized by individual reindeer identification numbers, the first round of user-end filtering was applied using Movebank. Movebank was the web platform used for basic outlier filtering, mapping and analysis of Argos data. There are two kinds of filtering: Simple Argos Filter and Douglas Filter, which was developed by Douglas et al. (2012). Initially, the Douglas Filter was to be applied to the TRH data, however, this was not possible due to lack of specific attributes. Therefore, the Simple Argos Filter (SAF) had to be applied for filtering and cleaning the data. Each reindeer ID was run individually on Movebank with the following SAF options: “filter by value range” and “filter by speed” (Fig. 18). The “filter by value range” removed all null values and highlighted the remaining data with an error radius of less than 250. The “filter by speed,” which at the time of application was in an experimental stage, had the maximum “plausible speed” of 16.7 meters per second, and the maximum location error of 1000 meters. The algorithm applied was the valid anchor algorithm. Once each of the addressed outliers had been highlighted and removed, each of the updated reindeer ID datasets were downloaded for further filtering using ArcGIS.

A second round of filtering was completed by visually highlighting and manually removing data points in ArcGIS. This allowed spatial disparities between data points to be addressed by removing points which could not logically be sequential in time and distance, but were not removed through the SAF algorithm. At the completion of this
second filtering, data were ready for conversion from ArcGIS shapefiles to Microsoft Excel files for each reindeer for further analysis.

![Figure 18. SAF options applied to each of the reindeer files in Movebank.](image)

**Distance and Temporal Analysis Methods**

Each original reindeer Excel file contained a single sheet of data. Columns named attributes that had been selected for analysis. These attributes, along with their units, have been displayed in Table 5. Key attributes for further analysis were: “timestamp,” “location-long,” “location-lat” and the “event-id,” which provided distinct identifiers to each location record.
Table 5. Reindeer Excel column titles of Argos attributes with units.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Units</th>
<th>Attribute</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>event-id</td>
<td>Numeric</td>
<td>argos:error-radius</td>
<td>Numeric</td>
</tr>
<tr>
<td>visible</td>
<td>“True” or empty</td>
<td>sensor-type</td>
<td>GPS or Argos Doppler Shift</td>
</tr>
<tr>
<td>timestamp</td>
<td>“MM/DD/YY HH:MM”</td>
<td>tag-local-identifier</td>
<td>Reindeer ID number (000,000)</td>
</tr>
<tr>
<td>location-long</td>
<td>Degrees</td>
<td>study-local-timestamp</td>
<td>“MM/DD/YYYY HH:MM:SS AM/PM”</td>
</tr>
<tr>
<td>location-lat</td>
<td>Degrees</td>
<td>utm-zone</td>
<td>Zone code</td>
</tr>
<tr>
<td>utm-easting</td>
<td>UTM Cartesian coordinates</td>
<td>study-timezone</td>
<td>Time zone name</td>
</tr>
<tr>
<td>utm-northing</td>
<td>UTM Cartesian coordinates</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These attributes were used to develop additional variables. Distances between subsequent data points were computed utilizing the Haversine Formula, which calculates distance using the Earth’s radius, latitude and longitude of two coordinates, and the Spherical Law of Cosines (Fig. 19; Stevenoski, n. d.). The Spherical Law of Cosines represents “d” in the Haversine Formula (Fig. 20). To correctly calculate the distances, the angle values had to be radians, which was applied using an Excel formula (Fig. 21). The value of 3958.756, in the Excel formula, converts all output values from radians into miles. The final distances were then multiplied by 1.60934, converting values to kilometers, the units used in this study for distance analysis.
\[ R = \text{earth's radius (mean radius }= 6,371\text{km)} \]
\[ \Delta \text{latitude} = \text{latitude}_2 - \text{latitude}_1 \]
\[ \Delta \text{longitude} = \text{longitude}_2 - \text{longitude}_1 \]
\[ a = \sin^2 \left( \frac{\Delta \text{latitude}}{2} \right) + \cos(\text{latitude}_1) \cdot \cos(\text{latitude}_2) \cdot \sin^2 \left( \frac{\Delta \text{longitude}}{2} \right) \]
\[ c = 2 \cdot \text{atan2} (\sqrt{a}, \sqrt{1 - a}) \]
\[ d = R \cdot c \]

Figure 19: Equations within the Haversine Formula (Stevenoski, n. d.).

\[ d = \text{acos} (\sin(\text{lat}_1) \cdot \sin(\text{lat}_2) + \cos(\text{lat}_1) \cdot \cos(\text{lat}_2) \cdot \cos(\text{long}_2 - \text{long}_1))). R \]

Figure 20: Equation “d” within the Haversine Formula (Stevenoski, n. d.).

\[ \text{ACOS} (\text{COS} (\text{RADIANS}(90 - \text{LAT}_1)) \cdot \text{COS} (\text{RADIANS}(90 - \text{LAT}_2)) + \text{SIN} (\text{RADIANS}(90 - \text{LAT}_1)) \cdot \text{SIN} (\text{RADIANS}(90 - \text{LAT}_2)) \cdot \text{COS} (\text{RADIANS}(\text{LON}_2 - \text{LON}_1))) \cdot 3958.756 \]

Figure 21: Excel formula used to calculate distance between coordinate points.

In a fully filtered dataset, the values of distance between location points were measured in kilometers. Variables were analyzed using three temporal timeframes of mobility: monthly, weekly and daily. The following methods analyzed reindeer individually and as a chosen subset. Within these timeframes: distance covered, speed, daytime versus nighttime movement analysis were applied. Distance covered was calculated by the addition of all distances within a chosen timeframe. Speed was calculated by distance divided by timeframe. Daytime and nighttime movement was
calculated by distances covered during 12 hours of “day” and 12 hours of “night” and compared, but only for the subset of individuals.

Further analysis was compared for a subset of 4 reindeer with the most complete data, were analyzed for in depth distance and movement values. These individuals were chosen for the length and completeness of their datasets and compared to the entire viable, migratory collared reindeer set. It was originally comprised of five individuals: Sasha, Grisha, Boris, Nikolai, and Fyodor. Unfortunately, Fyodor had to be removed from the analysis, for reasons that will be explained in a later section. This second round of analysis focused on daily mobility, including diurnal and nocturnal mobility, and destination distance per day.

Daily Averages and Sums. Using basic mathematical functions from the Argos attributes, the average distance per record per week (km), sum distance per week (km), average distance per day (km), and average speed in kilometers per hour were calculated for all individuals. The day vs night variables were calculated for the subset by dividing each date into two twelve-hour time frames. There is a seven-hour time difference between the Coordinated Universal Time (UTC), which is used by Argos and local time in Taimyr. All time calculations were computed in 24:00:00 hour time format, but the actual time in Taimyr is 7 hours ahead of the timestamp. Each day and night were divided by 00:00 to 11:59 and 12:00 to 23:59. However, the actual time which the reindeer experienced in Taimyr would have been 07:00 to 18:59 as “daytime” and 19:00 to 06:59 as “night time.” Each day was divided by these twelve hour blocks and average
distance per hour was calculated by dividing all data points for one date in their twelve-hour time frames by 12. The result is the average distance traveled for either the first or second half of the date, which is referred to in this study as day and night.

The destination distance used the Haversine distance equation. However, rather than measuring the distance between the sequential records, the distance was measured between the first and last point of each day. This provides the “net” distance traveled in migration versus total daily distance, which measures the total movement during one day. Lastly, we derived the “effective daily movement rate” by dividing the total distance traveled by the “net” distance. This measure provides a relative value that compares the amount of distance covered in 24 hours by the migration distance from the first data point to the last. This final value provides an idea of days when an individual moved, but didn’t migrate, versus days where the individual’s movement was direct and migratory. The latter presented itself when there was movement and distance was covered. These analyses were compared for the subset of reindeer.

Results

Filtered Biotelemetry Data

The image on the left of Figure 22 illustrates the differences before the application of the SAF algorithm was applied and highlights the outliers in the “after” image for the reindeer named Igor. Each point in the “before” image represents a recorded location. However, there were clear outliers which did not follow the general,
logical path Igor took. Evidence of this can be seen in the upper left quadrant of the left image, where there were locations far off the general path (Fig. 22). The image on the right illustrated both the collected data points, as circles, and the filtered outliers, as x’s. All of the obvious visual outliers seen in the upper left quadrant of the first image were represented as x’s, and were removed from the analysis due to falling outside the maximum speed and location error set in the SAF filtering on Movebank (Fig. 18). The output of 11 reindeer after filtering can be seen in Figure 23, showing the breadth of distances the reindeer traveled throughout their migration.

Figure 22. The left image is Igor’s data points before SAF, and the right represents all data points and highlights filtered points.
Figure 23. Post SAF filtering of reindeer paths. Map by Michael Madsen.
Table 6 represents the total number of location records per reindeer and the number removed through filtering. Of the twelve reindeer ID’s that were provided by Argos during the downloading process, only 11 had data points. Collar 61806 never recorded data, appearing empty during downloading. It was also discovered that Vladimir was not a migrating reindeer. It is believed that the collar was being carried by a human, most likely in a vehicle, causing removal from analysis. Fyodor was originally part of the subset for further analysis, but was removed because all records appeared to be located in the same small area for the entire length of collar transmission. The reindeer was most likely non-migratory or domestic, and could not be included in this study. Finally, Peter’s path follows the logical migration, until its recordings became deliberate and linear from town to town. The collar’s final locations were believed to be an address to send the collar in case it was found. Most likely, the reindeer was hunted, or the collar was found, and someone returned the collar to the address.
Table 6. Reindeer ID numbers, names and record information results.

<table>
<thead>
<tr>
<th>Reindeer ID Number</th>
<th>Total Records</th>
<th>Outliers (Filter &amp; Visual)</th>
<th>Remaining Records</th>
<th>% of Removed Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>50748 “Andrey”</td>
<td>2614</td>
<td>1435</td>
<td>1179</td>
<td>54.89</td>
</tr>
<tr>
<td>61806 (No Records)</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>61807 “Rudolf”</td>
<td>566</td>
<td>152</td>
<td>414</td>
<td>26.85</td>
</tr>
<tr>
<td>61821 “Sasha”</td>
<td>5293</td>
<td>2405</td>
<td>2888</td>
<td>45.43</td>
</tr>
<tr>
<td>61916 “Vladimir”   (Non-functional)</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>61927 “Grisha”</td>
<td>4047</td>
<td>2307</td>
<td>1740</td>
<td>57.00</td>
</tr>
<tr>
<td>61930 “Boris”</td>
<td>5334</td>
<td>2805</td>
<td>2529</td>
<td>52.58</td>
</tr>
<tr>
<td>97601 “Fyodor”     (Non-functional)</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>101120 “Leonid”</td>
<td>1866</td>
<td>867</td>
<td>999</td>
<td>46.46</td>
</tr>
<tr>
<td>101121 “Peter”     (Hunted or Deceased)</td>
<td>1172</td>
<td>314</td>
<td>858</td>
<td>26.79</td>
</tr>
<tr>
<td>132451 “Igor”</td>
<td>3980</td>
<td>1488</td>
<td>2492</td>
<td>37.38</td>
</tr>
<tr>
<td>132452 “Nikolai”</td>
<td>8208</td>
<td>2827</td>
<td>5381</td>
<td>34.44</td>
</tr>
</tbody>
</table>

Andrey, Rudolf, Leonid, and Igor lacked sufficient data to be considered for further analysis. Either these reindeer did not record data long enough into the migration or there were large gaps in the data. The remaining reindeer, Sasha, Grisha, Boris, and Nikolai, have the shortest gaps in data, the most complete migration data
coverage, and three of the four highest percentage of filtered datasets, allowing them to be included in the subset.

Distance and Temporal Analysis

**Daily and Weekly Total Distances.** The top graph in Figure 24, “Daily total distance traveled,” visualized the sum of distances for each day containing recorded locations. Each line corresponds with a specific reindeer and ends whenever the collar stopped transmitting data. The graph was split into visual sections, the first being from October 10th, 2013 to December 15th, 2013. There is a decreasing trend in daily sum distance by the majority of reindeer, with a spike around November 3rd, 2013 by Nikolai and Rudolf. The next section is from December 22nd, 2013 to February 2nd, 2014, where there was a large increase in daily distances for Sasha, Grisha, and Boris. All of the reindeer, other than Nikolai, Sasha and Boris, had noticeably lower sum distances during this section of time. The third section, February 2nd to the 12th of 2014, there is no recorded data. It is unclear if the data for this time period was not properly downloaded from Argos or there was a malfunction with the Argos satellite system. The last section from February 13th, 2014 to May 11th, 2014 accounts for mainly three reindeer: Sasha, Peter, and Nikolai. These reindeer have distance sums of around 55 km a day or less for the entire section. Around March 2nd, 2014 and April 6th, 2014 there are cyclical increases, with a low point between them and in late April to the end of recording.
The bottom graph in Figure 24, “Weekly total distance traveled,” visualizes the sum total of the weekly distance traveled in kilometers. Weeks were calculated from the first date of recording to following seven days, for example, October 13th to the 20th, 2013. Some instances there were only one or two days within the supposed seven-day week, meaning not all weeks have seven days of distances. The graph created follows the same three sections described in the top graph of Figure 21. The first section, corresponding to the fall migration, week 1 to week 8, mid-October to early December, represents a decreasing trend in weekly distances. This is assumed to be the end of fall migration into the winter season. The second section, week 9 to week 16, which was mid-December to early February, displays an increasing weekly distance, during the winter season. This is seen clearly in Grisha’s and Nikolai’s lines, which are similar to the results in the left graph. The last section, week 17 to week 31, mid-February to mid-May, illustrates the same decreasing trend for Sasha, Peter and Nikolai. These weeks would be assumed as spring migration.

When looking at the daily and weekly total distances traveled for each individual reindeer, there are two that should be addressed separately, Nikolai and Sasha (Fig. 25). In the top left graph, representing Nikolai’s daily distance, there was an overall downward trend throughout the data. This was with an exception in late January and early February where there were a few days of consistent increased distances. However, the days with the largest distances occurred within the first month and a half of recording. These observations were seen clearly in the right graph of
Figure 24. Graphs representing daily and weekly total distances in kilometers.
Figure 25, referring to weekly distance totals. It was inferred that Nikolai was traveling farther and faster in the first few months to reach the winter grounds, which was logical during a migration.

Sasha has a less expected distance traveled pattern (Fig. 25). Daily traveling distances were between 20 and 40 kilometers a day, until late November and early December, the end of fall migration, when there was an increase for a few days to around 60 km a day. There was a lull with a few days around 20 km a day, until mid-December to early February, where there was at least 6 days of distances of over 80 km, and two of those days being at over 140 km. After mid-February the daily distances stay well under 40 km a day, closer to 20 km a day. This was also visible in the weekly distance totals (Fig. 25).

Sasha’s pattern infers that the individual was traveling large distances during the wintering season, unlike Nikolai, who traveled long distances during fall migration to reach the wintering grounds. Grisha showed a similar pattern to Sasha, traveling large distances during winter, rather than during fall migration. Another reason for these results may be from technical issues with the collars, which will be discussed in the Discussion section.
**Average Distance and Speed.** The top graph in Figure 26 represents average distance traveled per 24-hour period over the entire transmitted range, whereas the bottom graph illustrates the average speed for 24-hour intervals. Both of the graphs have corresponding bar size for each reindeer’s distance (km) and speed (km/hr). These data have similarities to daily distance, as well (Fig. 24). Grisha had the most erratic, largest distances (Fig. 24) and the fastest average speed and distance (Fig. 26), yet the collar stopped working in February. Nikolai has the longest temporal range, ending in May, and the shortest daily distance and speed. Nikolai’s average speeds and distances follow the expected migration distance and speed patterns. Sasha and Boris also had distinctive distance patterns during the winter season, but both fall between Grisha and Nikolai with average distance and speed per hour. To understand the differences between these four reindeer’s movement patterns, further analyses were performed.
Figure 26. Top: average distance traveled per 24-hour period. Bottom: average speed per 24-hour period.

Day vs Night Distance Traveled Patterns. The patterns presented in the average day versus night graphs (Fig. 27) are similar to the previous distance graphs each of the reindeer in the subset, and yet also provide evidence to differences between, daytime, 07:00 to 18:59, and nighttime, 19:00 to 06:59, movement. Grisha and Sasha, in
particular, exhibited very large distances in between mid-December to early February during the winter season. This had been seen in previous analyses. However, there were clear differences between day and night distances for Boris and Sasha.

Boris’s day verses night distance per hour patterns indicate times when the individual was more active (Fig. 28). Arctic winter has an extended period of no sunlight. Therefore, there is no daytime sunshine, which is commonly used to differentiate between day and night. It can be understood that Boris’s daytime movement was not contingent on sunlight. In October, day and night movement were at times equal or very similar, meaning Boris was moving throughout both time periods during the migration. There are other times, like early November and early March, where there was a clear divide in day and night movement. Overall, Boris’s record provides a logical timeline of day versus night movements.

Sasha demonstrated unusually large distances in the midwinter season (Fig. 25), and day versus night movement was no different (Fig. 28). Not only did Sasha have larger distances, compared to Boris, but the larger distances occurred during the night, 19:00-06:59. Boris’s daytime distance had values far above the nighttime distances. However, Sasha’s nighttime distances were almost always longer than daytime distances. This is seen in November, as well as from mid-February to late April, which could have been spring migration. Figure 28 illustrates Boris had longer distances in February to April during daytime hours, and Sasha had comparably similar, if not larger, night time distances for the same assumed spring migration period.
Figure 27. Top: average day distance between (07:00 – 18:59). Bottom: average night distance between (19:00 – 06:59).
Figure 28. Top: average distance traveled per hour between day and night for Boris. Bottom: average distance traveled per hour between day and night for Sasha.
Effective Daily Movement Distance and Rate. The larger effective daily movement distances from October to early March, (fall migration through to early spring migration), represent the difference between the first recorded location and the last of each day (Fig. 29). This means that all four reindeer in the subset spent the majority of the recorded time migrating, even in February and March, as seen with Grisha and Boris. Nikolai and Boris finished fall migration by mid-November, although Nikolai seems to have continued some shorter migrating from mid-February to early March. Sasha and Grisha, however, continued migrating well into January, and in Grisha’s case, February. All reindeer ceased migration by early to mid-March with virtually no migration to the end of the recorded period in May, which would have been assumed as spring migration.

The bottom graph in Figure 29 represents the division of the daily total distance traveled by the effective daily movement distance. By dividing these two values provides a ratio of how far the reindeer traveled within a day vs the distance between the first and last recorded data point for that day. If the effective daily movement distance highlights migration movement, the effective daily movement rate provides an analysis of the distance covered moving around the same area, “localized mobility” vs. “destination mobility.” Essentially, this provides a value for non-migratory movement, which could be movement of foraging for food, shelter, passable trails, etc. among other activities.
The “destination mobility” analysis fits like an opposite puzzle piece to the “localized mobility” analysis, mimicking the opposite values of migration vs. non-migration (Fig. 29). Boris stands out in the later months with the largest values meaning the individual favored the location it reached by the end of the winter, spending little time migrating to any alternative location. Nikolai has several spiked values, specifically in mid-October, early and late November, and numerous small spikes in January, before the largest in late February. Nikolai did not often change or move locations throughout the fall migration and winter season. Grisha, unlike the other three reindeer, had no major spikes at any point. The last reindeer, Sasha, similar to Grisha, had with very little presence on the graph until, like Boris, becoming more noticeable in March, during the assumed beginning of spring migration. In all, Grisha had the largest disparities between the two graphs, being very active in the destination distance, but less so in total distance vs destination distance. Thus, Grisha, the reindeer that had the largest migratory movements, spent the least amount of energy in movement at any location.
Figure 29: Top: total destination for the chosen subset of reindeer. Bottom: total daily distance traveled divided by the destination distance for the subset of reindeer.
Discussion and Conclusions

Discussion

The individuals collared in the first satellite telemetry research of the TRH have provided excellent insight into the patterns of migration and movement during the winter season. The general, overall pattern indicates a trend from longer daily distances during fall migration to the wintering grounds, comparatively shorter distances while foraging in during winter season, and eventual increases in distances while migrating to the calving grounds. Although limitations will be discussed below, it is worth noting that without indication of individual reindeer sex, there is no way to analyze daily distances for a pregnant cow migrating into the calving season. There are studies which have analyzed female movement and can provide information about calving and calf survival, but without definitive knowledge of sex and calving ground information, this would not be an advisable analysis (DeMars, Auger-Méthé, Schlägel, & Boutin, 2013; Joly, 2011).

However, by comparing daily total distances to localized distances may provide an estimation of sex for specific individuals worth mentioning. Grisha had large distances recorded in every analysis, but had very little localized distances throughout. Thus, meaning Grisha spent most days traveling from one point to another with purpose. On the other hand, Nikolai who has the lowest distances, and longest recording time, had high localized distance values. Essentially, Nikolai moved with somewhat consistent, short destination distances during the fall migration, but spent a
large portion of time moving within each day. This was particularly evident in February where there is a very large spike in localized distance. What could be surmised from this information is that Grisha moved with purpose during the fall migration season to the wintering grounds, whereas Nikolai moved slowly until spring migration period from the wintering grounds to calving grounds. To guess that Nikolai may have been a pregnant cow, heavily foraging in the springtime while migrating to the calving grounds seems reasonable, however, it would be impossible to know at this time (Boertje, 1985; Duquette & Klein, 1987). Any further studies of this herd would require data collection on data specific to each collared reindeer, i.e., sex, age, etc.

TRH and Woodland Caribou Monthly Activity

While the depth of data for the TRH and other Rangifer herds in Siberia are slim, specifically in biotelemetry research, there is extensive data for other herds. One particularly in depth, albeit dated, study by Hillis et al. (1998) used early Telonics Argos collars to monitor habitat use and activity of the Rangifer t. caribou in northwestern Ontario, Canada. This study produced results of the main caribou activities throughout the year: running, walking, feeding and resting (Fig. 30). Although data for essential winter months, January and February, are missing, the reduction in movement, running, walking and feeding, between October to December corresponds directly with the TRH daily total distance analysis (Fig. 30). March has one of the lower months for resting, with large amount of energy spent feeding, which relates to the localized movement for of the subset of the TRH; where the spring migration had low destination distance, but
high localized distances. This supports the idea that the slow migration, and shorter daily destination distances to the calving grounds is related to time spent foraging.

Without the data for the months of January and February, it is not possible to completely compare the two studies for total winter migration patterns, however, the data provided from Hillis et al. (1998) supports conclusions made for the TRH.

Figure 30. Monthly averaged caribou activity from Hillis et al. (1998).

Limitations

Unknown, unforeseeable, technological and human errors caused three limitations within this study. At the time of collaring there were very dry summer
conditions and tundra fires causing only reindeer located in Eastern Taimyr, near the village of Khatanga, to be collared. Therefore, individuals located in other areas could not be collared, limiting the geographic extent to access other reindeer within the herd. The most important limitation, from the researcher’s point of view, is only moderate success of satellite collars on individual reindeer. Due to the methods of collaring the animal while swimming, there was no way to evaluate each individual’s health. A much more thorough analysis could have been pursued had the data on individual sex, weight, age, and overall health been collected and provided to this study. These pieces of data would be crucial to a continuation of this research.

The final limitation lies within the missing data in Section 3 of the “Daily total distance traveled” graph in Figure 24. It is unknown why or how this data became missing, but there are three possibilities. The first, human error in the downloading intervals. It is possible that a downloading interval was missed and data was lost within Argos. Another possibility is that the data was erased, lost, or corrupted during the transmission to the processing center before being made available for downloading. The final possibility is that there was a malfunction with the Argos satellite system or with the collars. Regardless of the actual reason for this lack of data, it limited the completeness of the winter migration analysis for this study.

Conclusions

Biotelemetry has significantly influenced a shift in animal biogeography and ecology. By providing new ways to collect location data from inaccessible areas the
technology to retrieve data without constant human presence has enhanced the field to a new era of scientific discovery (Alarcón et al., 2015; Hussey et al., 2015). Pairing satellite biotelemetry with species like the R. tarandus has given researchers an increased ability to learn and understand the importance of their relationships to the Arctic environment. As the changing climate increases instability in the Arctic, gaining an understanding about the native flora and fauna and how they adapt, or fail to adapt, could provide insight into minimizing effects worldwide.

This innovative, first-time study about the world’s largest wild reindeer herd has created a baseline for insights into movement and migration patterns. The previously undocumented annual movements of the herd have been revealed, providing researchers a look into extreme migration patterns of the TRH. The daily and weekly distances of the collared reindeer exposed the “fall migration to winter season to spring migration” story for the winter season of 2013 to 2014. This research thus fulfilled the objectives of this study, (1) to measure key characteristics of reindeer mobility: average distances and speeds over the temporal range of winter migration for both individuals and the collared cohort; and (2) to complete an in-depth analysis of seasonal, monthly and daily mobility patterns for a subset of reindeer with highest quality data.

The analyzed data in this study provides an excellent baseline for future research on the TRH. The key element in continuing this research would be to analyze the location data with a topographical geospatial component. An important question moving forward is how each reindeer’s chosen migration paths influenced their daily,
weekly and seasonal distances. Essentially, how do topography, elevation, slope, and aspect, as well as temperature, precipitation, and snow depth, influence migration paths and selection of wintering grounds. Further analysis of day and night distances may provide meaning to the differences in the temporal periods that each reindeer moved. This could have been effected by their topographical or weather related surroundings, but until this is investigated, the significance in differences are unknown. Continued analysis could also improve understanding the large distances for specific reindeer in the daily distances during January and February. Unfortunately, without further analysis there are still unanswered questions about this data, although continuing research with the current data should be pursued to enhance this baseline study.
CHAPTER 4
CONCLUSIONS

This research fulfilled three objectives: (1) to identify the spatial temporal dynamics of the winter season for the Taimyr reindeer herd (TRH) using 10 different years of winter aerial population censuses; (2) to identify the TRH’s wintering range and its relationship to climatic factors including, temperature and precipitation, with the use of NASA’s MERRA data; and (3) to analyze temporal migration patterns of 12 individuals of the TRH who were tracked using Argos satellite telemetry collars for a maximum of 11 months between 2013 and 2014. Through these objectives, extensive knowledge has been gained about the TRH’s historical fidelity of wintering grounds, as well as analysis of winter seasonal migration patterns.

In fulfillment of the first objective, GIS analysis of the 10 winter censuses provided four areas of high fidelity where reindeer returned at least four of the ten years. These four separate and distinct areas are spread over the wintering ground range and across varying physical topography. No two years of census footprints had the exact same outlines. Overall, the size, shape and distribution of each year’s wintering grounds changed, but each year had overlap. These hotspots indicate areas that may have been returned to for generations.

In fulfillment of the second objective, using the winter range outline for three specific years of census data, 1980, 1990 and 2000, remote sensed climatic data of the same winter were paired to statistically analyze data precipitation and temperature data.
over the course of said winter. The results of each series of statistical analyses provided analysis of which climatic variables were less favorable for reindeer presence during that winter. In 1980 and 1990, statistical analysis provided strong evidence that low mean surface temperature and high total surface precipitation (snow) were negative drivers for reindeer presence. In 2000, snow depth was the most significant variable, albeit weakly, that discouraged reindeer presence. Ultimately, the analysis from 2000 was not helpful in determining influence of reindeer presence. Overall, it was discovered the least collinear variables with the most influence on reindeer wintering grounds were mean surface temperature, total precipitation and snow depth.

In fulfillment of the third objective, Argos collar analyses have provided evidence that a fall-to-spring migration most certainly occurred for the collared individuals of the TRH. Confirmation of this being found in the common trends of daily distances starting from the very beginning of transmission. Even with the unknown spikes in distances for Grisha, Sasha and Andrey, the overall pattern indicates a trend from longer daily distances during fall migration, reduced or shorter distances while foraging in the wintering grounds, and eventual increases in distances during spring migration to the calving grounds. The discovery of destination and localized movement analyses indicated daily movement patterns for individual reindeer. This created a categorization of movement patterns, seen specifically in Grisha’s purposeful migration, and Nikolai’s slow moving, most likely foraging-based movement. Future studies, discussed below, will direct future research to continue analysis of movement patterns.
Overall Limitations

There are significant limitations within this research. As mentioned in Chapter 2, the lack of depth with literature and data for the TRH has a negative impact on the research. This herd is far behind research produced about other, smaller herds around the world, although this is congruent with the amount of research on most Russian wild herds. Only continued research will provide to the depth of knowledge, something this study has tried to accomplish.

The two main limitations for this study have been the gaps in census data and lack of current data, as well as lack of information demonstrating the characteristics of the collared reindeer. The census data, while historic, is becoming dated. Without updated population numbers and winter census data, it is impossible to know the changes in herd dynamics and relationship with the environment. Without individual reindeer data, i.e. sex, age, weight, etc., it is impossible to understand motive for chosen paths, distances traveled per day, or even time of travel during a 24-hour period.

Although other limitations were mentioned within Chapters 2 and 3, these are the most important and have the largest significance over the research as a whole.

Future Studies

As mentioned in the previous section, there are ways to improve data collection for future research, which must be applied in future studies. Future studies for Chapter 2 will be discussed first, followed by Chapter 3, and finally overarching studies. To summarize, winter aerial census collection must be continued. Without the data
collection the current datasets will become outdated and unusable without current data to compare with. Within these future aerial censuses, polygon counts need to be included with the raw data to provide insight into which regions within the winter range are being used by the largest percentage of the herd. Future studies of the data should focus on drivers of spatiotemporal dynamics, i.e. areas of use, climatic variables and include physical topography. It would also be important to measure human disturbances, like pipelines, mines, towns and potentially powerlines, which reindeer tend to avoid (Johnson & Russell, 2014; Nellemann, Jordhøy, Støen, & Strand, 2000; Tyler, Stokkan, Hogg, Nellemann, & Vistnes, 2016). A joint analysis of predation changes in the wintering ground would also be helpful to recognize changes in populations and habitat use.

Future studies involving the research in Chapter 3 and satellite biotelemetry would include, first and foremost, a continuation of future collaring of the TRH. An effort of this study was to test how long and how well the collars worked. It would be advisable for future studies to record locations at a longer interval, rather than every 15 minutes. A suggestion would be locations of every 2 to 4 hours. This would improve the battery life of the collar and a temporally longer dataset. It would also be extremely important to weigh, measure and inspect potential individuals before collaring. This data is essential for future research.
However, there is still much that can be done with the current datasets. Most importantly, the reindeer tracks must be analyzed with surrounding physical environment for the day, time and location of each data point. Utilizing Digital Elevation Models (DEM), MERRA snow and temperature data, as well as lichen forage data, would provide excellent insight into migration patterns and preference by individuals. Lastly, forage is extremely important for the winter migration. Using remote sensed images of wintering grounds during the summer months, it might be possible to identify areas of high quality forage, thus further insight into wintering ground choice by the herd (Falldorf, Strand, Panzacchi, & Tømmervik, 2014; Gilichinsky et al., 2011).

Finally, data from both of these studies can facilitate future research. By overlaying the Argos tracks on the historical census data, a comparison of habitat use can be established. Using the locations of where the collared reindeer spent the most time, would be an interesting analysis in relation to historically used areas. Also, MERRA data is calculated by daily averages, it would be possible to compare overlapping collar and census locations with climatic data. This could provide an idea of reindeer presence and preference for using specific habitats during the winter. Overall, further research using data from these studies as high potential and a plethora of options for future research.
REFERENCES


Cooney, M. D. (2014). *Understanding the long-term spatiotemporal dynamics of the Taimyr reindeer herd during the summer concentration period* (Unpublished master's thesis). University of Northern Iowa, Cedar Falls.


APPENDIX

MAPS OF FILTERED ARGOS REINDEER COLLARS

*Figure 31.* Map of post-filtered Argos collar tracks for eight best datasets.
Figure 32. Map of Andrey’s post-filtered Argos collar tracks.
Figure 33. Map of Boris’s post-filtered Argos collar tracks.
Figure 34. Map of Grisha’s post-filtered Argos collar tracks.
Figure 35. Map of Nikolai’s post-filtered Argos collar tracks.
Figure 36. Map of Igor’s post-filtered Argos collar tracks.
Figure 37. Map of Leonid’s post-filtered Argos collar tracks.
Figure 38. Map of Sasha’s post-filtered Argos collar tracks.
Figure 39. Map of Rudolf’s post-filtered Argos collar tracks.