2014

# Understanding the long-term spatiotemporal dynamics of the Taimyr Reindeer Herd during the summer concentration period

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UNDERSTANDING THE LONG-TERM SPATIOTEMPORAL DYNAMICS OF THE TAIMYR REINDEER HERD DURING THE SUMMER CONCENTRATION PERIOD

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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University of Northern Iowa

August, 2014

ABSTRACT

This study was part of a larger research effort devoted to investigation of spatiotemporal patterns and dynamics of the Taimyr Reindeer Herd (TRH) migration under changing climate and environmental conditions. The research aimed to systematize and analyze available historical (archival) data on wild reindeer (*Rangifer tarandus L.*) migration and ecosystems change in the Taimyr Peninsula, Russia. The summer concentration patterns of the TRH as observed from 1969-2009 were investigated through the utilization of existing and innovative spatioanalytic methods and advanced GIS technologies not previously used to examine *R. tarandus* migration in the Russian Arctic. The project applied and tested the concepts of spatial fidelity and spatial shift as described for other *R. tarandus* populations, as well as mapped and identified spatiotemporal trends of summer ground selection by the TRH. An exploratory analysis of climate and ecosystem factors which influenced the spatial selection process was also conducted. Statistical and empirical results of the study generally confirmed preliminary conclusions which were largely based on field observations. Multiyear patterns within locations of summer grounds are indicative of spatial fidelity and spatial shift. The analysis contributed new findings about spatiotemporal patterns by identifying a northeast shift, not observed in the past, which significantly added to the existing knowledge base. Western concentrations are losing animals while central and eastern concentrations are developing and getting larger; however, the population of the TRH is decreasing as a whole. Distribution of summer concentration grounds formed a statistically compact, normal distribution, while simultaneously the distance between

concentration grounds of consecutively observed summers is increasing. The TRH are reusing smaller percentages of their range from year to year, and summer concentrations are becoming more compact and more densely populated. Four distinct areas have been identified and as areas frequently used (i.e. more than 50% of observed summers). Summer concentration grounds are shifting to the east and to the north and rising in elevation; thereby expanding the observed range of utilized habitat. These changes may indicate adaptation to climate change and anthropogenic disturbance. Logistic regression and ecological niche modelling identified the best predictors of reindeer presence to be higher wind speed, cooler temperatures, and whether or not the areas had been previously used as summer concentration grounds. The optimal ranges of July variables for TRH ecological niche requirements have been amassed for future research and modeling techniques. Analysis of spatiotemporal patterns and identification of ecological niche requirements will allow TRH summer surveys to be more cost-effective and comprehensive. The findings may also contribute to the development of sustainable *R. tarandus* management strategies throughout the Artic. The methodology employed by this study may prove useful not only to *R. tarandus* studies, but to the development of future analysis of other migratory animals.

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has been approved as meeting the thesis requirement for the

Degree of Master of Arts

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# ACKNOWLEDGEMENTS

First and foremost, I would like to thank Dr. Andrey N. Petrov for providing me with the opportunity to participate in this exciting project. I would also like to thank Dr. Leonid Kolpashchikov and Dr. Vladimir Mikhailov, for without their decades of hard work, none of this would possible. Also, many thanks to Anna Pestereva and Susan Meerdink for laying the groundwork in her previous and continuing examination of the Taimyr Reindeer Herd's spatiotemporal dynamics. I would like to thank Dr. Bingqing Liang and Dr. Peter Berendzen for serving on my thesis committee and offering their valuable insights and directions. My thanks and gratitude to the Department of Geography at the University of Northern Iowa for all of the amazing opportunities and lifelong knowledge. I must give endless thanks to my extraordinary wife, Amber, for her continued support and patience as I have worked on this study. I would also like to thank my parents for the encouragement they have given me throughout my entire life.

# TABLE OF CONTENTS

PAGE

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

Throughout the Arctic wild reindeer and caribou (*Rangifer tarandus* L.) have played a structural role in the economy of indigenous and nonindigenous peoples as well as being a quintessential species for the ecosystem at large. Wild reindeer and their environment have been observed for thousands of years by Arctic indigenous people who can attest to dramatic fluctuations in population size and significant changes in vegetation (Arctic Climate Impact Assessment [ACIA], 2004). Extensive monitoring of *R. tarandus* by scientists has been conducted for more than 40 years across Arctic regions and has revealed significant fluxes in populations and substantial shifts in the spatial distribution of their populations (Gunn, Russell, White & Kofinas, 2009; Kolpashchikov & Mikhailov, 2004; Petrov, Pestervera, Kolpashchikov & Mikhailov, 2012). It has been recorded that wild reindeer populations worldwide peaked somewhere in the late 1990s to early 2000s and this peak has been followed almost universally by a dramatic loss in the *R. tarandus* population by as much as or more than 30% (Gunn et al., 2009; Kolpashchikov, 2009). It has been observed that four out of five herds across the Arctic are currently experiencing population decline (CircumArctic Rangifer Monitoring Network [CARMA], 2014; Gunn et al., 2009).

The efforts of the scientific community are currently geared towards providing a sufficient knowledge base for understanding patterns of reindeer demographic and spatial dynamics and to identifying factors that determine these patterns (CARMA, 2014). Decline in the wild *R. tarandus* population is undoubtedly related to changes in the Arctic environment likely caused by climate change and increased anthropogenic activity (Gunn et al., 2009; Kolpashchikov, 2009). However, we have yet to understand how exactly these environmental and human-made changes affect the abundance and spatial distribution of *R. tarandus*. In this context, there is a necessity to focus on developing comprehensive datasets (long-term and seasonal observations of wild reindeer and their habitats) which can be utilized in construction and parameterization of multifactor ecosystem-based models able to simulate and explain the demographic and spatial responses of wild reindeer to changing conditions (CARMA, 2014; Gunn et al., 2009).

The knowledge about spatial distribution, migratory paths, and fluctuations in *R. tarandus* population density are largely fragmentary which is attributed to an insufficient amount of raw data collected about reindeer herds and collection of environmental data pertaining to their habitats (Ryder et al., 2007; Weladji, Klein, Holand & Mysterud, 2002). In some areas, the data have been more systematically collected than in others; however, the synthesis of existing datasets has yet to be accomplished (CARMA, 2014; Gunn et al., 2009).

The Taimyr Reindeer Herd (TRH) has been regularly monitored since the 1960s. In fact, the TRH is both the largest wild herd of *R. tarandus* in Eurasia and the most systematically monitored herd in the world (Klein & Kolpashchikov, 1991; Kolpashchikov, Mikhailov, & Pestereva, 2007; Kolpashchikov, et al., 2008). It represents a geographically and ecologically unique phenomenon for several reasons. First, the population is comprised of, as of last count in 2009, nearly 700,000 animals (Kolpashchikov, 2009; Mikhailov & Kolpashchikov, 2012). Second, the vast habitat that the reindeer population occupies in the northern central Siberian peninsula of Taimyr encompasses 1.5 million km² which spreads across multiple ecozones ranging from northern taiga to polar desert. The TRH habitat is a vantage point from which to study environmental changes that reflect not only regional processes, but, too, inform us of global processes. Third, one can describe the seasonal migration of the TRH as very large masses of *Rangifer* moving extremely long distances, some 1500 km from southern wintering grounds to northern reaches of the Taimyr Peninsula in the late summer (Kolpashchikov & Mikhailov, 2004; Kolpashchikov et al., 2007; Syroechkovski, 1984). Yet another unique feature of the TRH population is its spatial unity and geographical integrity. Kolpashchikov, Mikhailov, and Shapkin (2009) used long-term observations and suggested the herd was not divided by natural barriers into a number of local populations as observed in other Arctic reindeer herds.

The TRH is a biological resource that has ecological, economic, social and aesthetic importance. The abundance and distribution of this vital resource affects the overall ecological balance of the region; reindeer impact vegetation cover and are an important component in the food chain (Forbes, 2005; Forbes & Kumpula, 2009; Kolpashchikov & Mikhailov, 2004; Zockler, et al., 2008). Historically, wild reindeer have played a crucial role in traditional nature management by Taimyr aboriginal peoples: Nenets, Dolgans, Nganasans, and Evenks (Klokov, 1997; Kolpashchikov, Layshev & Muhachev, 2003). Alongside domesticated reindeer, the wild reindeer is a very important component of the aboriginal economy and also has significant cultural value (Stammler, 2005; Ulvevadet & Klokov, 2004; Vitebsky, 2005). In conditions of aboriginal mixed economy, the availability of *R. tarandus* for hunting is essential for economic and cultural vitality (Arctic Social Indicators [ASI], 2010; Petrov, 2008; Ulvevadet & Klokov, 2004; Ziker, 2002). Simultaneously, there is considerable negative impact being imposed on wild reindeer from direct human activity, such as exceeding the needs of traditional economy through illegal harvesting, and indirect activity, such as anthropogenic changes to the wild reindeer habitat (Gunn et al., 2009; Kolpashchikov et al., 2007).

To develop a systematic knowledge of reindeer spatiotemporal dynamics, it is crucial to integrate data collected on reindeer spatial distribution with the data on population and habitat conditions. Such complex, integrated research is an extremely important step in creating new knowledge on patterns and factors of reindeer spatial dynamics, especially when considering the current trend of global climate change, which is especially significant in the high latitudes (ACIA, 2004; Kolpashchikov et al., 2007). The lack of such knowledge not only leaves uncertain the impacts of environmental change and human activity on sustainability of wild reindeer populations, but also complicates monitoring and undermines management of wild and domestic reindeer herds in Taimyr and across the entire Arctic. Without an integrated model that is based on detailed multiyear observations of environmental factors we are unable to construct reliable forecasts of reindeer population distribution and movement under changing ecological conditions.

## 1.1 Research Objectives

Arctic people indigenous to Taimyr have observed triggers of reindeer movement including temperature, length of the day, and onset of the growing season (ACIA, 2004). Weather and climate have noticeably impacted reindeer spatiotemporal dynamics and their ecosystem (Euskirchen, McGuire, Chapin & Yi, 2009; Joly, Jandt, Meyers & Cole, 2007; Meerdink & Petrov, 2012; Ryder et al., 2007; Weladji et al., 2002). Research in the Arctic, specifically in Taimyr, has concentrated on interactions between *R. tarandus* and environmental elements (Gunn, Poole & Nishi, 2012; Johnstone, Russell & Griffith, 2002; Meerdink & Petrov, 2012; Racey, 2005; Rees, Stammler, Danks & Vitebsky, 2008; Stephens, Coops & Wulder, 2009). Although studies have been conducted, there is still a lack of systematic understanding of what the specific factors are and to what degree those factors impact long-term spatial dynamics of the TRH (Gunn et al., 2009; Kolpashchikov et al., 2007; Meerdink & Petrov, 2012). Literature suggests the future direction of *R. tarandus* research to include quantitative spatiotemporal analysis linking reindeer spatial dynamics, spatial fidelity, and climate variables as the primary task (CARMA, 2014; Gunn et al., 2009; Kofinas, 2005; Meerdink & Petrov, 2012; Russell, Kofinas & Griffith, 2000).

The goal of this thesis is to contribute to the existing knowledge base by quantifying, analyzing and modeling TRH summer spatial dynamics, spatial fidelity, and the interactions between spatial distribution and environmental (i.e. climate, physiographic, and vegetative) variables by addressing the following research objectives:

1. Map and analyze the spatial dynamics of TRH summer concentrations between 1969 and 2009 using various spatioanalytic methods.
2. Identify climate and environmental factors and their significance that influence the TRH's selection of summer grounds.
3. Create a regional model for a frequently utilized area of summer concentration grounds that incorporates climate, elevation, vegetation, and spatially and temporally lagged variables.

This work provides a review of relevant literature and identifies the existing knowledge base in Chapter 2. The thesis adds to the existing reindeer knowledge base as called for by the scientific community employing peer reviewed and innovative methods which address the research objectives. Descriptions of these methods are in Chapter 3. Results of all spatioanalytic methods and modeling techniques are presented in Chapter 4. A discussion of the results, conclusions, limitations of the study, and future research directions are provided in Chapter 5.

# CHAPTER 2

# REVIEW OF LITERATURE

This chapter presents an overview of the existing literature pertaining to the different ecotypes of *R. tarandus* L. and characteristics of the animal's body. It is also important for this study to present literature on migration and population trends as a main objective is to understand reindeer spatiotemporal dynamics. This chapter will also address environmental factors that influence reindeer mobility, and it will conclude with the state of the knowledge of the Taimyr Reindeer Herd.

## 2.1 *Rangifer tarandus* and Its Habitat

### 2.1.1 Species and Subspecies

Three major ecological groups of *Rangifer tarandus* have been classified: woodland, continental tundra, and high Arctic island. The three major ecotypes are thought to have originated during the last glacial period (Flagstad & Roed, 2003). Three ecotypes along with all known extant subspecies is shown in Figure 1. The continental tundra form (*R. t. tarandus, R. t. grantii*, and *R. t. groenlandicus*) are smaller in body size, have shorter legs, and typically carry longer antlers than their woodland counterparts (*R. t. fennicus* and *R. t. caribou*; Flagstad & Roed, 2003).

*R. t. tarandus* in Taimyr, Russia, may belong to a more refined subspecies known as *R. t. sibiricus* Murray (Kholodova, Kolpashchikov, Kuznetsova, & Baranov, 2011). They have elongated bodies of which adult bulls may be 186 cm long, 125 cm high, and weigh in at 137 kg while adult cows are somewhat smaller and may be up to 165 cm long, 120 cm high, and weigh up to 87 kg (Yakushkin, Kokorev, & Kolpashchikov, 2012). Bulls lose up to 40% of their body weight during the course of winter while pregnant cows maintain their weight. Bull reindeer have impressive antlers that reach full size (77 - 83 cm wide) when they are four years of age, and the antlers are shed each fall post-mating season. The cows have antlers as well which are smaller but more symmetrical and are shed in July post-calving period. Reproduction age is four years for bulls and three years for cows and each cow typically births a single calf; however, nearly

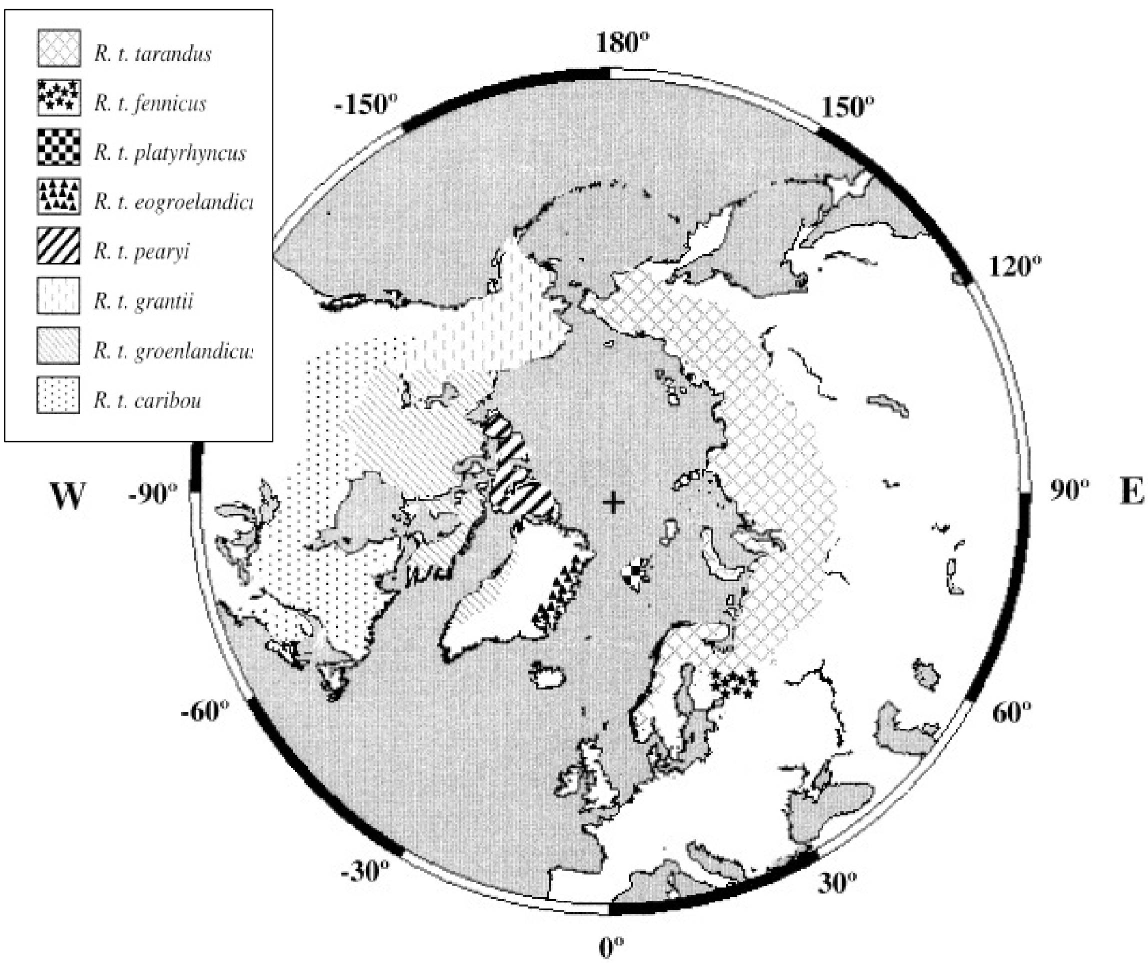


*Figure 1. Rangifer tarandus* subspecies distribution (Flagstad & Roed, 2003)

40% of calves die within the first year. Those calves that do survive often live as long as 21 - 23 years. *R. tarandus* are equipped with concaved hooves great for swimming and navigating rock and snow, and their brown-gray fur insulates them against the long winters which they shed each spring (Yakushkin et al., 2012).

2.1.2 Migration

*R. tarandus* make annual migrations of extremely long distances, ranging from 800 - 3000 km (Fancy, Pank, Whitten & Regelin, 1989). In fact, migrating reindeer/caribou are the last large scale ungulates in the northern hemisphere that still make these impressive journeys (Vors & Boyce, 2009). Long distance migrations of *R. tarandus* typically include distinct seasonal habitats within the migratory range observed in winter, spring and summer. The southern extent of the migratory range is where winter grounds are found and are generally characterized by regions with high availability of carbohydrate-rich lichens (O’Brien, Manseau & Fall, 2006; Theau & Duguay, 2004; Vors & Boyce, 2009). The migration travels north to the spring calving grounds where snow melt and longer days provide access to higher availability of nutrient-rich vegetation which mothers and newborn calves place in high demand (Miller, 2003; Vors & Boyce, 2009). Calves join the herd in their migration within days of being born as they must flee predators and move further north in search of protein-rich green vegetation. This is necessary for calves to develop and the health of mature female caribou entering the mating season (Couturier, Brunelle & Vandal, 1990; Rettie & Messier, 1998; Vors & Bryce, 2009).

The route travelled by migratory reindeer is affected by and a result of multiple responses to independent variables not necessarily well understood, of which some can be attributed to human disturbance of the natural world (Petrov et al., 2012). As humans continue to extend their reach further north for valuable resources, the necessity for mines, roads, power lines, pipelines, and hydroelectric dams grows (Klein, 2000; Mahoney & Schaefer, 2002; Vistnes & Nellemann, 2008). It is not only the physical impediment that must be considered in migratory routes, but also the effects of development on the habitat's vegetative characteristics and predator abundance must be considered (Klein, 2000). For example, the ongoing development of the Norilsk metallurgical complex significantly affected wild reindeer in Taimyr as a pipeline blocked historical migration route as some could not cross the newly constructed barrier. The fallout of pollutants from the complex has devastated thousands of acres to the south which were once wild reindeer winter grounds rich in nutrient-filled vegetation (Klein, 2000).

Although extremely significant driving factors of altered migratory routes for some populations of some *R. tarandus* herds, anthropogenic factors cannot always be separated from natural factors (Cronin et al., 1998; Cronin, Whitlaw, & Ballard 2000; Noel, Parker, & Cronin, 2004; Pollard, Ballard, Noel, & Cronin, 1996; Vistnes & Nellemann, 2008). Wild reindeer may tend to avoid human structures instinctively, but when under intense harassment from biting flies and mosquitoes this instinct may be overwritten as the animals will do anything find relief from the harassment (Joly, Nellemann & Vistnes, 2006; Nellemann, Vistnes, Jordhøy & Strand, 2001; Vistnes &

Nellemann, 2008). Independent of anthropogenic factors, however, mosquitoes have been identified as drivers of reindeer mobility in summer months R. This effect was observed by researchers in Taimyr, Russia, in the 2000 census of wild reindeer. The unprecedented abundance and harassment from biting insects contributed to a degree of reindeer aggregation that had never been observed historically (Kolpashchikov, Yakushkin & Kokorev, 2003).

2.1.3 Circumpolar Population Trends

Migratory reindeer and caribou have been observed to exhibit a rather large range of population and habitat fluctuation. The rise and fall of the herd population size is potentially cyclic, and if this is so, 40 years ago is thought to have been a low part of the cycle and the turning of the 20th to the 21st century is thought to have been the high point in the cycle (Gunn et al., 2009; Syroechkovski, 1990). Current trends in the circum-Arctic population size of *R. tarandus* are again in the downward direction for most observed herds with few herds observed to have growing populations (Figure 2; Gunn et al., 2009; Kolpashchikov et al., 2009; Petrov et al., 2012). The Beverly Herd in Canada, for example, had 270,000 head as recently as 1994, but astonishingly by 2009 there were fewer than 100 cows available for breeding (Gunn et al., 2009; Kolpashchikov et al., 2009; Petrov et al., 2012). Observations made in Russia show four out of five major herds to be in decline, the Western Arctic Herd and Porcupine herds in Alaska are said to also be in decline, and one of two herds in Greenland is in decline (Gunn et al., 2009; Kolpashchikov et al., 2009; Petrov et al., 2012). Populations are growing, however, in Norwegian and Finnish herds, in Alaska's Teshekpuk Lake and Central Arctic herds at

7% per year, and also in the George River Herd and Leaf River Herd of Canada (CARMA, 2014; Gunn et al., 2009; Kolpashchikov et al., 2009; Petrov et al., 2012).

2.1.4 Environmental Factors

Understanding of this phenomenon of decline is being sought by biologists and geographers worldwide. Continental climate changes are a driving force behind the phenomenon, and the Arctic Oscillation is the driving force behind Arctic climate change (ACIA, 2004; Weladji et al., 2002). It is also important to understand the Arctic as a whole as climate change does not impact all areas equally (Mysterud, 2000; Weladji et al., 2002). Multiple variables are known to influence migratory reindeer spatial dynamics throughout the cycle of the migration including cloud cover, temperature, wind, snow cover, predation, anthropogenic factors, mosquito harassment, and high quality forage availability (Petrov, 2010; Sharma, Couturier, & Cote, 2009). These variables and their interactions with caribou spatial dynamics are not yet systematically understood (CARMA, 2014; Gunn et al., 2009; Meerdink & Petrov, 2012; Petrov, 2010). Few studies have shown consistent effects of climatic variables, and forage quality and quantity are extremely susceptible to large variances from year to year based on specific occurrences within the climatic zone such as timing of snow melt, early summer precipitation, and temperatures from spring to late summer (Weladji et al., 2002)

While observing alpine reindeer in Norway and Arctic reindeer in Alaska, Skogland (1980) was able to develop a very detailed understanding of the feeding strategies employed by arctic and alpine species. He documented alpine reindeers' summer feeding tendencies to be on South facing slopes, 1150 - 1300 m above sea level in tune with the receding snow line. Arctic reindeer (the TRH are also considered Arctic reindeer) followed other trends due to the lack of water runoff from the flatter terrain

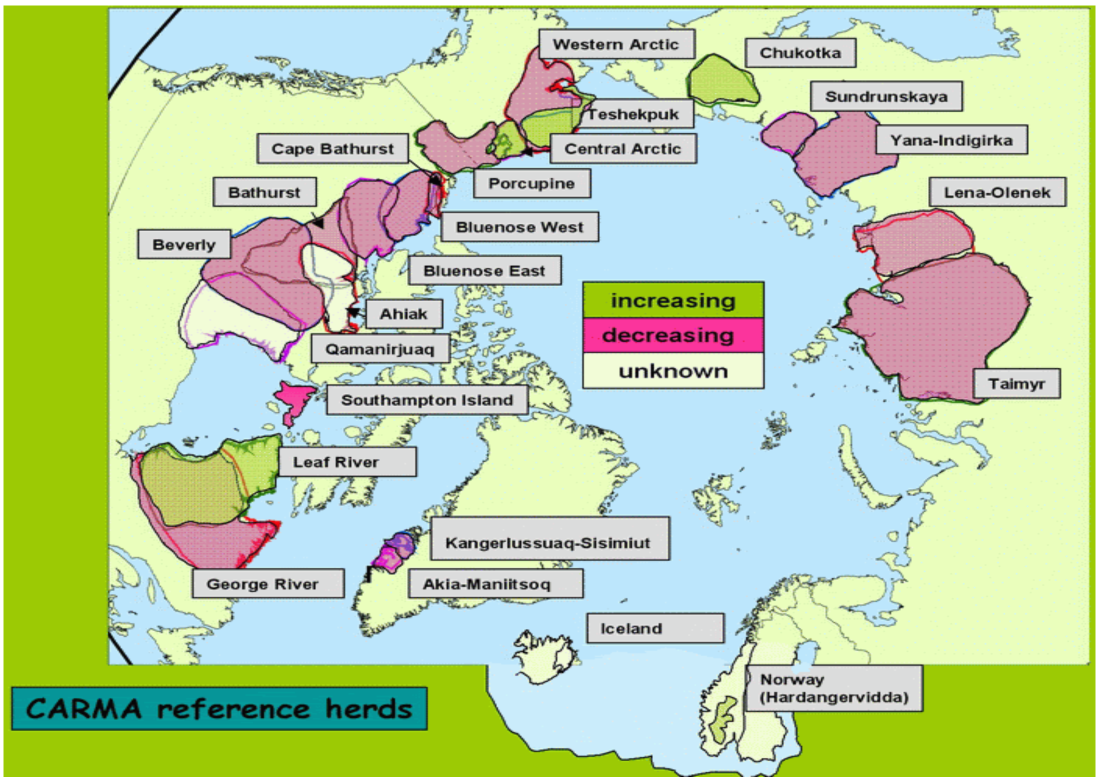


*Figure 2*. CARMA herd population trends (CARMA, 2014)

which is a factor in the water table recession. These Arctic reindeer reacted not to snow melt, but to the gradient of green plant shoots emerging from the ground which is a direct response to water table recession (Skogland, 1980). Following the wave of new growth, reindeer sought to maximize their intake of protein and vitamins (Baskin, 1990). The rate at which these green plants grow determines both cellular structure and nutritional value, and the rate at which they grow is determined by climatic variables (Weladji et al., 2002).

Where green vascular plants grow is also determined by climatic variables, and within models of climate change these plants can now be found growing farther north (ACIA, 2004).

2.1.5 Taimyr Reindeer Herd: State of the Knowledge

*R. tarandus* have adapted to many different ecosystems and have been able to adjust migratory routes as an adaptive measure; however, the more their ranges are infringed upon by human exploration and resource development, the less area they have to adjust their seasonal grounds in response to both climate and vegetation changes (Gunn et al., 2009). The TRH is unique in its ability to utilize varying vegetative zones and in their ability to vary the range of their migration (Kolpashchikov, 2009). The TRH is also unique because it has been extensively monitored, in addition to the region's climatic variables, for the past 40 years. These large datasets provide a unique opportunity to examine the spatiotemporal aspects of the herd for the past 40 years and to examine the impacts that are directly due to climate change on the region (Petrov et al., 2012).

In Taimyr, during the early 1960s, *R. tarandus* were estimated to number somewhere between 200,000 - 250,000 animals, and by the year 1990 estimates near one million animals, half of which belong to the TRH (Syroechkovski, 1990). The next 10 years were very prosperous for the TRH as they doubled in size which was recorded in the 2000 census (Figure 3; Kolpashchikov, Yakushkin, & Kokorev, 2003). Estimates ranging from 1,038,000 - 1,081,000 animals in unusually dense concentrations were made, which was the highest number ever recorded (Kolpashchikov, Yakushkin, &

Kokorev, 2003). By 2009, the population of the TRH was estimated to be around 700,000 animals (Kolpashchikov, 2009; Petrov et al., 2012).

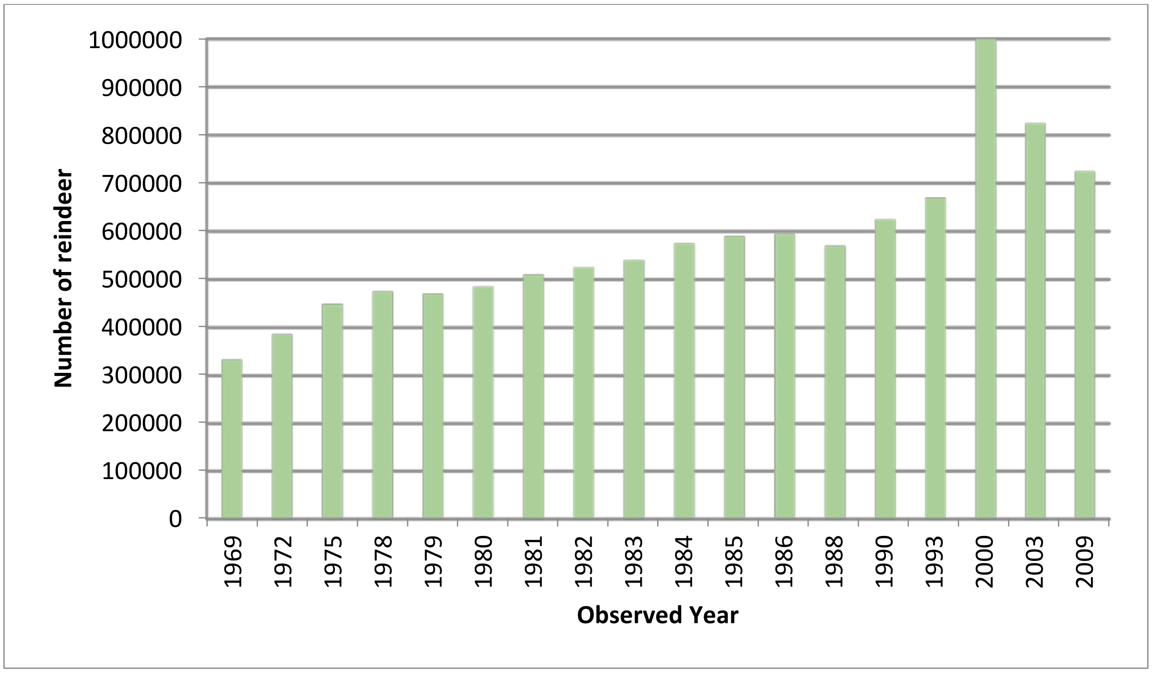


*Figure 3*. Population of Taimyr Reindeer Herd

Migratory reindeer herds around the world have gone through synchronized periods of scarcity and abundance and the 1960s was a time of universal scarcity (Gunn et al., 2009; Petrov et al., 2012). The total number of Taimyr wild reindeer increased almost four times between 1969 and 2000: from 252,000 to almost one million. The rate of increase in the 1970s was quite rapid: in 1972 there were 386,000 reindeer, in 1975 the total population was estimated at 450,000, and by 1980 there were just shy of half a million. Available data show a gradual increase in wild reindeer to 625,000 by the year 1990. The growth of the reindeer population was accompanied by the expansion of the population's range (Kolpashchikov, Layshev, & Muhachev, 2003). After the collapse of the Soviet Union, the organized use and control of the wild reindeer population disappeared. As a result the TRH population quickly grew from 625,000 to one million in just 10 years (1990 - 2000). However, since the population peaked around 2000, a rapid population decrease was observed; in the 2000s the population declined by one third, and the loss is forecasted to continue. Currently, the population of the TRH is estimated at 650,000-700,000. It is important to point out that TRH population decline corresponds with substantial reductions of wild reindeer populations around the world (Gunn et al., 2009; Petrov et al., 2012).

The wild reindeer in Taimyr constitute the largest wild herd in Eurasia, and account for roughly one third of all wild reindeer globally. Migratory paths of TRH can stretch 1500 km annually, and correspondingly, they have a large multi-seasonal range encompassing 1.5 million km² of the Taimyr Peninsula (Figure 4), of which around 280,000 km² is identifiable as summer habitat (Kolpashchikov, Layshev, & Muhachev, 2003; Petrov et al., 2012). Each summer aerial survey has observed anywhere from 3 - 7 summer concentrations annually. These areas contain the majority of reindeer, but are not inclusive of the total population as some animals do not select to congregate during the few days of mass concentration formations. There exists significant variability within the amount of utilized areas from summer to summer (Figure 5). Researcher have observed some areas to be as large as 40,566 km², as in 1993, and as limited to only 3385 km² in 2000 when concentrations were observed to be unusually dense as a result of intense insect harassment (Kolpashchikov, Yakushkin, & Kokorev, 2003).

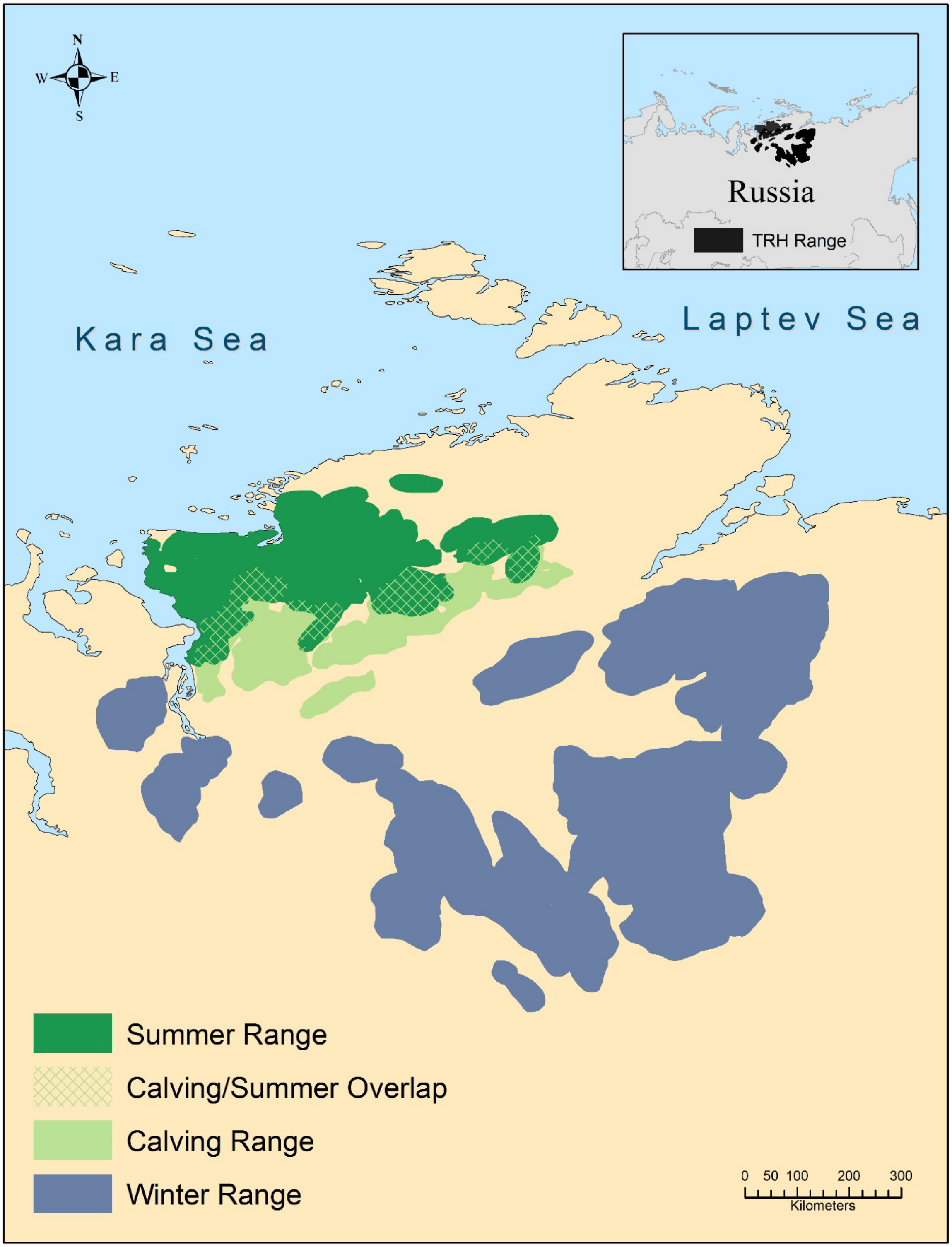


*Figure 4*. Seasonal ranges of Taimyr Reindeer Herd

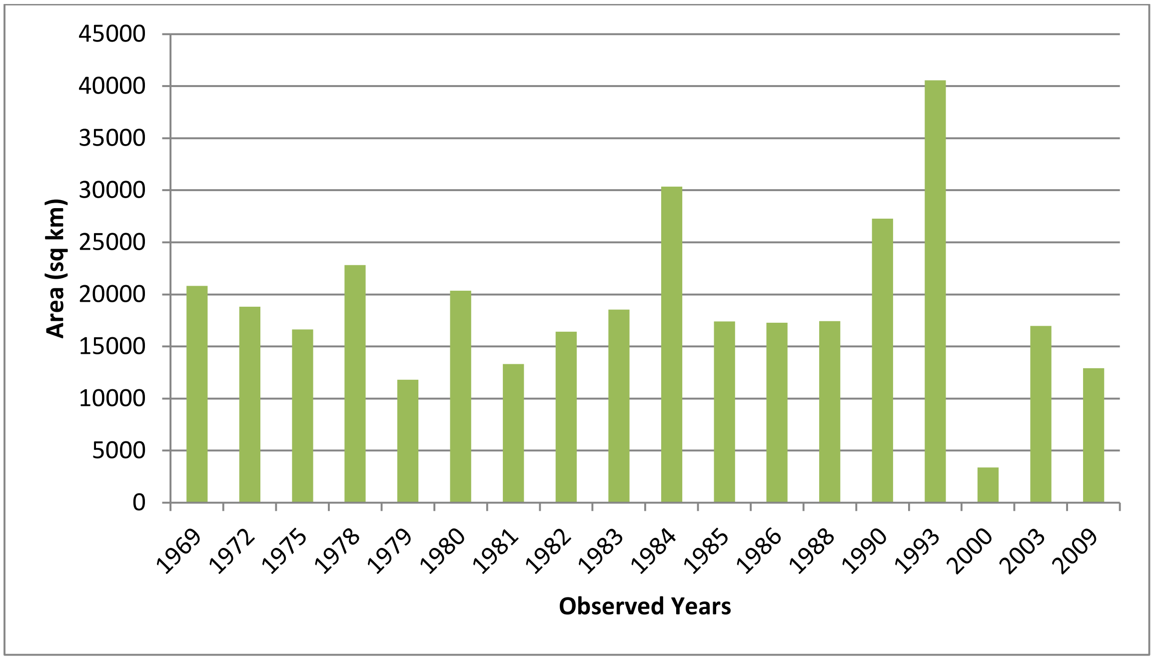


*Figure 5*. Area of annual summer grounds

Summer observations have led researchers to preliminary conclusions regarding the spatial dynamics of the TRH. First, there seems to always be a summer aggregation in the western area of Taimyr Peninsula, the Yenisei concentration (Petrov et al., 2012; Kolpashchikov et al., 2007). This concentration has been observed making adjustments to the south and to the north throughout the study period. Due to increasing populations, the TRH was observed to increase in both the sizes of concentrations and the range being occupied during the summer (Kolpashchikov et al., 2007). By the late 1980s, two new regularly forming concentrations were detectable, the Logata and the Upper-Taimyra. These concentrations stretched the utilized area of the summer range further north and east than in previous decades, with the western banks of Lake Taimyr now being utilized as part of the summering grounds (Kolpashchikov et al., 2007; Petrov et al., 2012). The observations of concentrations spanning greater areas, having larger numbers, and the TRH collectively occupying a greater overall geographic area continued into the 2000s (Kolpashchikov et al., 2007; Meerdink & Petrov, 2012; Petrov et al., 2012).

Analysis of the herd through construction of maps has led authors to believe that three trends are apparent (Petrov et al., 2012). First, there is a distinction within Taimyr wild reindeer migration flows; one being western and the other being eastern. The second trend is the expansion of the summer range due to an increase in the population size. The third trend is that the summering grounds are shifting to the south and to the east, which is similar to observations made on the spatiotemporal dynamics of calving grounds (Kolpashchikov et al., 2009; Meerdink & Petrov, 2012; Petrov et al., 2012).

There has been no systematic study done on the spatiotemporal dynamics of the TRH during the summer concentration period using the vast data resources available from the Extreme North Agricultural Research Institute (ENARI; Petrov et al., 2012). In accordance with the study objectives previously presented, the study herein aims to answer the following questions that remain unexplored in the current literature:

1) Do the visual observations made over the past 40 years align with spatial statistical analysis?

2) Is there statistical evidence of spatial fidelity and what are the multi-year patterns discernible from spatial analysis?

3) What are the specific factors that the TRH are sensitive to when choosing the location of its summer grounds and to what degree do the factors influence this selection at a habitat-wide scale and at a regional scale?

# CHAPTER 3

# DATA AND METHODS

This chapter of the study begins with a description of the study area's physiographic characteristics. Descriptions of the unique data used and methods describing the collection process are also presented in this chapter. Spatioanalytic methods utilized to better understand the long-term patterns of the TRH summer ground locations are presented, and methods employed to identify which factors and to what degree those factors influence the summer ground selection process are also described in this chapter of the study.

## 3.1 Study Area

The Taimyr Peninsula in northern central Siberia is Arctic tundra, much of which is located north of the tree line (CircumArctic Vegetation Map [CAVM], 2003). The region of Taimyr is located between 67° N and 78°N latitude and 77° E and 113° E longitude and is bordered by the Kara Sea on the West and by the Laptev Sea to the East (Figure 6). Taimyr is home to four major river systems which are the Yenisei, Pyassina, Upper Taimyra, and Khatanga. There are many tributaries and countless streams as well as thousands of lakes in this region (Ziker, 2002). The most northerly located forest in the world stretches across the Taimyr lowlands and is primarily made up of larch trees. There is substantial variation in the composition of vegetation cover with less than 5% vascular plants in northern zones to over 80% in southern zones (CAVM, 2003). The region is comprised of eight geobotanical zones: high arctic tundra, arctic tundra, northern hypoarctic, middle hypoarctic, southern hypoarctic, forest tundra, mountain tundra, and northern taiga (Figure 7).

The northern area of Taimyr experiences polar days and polar nights when temperatures can reach -50° C and blizzards can affect the region until April (Ziker, 2002). Lake ice up to two meters thick forms and some years the summer does not warm up enough for the ice to fully recede. The rivers are vital avenues of transportation for the Dolgan and Nganasan people who rely on fish and game for sustenance (Ziker, 2002). The economy of the region is centralized around hunting, trapping, and fishing which makes the ecological variables inseparable from the people and their well-being. Hunting wild reindeer is a cornerstone in the way of life, and some families consume up to 3 animals each month (Ziker, 2002). Reindeer are also raised domestically and during the Soviet Union era, both reindeer hunting and husbandry were subsidized by the state (Baskin, 2003, Klokov, 1997)). After the dissolution of the Soviet Union, people of the Taimyr region practiced unregulated hunting and harvesting of domestic and wild reindeer (Baskin, 2003; Kolpashchikov, Mikhailov, & Russell, 2014).

## 3.2 Data

### 3.2.1 Wild Reindeer Location and Population Data

The data on wild reindeer location was systematically collected by ENARI beginning in 1959 and is currently stored as sets of analog maps, tables and notes (Figure 8). These datasets were mostly collected during the Soviet period and remain largely unpublished. Since 1959 there have been 20 comprehensive aerial surveys of the TRH. They provide systematic coverage of the TRH habitat with airborne visual and


*Figure 6*. Reference map of study area

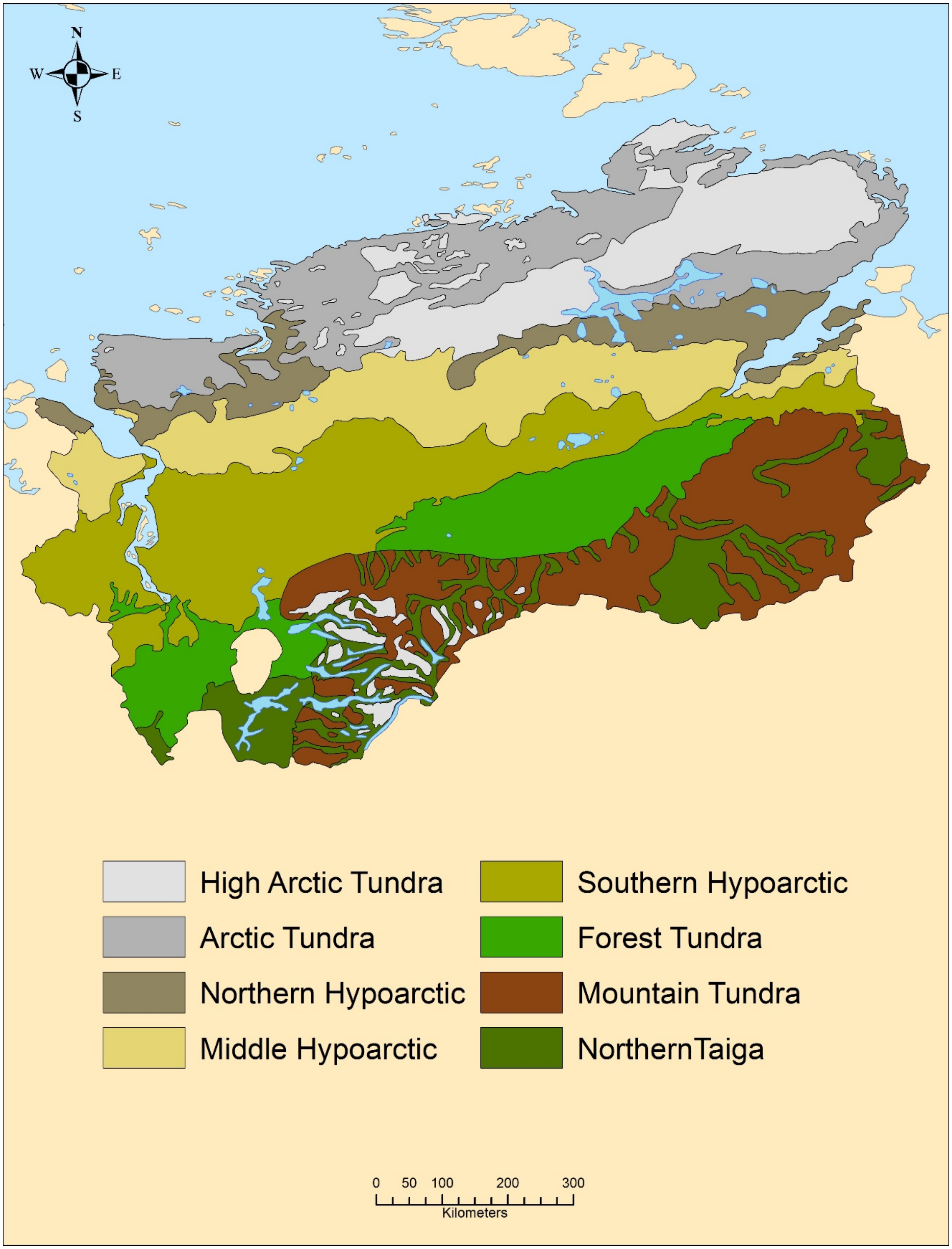


*Figure 7*. Geobotanical zones of Taimyr (Kolpashchikov et al., 2007)

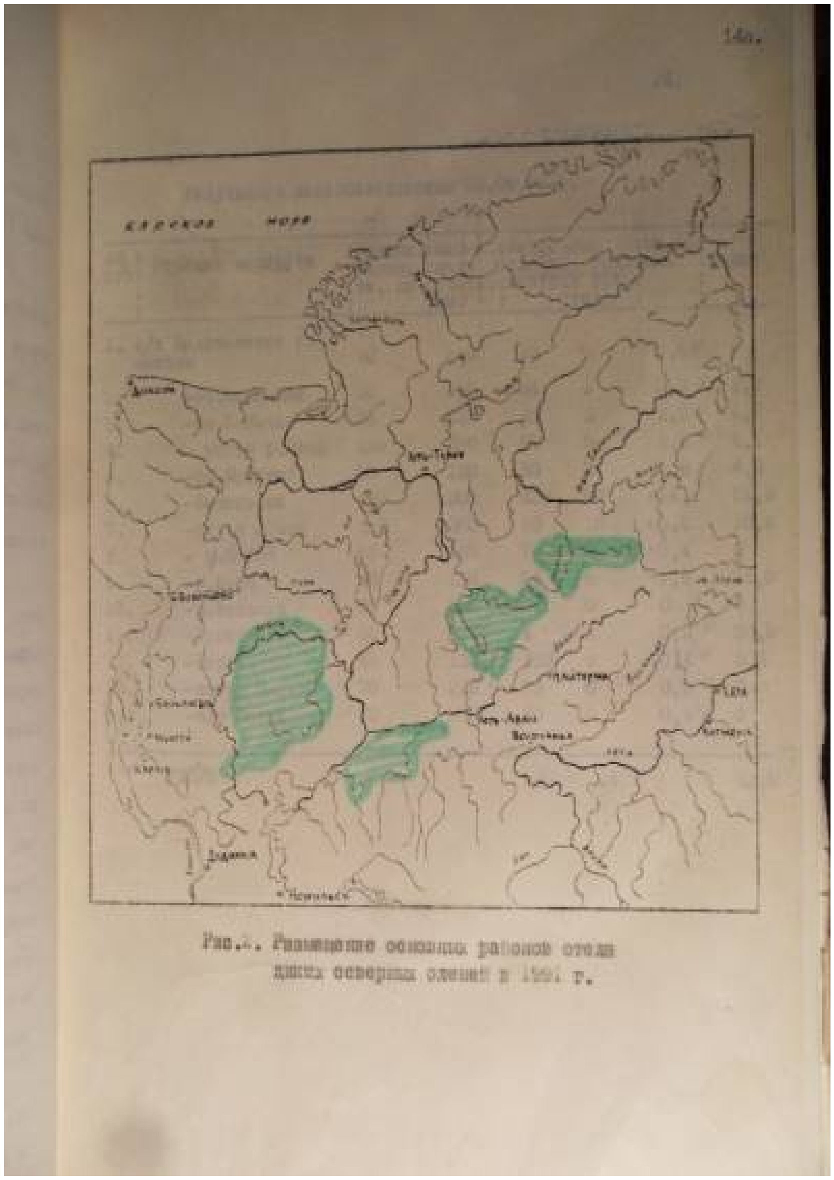

*Figure 8*. Analog map of TRH concentration areas

photographic evidence corroborated by land observations. During the land component of these surveys, the data from field observations were routinely corroborated and complemented by interviews with Indigenous residents and hunters. Therefore, the available dataset presents a unique source of information incorporating both scientific and Indigenous knowledge.

Surveys were conducted using standardized methodology approved by the Russian (USSR) Academy of Agricultural Sciences, and this methodology of data acquisition and processing remained relatively consistent. Although the methodology underwent peer-review process in USSR/Russia (Pavlov, Kuksov & Savelev, 1976; Kolpashchikov et al., 2008; Baskin, 2003), it is not well documented in published sources available to international audiences. The timing of the census during the post-calving period corresponded with the highest concentrations of reindeer and made observations comprehensive and cost effective. The aerial surveys (10 - 15 days) were completed in two stages: reconnaissance and data collection. The first stage involved observations from either of the fixed wing aircrafts Che-25 or AN-2. The flights followed the routes established based on known (past) locations of reindeer. All sightings of reindeer herds were recorded in the field notes and referenced by GPS. Data collected during reconnaissance flights was analyzed to develop a plan for a comprehensive aerial survey.

The second phase was conducted immediately after using two fixed wing AN-2 aircrafts with five observers, GPS, photography and video recording equipment on each (Figure 9). This aircraft is designed to fly at low altitudes (300 m) and low speeds (150 - 180 km/hr), but at the same time is capable of covering large territories (1,000 - 1,200 km or 4,000 - 4,800 sq. km) in 7 - 8 hours. The aerial vehicle flew following 10 - 20 km transects across all reindeer concentrations detected in phase one (Figure 10). Airborne photography is accompanied by recorded field observations. Large herds (>1,000 animals) received complete photographic and visual coverage. Dispersed animals were surveyed selectively with visual observations at an altitude of 300 - 350 meters. Whereas observers recorded their preliminary visual estimates of reindeer population during the flight, the final estimates of reindeer population density were completed in the lab using field notes and aerial imagery. To assist in the field census process, ENARI developed a computer simulator that was utilized for training observers (Kolpashchikov et al., 2008). The first stage of data analysis incorporated estimates of population numbers using a computer program ("Aeroecology") or using a population density

*Figure 9.* Aerial photograph of TRH acquired during census

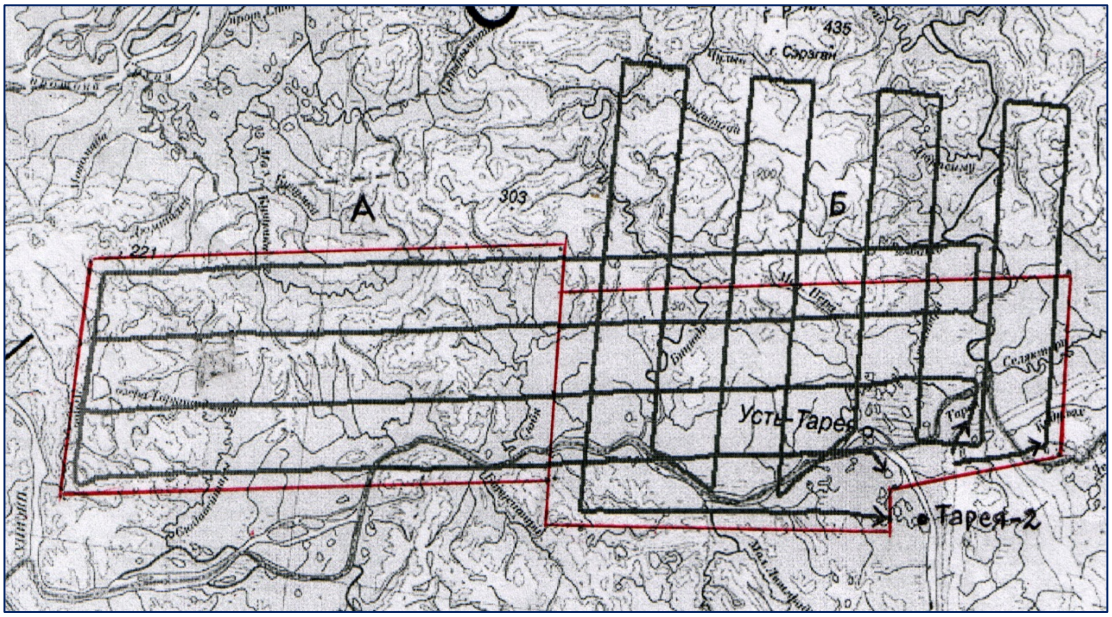


*Figure 10*. Flight paths used during TRH census

method (calculation of population density based on selected aerial images and extrapolation). These initial estimates were validated using bias-reducing techniques and accuracy assessment procedures (Griffith, et al., 2002; Gunn & Russell, 2008; Nagy & Johnson, 2006; Russell, Martell & Nixon, 1993). The second stage involved a detailed analysis of aerial photos, field notes and recordings. It also produced the estimates of age and sex structure of the reindeer population (Gunn & Russell, 2008; Kolpashchikov et al., 2008).

Surveys were conducted in late June during reindeer calving and in mid to late July (summer) when the TRH is known to form large concentrations (Kolpashchikov, Mikhailov, & Mukhachev, 2011). There are 21 years of summer aerial survey data available from ENARI, making summer the richest data-set (seasonally) available for detailed analysis. Summer concentration data is available for the years 1969, 1972, 1975, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1988, 1989, 1990, 1991, 1993, 1999, 2000, 2003, and 2009. For each year, reindeer were observed to aggregate in three or more defined groups across western Taimyr which were originally mapped by hand drawing polygons on paper maps, but have since been digitized for use in GIS software (Figure 11). The digitized shapefiles were verified for accuracy against publications to ensure accuracy. Digital data was found to be accurate except in the case of the shapefile for summer concentrations during the year 2000. Data correction was performed collaboratively with researchers who conducted the aerial survey during the given year.

### 3.2.2 Physiographic Data

Digital maps created by Russian scientists at ENARI during the past 50 years were transformed from hand drawings on paper to digital geospatial vector data format (Figure 11; Kolpashchikov et al., 2007). Shapefiles of the boundary of the region of Taimyr, the rivers, and the lakes were created by and acquired from the Taimyr Reindeer and Environmental Change (TREC) project. Elevation data was acquired from the National Aeronautics and Space Administration’s (NASA) Shuttle Radar Topography Mission (SRTM) in the form of 1x1 degree digital elevation models (DEM) with ~90 meter spatial resolution. Over 200 1x1 degree DEMs were mosaicked in ArcMap 10.2 to produce a single DEM encompassing the entire region of Taimyr.

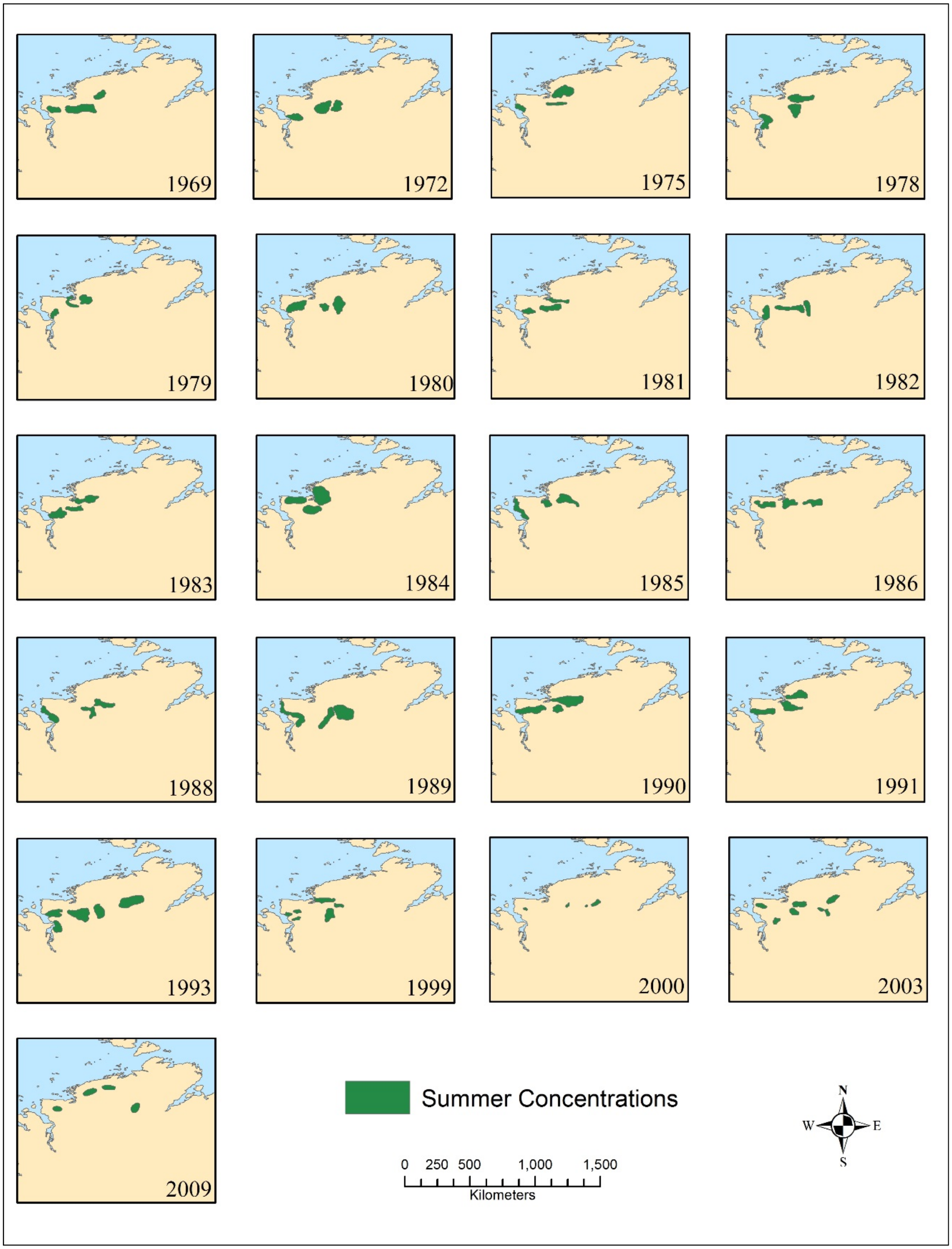


*Figure 11*. Digitized observed summer locations

3.2.3 Climate Data

The Russian Meteorological Service provided ENARI with 28 years of climate data acquired within and surrounding the Taimyr Peninsula region. ENARI in turn shared this data with the TREC project for use in this study. The Russian Meteorological Service operated 23 meteorological stations from 1980 - 1993, and the restructuring of the Russian government around this time resulted in reduced funding for the Meteorological Service. The lost funding forced a downsizing from 23 to 12 stations that were then able to continue data collection from 1994 - 2007 (Figure 12).

Data collected by the Russian Meteorological Service included the following weather variables: temperature (°C), wind speed (m/sec), precipitation (mm), humidity (%), total cloud cover (grade scale 1 - 10), and low cloud cover (grade scale 1 - 10). All data provided were in the form of monthly mean values for each station that was collecting during the given time period. To ensure data quality, the climate data was compared to NASA's encompassing data-set known as Modern Era Retrospective-Analysis for Research and Applications (MERRA) during previous research on TRH calving grounds (Meerdink & Petrov, 2012). Monthly mean values for previously listed climate variables for July 1985 and July 2000 were interpolated across remaining region of Taimyr utilizing the Spline method in ArcGIS. Satellite and ground station derived data containing similar climate variables does exist, but none contained measurements taken within the Taimyr Peninsula itself. This is unique data acquired from the Russian Meteorological Service by TREC and was considered to be the best available data for the region corresponding with the time span of data compiled on the TRH.

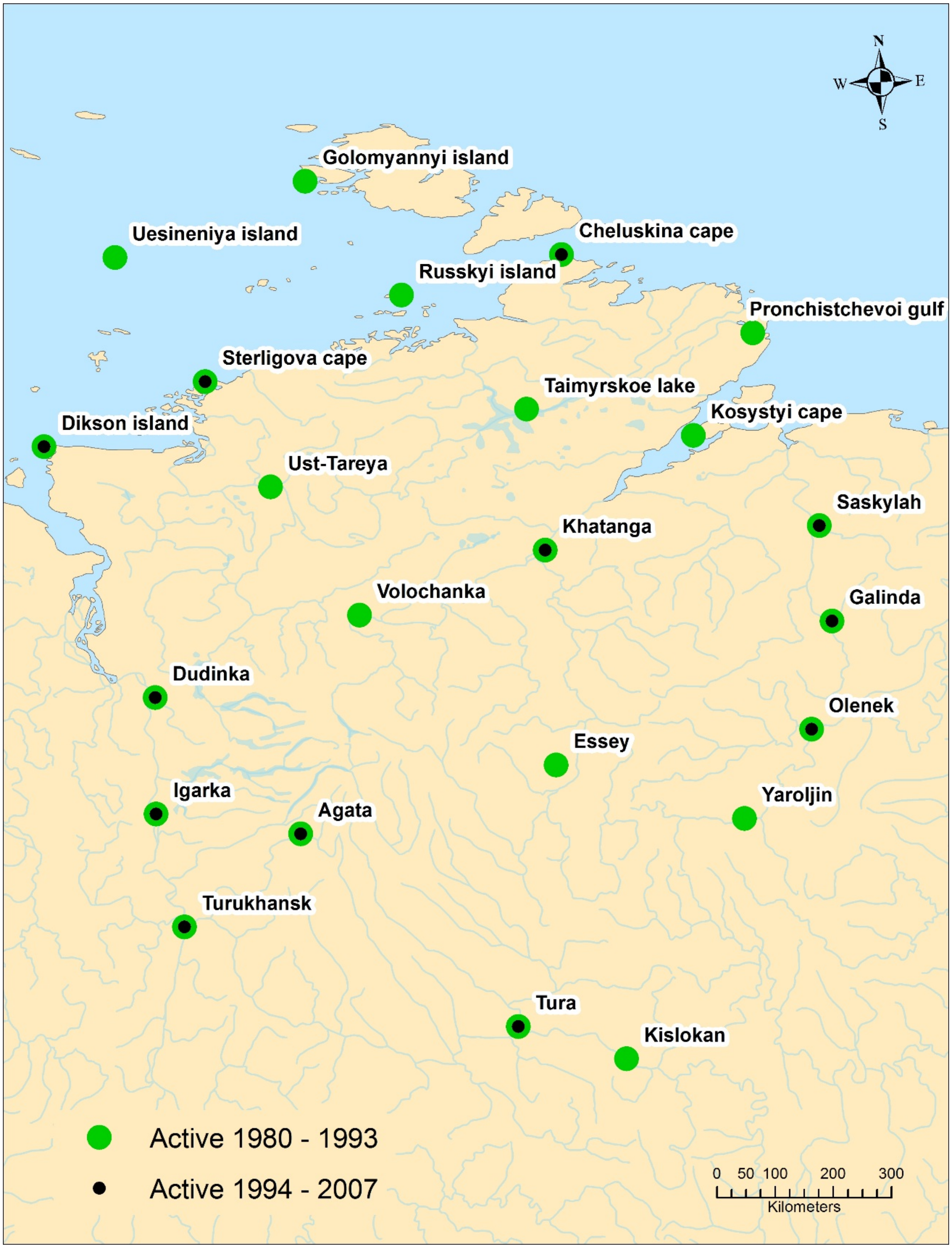


*Figure 12*. Meteorological stations

### 3.2.4 Remote Sensing Data

Preliminary analysis of spatiotemporal distribution of TRH summer concentrations revealed areas within the summer habitat that were more frequently used than others. One such area has been selected for more robust analysis based on its high frequency of utilization by TRH. The regional model used environmental, climate, and spatial variables which corresponded to those in the habitat-wide model, but the larger scale model was enriched with a satellite derived vegetation component. The Normalized Difference Vegetation Index (NDVI) is the measure of the amount and vigor of vegetation on the lands surface. Three level-1 satellite images capturing the same area (WRS Path 156 Row 008) but at different points in time were downloaded from the USGS Earth Explorer website (Figure 13). One image was acquired by the Landsat 5 Thematic Mapper (TM) sensor (LT5156008008520650 July 25, 1985) and two images were acquired by the Landsat 7 Enhanced Thematic Mapper (ETM) sensor (LE71560082000208SGS01 (July 26, 2000, and LE71560082000224AGS00 August 11, 2000).

## 3.3 Methods

### 3.3.1 Spatiotemporal Dynamics, Fidelity, and Shift

Spatial fidelity and shift of summer concentration ground distributions was analyzed according to parameters previously established by Gunn et al. (2009) and Meerdink and Petrov (2012). Meerdink and Petrov (2012) analyzed the spatial fidelity and shift of the TRH spring, or calving, concentration grounds. The study on calving


*Figure 13*. Landsat ETM+ August 11, 2000

grounds revealed both spatial fidelity and significant shifting of grounds through the utilization of the following methods: (1) *Concentration of range*, (2) *Standard distance*, (3) *Range overlap*, and (4) *Temporal variation*. Due to the availability of more collected data on summer grounds, some additional methods of assessment were added to enrich the analysis: (5) *Elevation characteristics,* (6) *Decadal concentration distribution,* and (7) *Dynamic population and frequently used areas*. Exploratory analysis of three-dimensional space (i.e. elevation) utilized by Taimyr reindeer was done to complement two-dimensional spatioanalytics. This study added empirical analysis of concentration mean centers' decadal distribution to the existing dataset using a temporal overlay technique that examined small and large scale trends of spatial and population dynamics.

The average x and y values of mapped reindeer summer concentration polygons was used to find the geometric centroids of the summer concentration grounds. These annual centroids (geographical mean centers) were further used to determine the geographic mean center of the utilized summer range. The geographic mean center of the entire summer range provided a point from which to measure shifts in spatial distributions of annual summer concentration locations. These quantifications provided the *concentration of range,* or the degree to which the yearly centroids were concentrated or dispersed around the mean center of the summer range to be calculated. A normal distribution of features identifies 68% of the features (yearly summer mean centers) within one standard deviation of the range mean center, 95% of the features within two standard deviations, and 99% of features will be distributed within three standard deviations of the summer range geographic mean (Coolidge, 2006). *Standard distance* analysis quantified annual observation variances from one another and at a scale that encompasses all 21 years of observations. This method was necessary in order to understand the amount of variability in distance between summer grounds researchers have observed and how much to expect in the future. Shorter distances between mean centers indicated higher levels of spatial fidelity, and longer distances indicated spatial shift.

The area of summer concentration grounds revisited from year to year, the *range overlap*, was analyzed as part of spatial fidelity assessment. This was measured using the following formula which was used in reindeer calving ground studies by Gunn et al. (2009):

$$\frac{(2 * \text{Area of Intersection}) * 100}{\text{Area of polygon } x + \text{Area of polygon } y}$$

These calculations provided the amount of land observed to be reused from year to year where higher percentages indicated spatial fidelity and lower percentages indicated spatial shift.

Another important analyzed measure of spatial fidelity was *temporal variation*, or frequency of use of specific areas, within the whole summer range. This was measured by overlaying yearly concentration datasets on top of one another. This geospatial technique led to empirical assessments as to which specific areas are most often used for summer concentration grounds, if any, and to what degree these areas have been used as seen by 21 years of observation.

The landscape of Taimyr Peninsula contains variation in *elevation characteristics* from the northern bordering seas to the Byrranga Mountains. Annual summer ground concentration data was overlaid on topographic data and a mean elevation was calculated for each year of observation. These calculations were used to examine trends of three dimensional spatial fidelity. The areas of frequent use were also analyzed using a similar method. The mean elevation for areas observed to have been used between 1 - 13 times was calculated and graphed.

A hybrid method of two previously utilized techniques was developed as a necessary step to further the analysis of TRH spatial dynamics. By adding another scale of temporality, looking at *decadal concentration distribution*, to the frequency of use illustration, it was possible to visualize larger scale trends of the entire herd as well as smaller trends of the concentrations. Annual concentration mean centers that were previously calculated and were then divided into the decades of which data is available (1960s, 1970s, 1980s, 1990s, and 2000s) and overlaid on the mapped areas of frequent use.

The study analyzed not only the spatial shifts but also the population fluctuation over time and space. Roughly ten year increments were chosen according to availability and quality of ENARI data to assess *dynamic population and frequently used areas*. Years closest to decadal divisions with complete population statistics (i.e. 1969, 1980, 1991, and 2000) were mapped and color coded according to year and proportionally sized according to population of individual concentrations.

3.3.2 Preliminary Analysis of Variables

The second objective of this study is to identify which conditions of climate and physiographic variables will yield higher or lower probabilities of reindeer presence. The relationships between independent variables was first explored using Pearson product-moment correlation analysis. Further analysis was conducted on variables used in the habitat-wide models for 1985 and 2000, as well as on variables used in the regional models for 1985 and 2000. Independent variables used in this exploration were climate data acquired from Russian meteorological stations for the years 1985 and 2000 in the form of monthly means for the following observed variables: temperature, precipitation, wind, total clouds, low clouds, humidity (Table 1).

Table 1. *Definition of variables*

| **Variables** | **Definitions** |
|---|---|
| Temperature | m/sec |
| Wind | m/sec |
| Precipitation | mm |
| Humidity | % |
| Total Clouds | grade (1 - 10) |
| Low Clouds | grade (1 - 10) |
| Elevation | meters above sea level |
| Previously Used Areas (spatial) | presence (1) or absence (0) |
| Previously Used Areas (temporal) | number of observations (1-13) |
| NDVI | (-1) - 1 |

Environmental variables used in correlation analysis were elevation and NDVI (regional models only). The dependent variable, reindeer presence, was also part of this analysis for visualization purposes only, and was only included in order to establish preliminary knowledge about the way in which the variables are correlated with one another. The independent categorical spatial lag variable of previously used areas was included for visualization purposes for habitat-wide models, and a spatiotemporal lag variable of frequently used areas was also included for visualization in the correlation analysis.

Maps constructed detailing the distribution of the annual TRH summer concentrations provided the initial reindeer distribution data necessary for spatial analysis. Polygons were drawn to delimit the extent of concentrations during aerial surveys, and this summer concentration data, compiled by ENARI, contained population estimates of the herd as a whole and an estimate made for individual concentrations formed within each observed summer. To represent reindeer (which are not continuously occurring in the real world, rather they are discrete objects) random points were created in ArcMap 10.2 utilizing the Create Random Points Tool. One point was created for every 1,000 reindeer and placed within the boundaries of each concentration for the years 1985 and 2000, and these points will be considered reindeer presence data (Figure 14). A field was added to the attribute table called, “Existence,” and all points were given a value of one.

In order to develop logistic regression models, a corresponding number of random pseudo-absence points were created outside of the concentration areas but within a greater accumulated area observed to have been previously utilized as summer habitat (Figure 14). This area was determined by merging and dissolving concentration polygons of all previous observations and then erasing any overlapping areas of the year in study. All summer concentration polygons from 1969 - 1984 were merged and dissolved, and then any areas that overlap the concentration areas of 1985 were erased. The remaining polygon was converted to raster format. The area within the polygon boundary was classified as 1 (presence) and the area outside the polygon was classified 0 (pseudo-absence). Next, all summer concentration polygons from 1969 - 1999 were merged and dissolved, and then the overlapping areas of 2000 were erased. The pseudo-absence points were randomly placed throughout the area, and a field was added to their attribute table called, “Existence,” and given a value of 0. The polygon feature class delimiting the areas utilized by reindeer from 1969 - 1999 was converted to raster format.

Once presence and pseudo-absence points were created, they were merged and added to a map document along with climate rasters, the areas previously used raster, and a digital elevation model. The Extract Multiple Values to Points Tool was used to acquire the cell values for temperature, wind, precipitation, humidity, total clouds, low clouds, elevation, NDVI (regional models only), and previously used areas. These values were added to the attribute table of the presence and pseudo-absence point feature class, the table was exported as a database file (.dbf), which transformed the data structure to one suitable for analysis in SPSS 22.0.

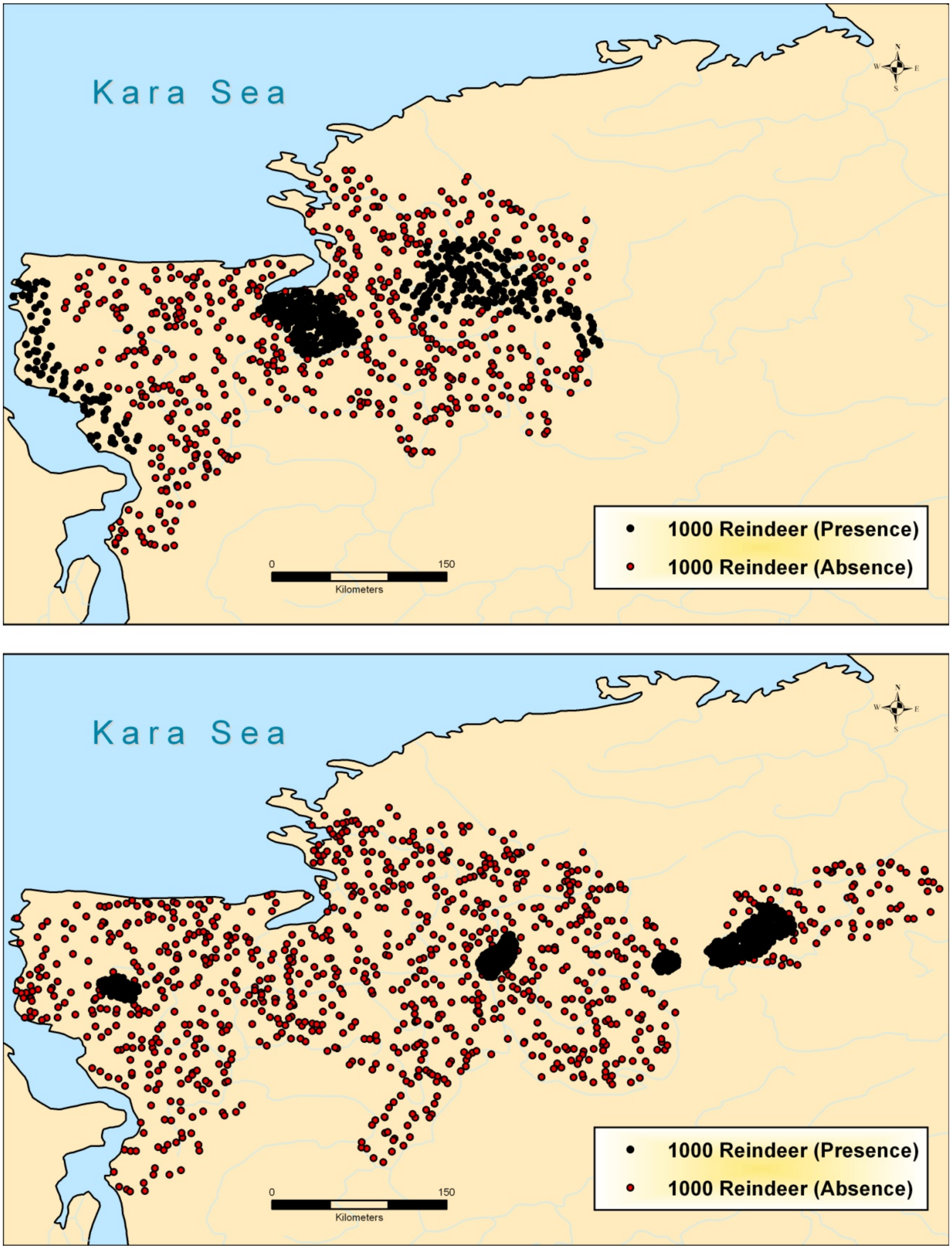


*Figure 14*. Presence and pseudo-absence points for 1985 (Above) and 2000 (Below).

3.3.3 Identification of Factors and Their Influence

In order to further investigate and identify which factors influence wild reindeer distribution and to what degree these factors do so, backward stepwise Wald logistic regression was employed. This method included all candidate variables in construction of the first model and tried to improve the explanatory power of the model through elimination of insignificant variables (if any). One habitat-wide model and one regional scale model were constructed for both 1985 and 2000. The data used for habitat-wide modeling contained a dichotomous dependent variable (presence and pseudo-absence points of reindeer) and eight independent variables of which one was categorical and seven were continuous. The relationship between the independent variables and the dependent variable was non-linear. The model constructed at the regional scale used the same dependent dichotomous variable, and nine continuous variables (previously used areas became spatially and temporally lagged) with the inclusion of NDVI. All variables for both model scales for the years 1985 and 2000 (Table 1) were used as inputs in the SPSS 22.0 which is capable of correlation analysis and logistic regression modeling.

3.3.4 Assessment of Biomass

Preprocessing was performed on the Landsat imagery in order to derive NDVI. The first preprocessing step was to mask out the clouds, snow, water, and bare rocks from the stacked Digital Number (DN) images using an unsupervised classification on pixels. Next, the masked DN images were converted to radiances. The DNs range from 0 - 255 in 8 bit systems; however, DNs are stored as integers and do not represent brightness in physical units (Watts per square meter per micrometer per steradian; NASA, 2014). The following formula was used to convert to radiance using Landsat TM/ETM sensor data as prescribed by the Landsat Handbook (NASA, 2014):

$$\text{Radiance } (L_\lambda) = [(L_{max} - L_{min}) / (Q_{calmax} - Q_{calmin})] * (Q_{cal} - Q_{calmin}) + L_{min}$$

Where:
$L_\lambda$ = spectral radiance at the sensor's aperture in W / (m²·sr·µm)
$Q_{cal}$ = quantized calibrated pixel value in DNs
$Q_{calmin}$ = minimum quantized calibrated pixel value (DN=0)
$Q_{calmax}$ = maximized quantized calibrated pixel value (DN=255)
$L_{min}$ = spectral radiance that is scaled to $Q_{calmin}$ in W / (m²·sr·µm)
$L_{max}$ = spectral radiance that is scaled to $Q_{calmax}$ in W / (m²·sr·µm)

The next process was to convert the radiance values to surface reflectance values using the following formula to calculate for surface reflectance:

$$P = d^2\pi(\text{Radiance} - \text{Lhaze}) / \text{ESUN}\cdot(\cos\Theta)^2$$

Where:
$d$ = earth-sun distance in astronomical units
Lhaze = $L\,\lambda min - L\,\lambda(1\%)$
$L\,\lambda(1\%) = .01\cdot\text{ESUN}\cdot(\cos\Theta)^2 / d^2\pi$
ESUN = mean solar exoatmospheric irradiances
$\Theta$ = solar zenith angle in degrees

The final satellite image processing step was to use band 3 (red) and band 4 (near-infrared) to calculate the digital brightness levels of biomass through band ratioing. Brightness values range from -1 (dark shadows/rock) to 1 (very high amounts of biomass). NDVI was calculated using the surface reflectance values with the formula:

$$NDVI = \frac{\text{Band 4} - \text{Band 3}}{\text{Band 4} + \text{Band 3}}$$

The extent of Landsat images for path 156 row 008 covers ~33,320 km² and serves as the extent for the regional scale model (Figure 13). During both years 1985 and 2000 the TRH used areas within this extent as concentration grounds. This area lied between the Tareya, Pura, and Pyassina rivers and is regularly utilized by the TRH, and annual summer concentrations that form here are referred to as the Puro-Pyassina. The summer concentration formed in 2000 was located completely within this extent and occupied ~642 km². The two concentrations formed in 1985 in this region were located almost completely within the model extent and occupied ~10,943 km². The two polygons representing the concentrations were clipped to the regional model extent and had minimal area lost as a result of the clip, with a new area of ~9950 km².

Random points were created using ArcMap 10.2 within the concentration polygons for 1985 and 2000 in order to extract cell values from environmental and climate raster layers to be used in the regional modeling framework. The NDVI rasters contained many cell values of "no data" as a result of masking out clouds, snow, rock, and water, therefore 1,000 points were created with the expectation of no more than 50% of points extracting "no data" values from the NDVI raster layer and the expectation that the majority of points would extract usable data values. An equal number of points were randomly created outside of the concentration areas and within the model extent with the same expectations of efficiency for data extraction. An observed ~25% of points extracted values of "no data" and produced an adequate number of usable sample points,

~750 for each year for both within the concentration area (presence) and outside of the concentration area (pseudo-absence) yet within the model extent (1985: presence = 737, pseudo-absence = 729; 2000: presence = 761, pseudo-absence = 749).

The regional models constructed used an additional physiographic variable which assesses amounts of reflectance by vegetation (NDVI). In order to extend the knowledge base of how NDVI influences the spatial distributions of TRH summer concentrations, independent-samples t-test were used to statistically quantify the comparisons of mean NDVI values from inside the concentration area and outside the concentration area within the extent of the regional model. The independent-samples t-test calculated the mean values and standard deviation for samples where reindeer were located and where pseudo-absences were placed, and also determined whether or not the differences in NDVI means for both groups was statistically significant or not and to what degree. NDVI values were derived for the August 11, 2000 Landsat image in order to assess the impact reindeer have on the vegetation. Values were first evaluated to ensure that violation of assumptions of the independent variables t-test (level of measurement, random sampling, independence of observations, normal distribution, and homogeneity of variance). Outliers were found in the data for July of 1985, and nine samples were removed before the t-test was run in SPSS 22.0. The following formula was used to calculate Eta Squared which tests the difference between two independent mean values:

$$Eta\ squared = \frac{\mathrm{t}^2}{\mathrm{t}^2 + (N1 + N2 - 2)}$$

which is the magnitude of the effect size where 0.20 is small, 0.50 is a medium effect size, and 0.80 is a large effect size (Cohen, 1988).

### 3.3.5 Identification of Niche Habitat

The wild reindeer in Taimyr are migratory ungulates that are capable of travelling 60 km/day. Researchers have compiled vast amounts of data pertaining to the locations of the TRH summer concentrations, but to identify where the reindeer did not appear at all would be an implausible task. This qualified the available data as presence-only data, making Maximum Entropy modeling an ideal framework in which to identify factors that influence the probability of reindeer presence. Maxent is a species distribution modeling framework that uses a number of environmental variables to best predict probabilities of areas for species habitat based on observations of where the species is known to exist, and Maxent has a high predictive performance when presence-only data are available (Elith et al., 2011).

Two habitat-wide models and two regional models were created using environmental and climate variables as independent variables and points of reindeer existence as the dependent presence-only variable. Independent continuous variables used were in the form of monthly means for the following: temperature, precipitation, wind, total clouds, low clouds, humidity, elevation, NDVI (regional models only) and previously used areas (categorical for habitat-wide model and continuous for regional model). The output format “Cumulative” was selected in order to obtain the sum of all probabilities for a given cell, multiplied by 100. Response curves were generated to produce graphs showing the probability of reindeer occurrence for each environmental variable. Jackknifing was also incorporated to further understandings about the environmental factors and their significance. Maxent is equipped with the power to validate models through cross-validation. This process retained 20% of the presence-only points as test data in order to validate the model constructed with the other 80% of data points.

# CHAPTER 4

# RESULTS

The fourth chapter of the thesis presents the findings from spatial analysis with descriptions, maps, and graphs that have added substantially to the existing knowledge base on the long-term patterns of the TRH summer grounds. A regional area of interest is established which allows for further analysis of TRH summer grounds. Climate and physiographic factors that influence the TRH selection of summer grounds have been identified, and also the degree to which these factors influence the TRH's selection of summer grounds have been quantified at a habitat-wide scale as well as a regional scale.

## 4.1 Spatiotemporal Dynamics, Fidelity, and Shift

Locational analysis of annual summer grounds has provided empirical results never before accumulated on the spatial dynamics of the Taimyr Reindeer Herd. The use of centrographic spatioanalytics, specifically the establishment of annual summer ground geographical mean centers, provided quantitative and statistical validation to visual analysis and expert opinion as to the TRH's demonstration of spatial fidelity. This study found that the Taimyr Reindeer Herd's *concentration of range*, in observed years, did in fact demonstrate a spatial pattern consistent with a statistically concentrated distribution of features.

The geographic mean center of the summer range was identified using ArcMap software to be 62 kilometers to the south and east of the southeast inlet of the Gulf of Yenisei. Geographic mean centers of 16 out of 21 observed summer concentrations, or 76.2%, were within one standard deviation, or 66 kilometers, of the geographical mean center of the summer range (Figure 16). Within 132 kilometers, or two standard deviations, of the geographic mean center of the summer range were 20 (95.2%) annual summer concentration mean centers. Three out of four of these mean centers were within 18 km of one standard deviation threshold which shows compactness. More evidence of spatial fidelity was found within three standard deviations (198 km) of the geographic mean as 100% of annual summer concentrations mean centers were within this boundary. The years 1969 (10 km), 1980 (12 km), and 1990 (16 km) were the closest to the geographical mean center of the summer range, and the years 2000 (131 km), 2003 (80 km), and 2009 (162 km) were the furthest from the summer range mean center (Figure 15). The average distance of each of 21 yearly observations from the geographical mean center of the summer range was 55 km (i.e. less than one standard deviation) again demonstrating the compactness of the distribution.

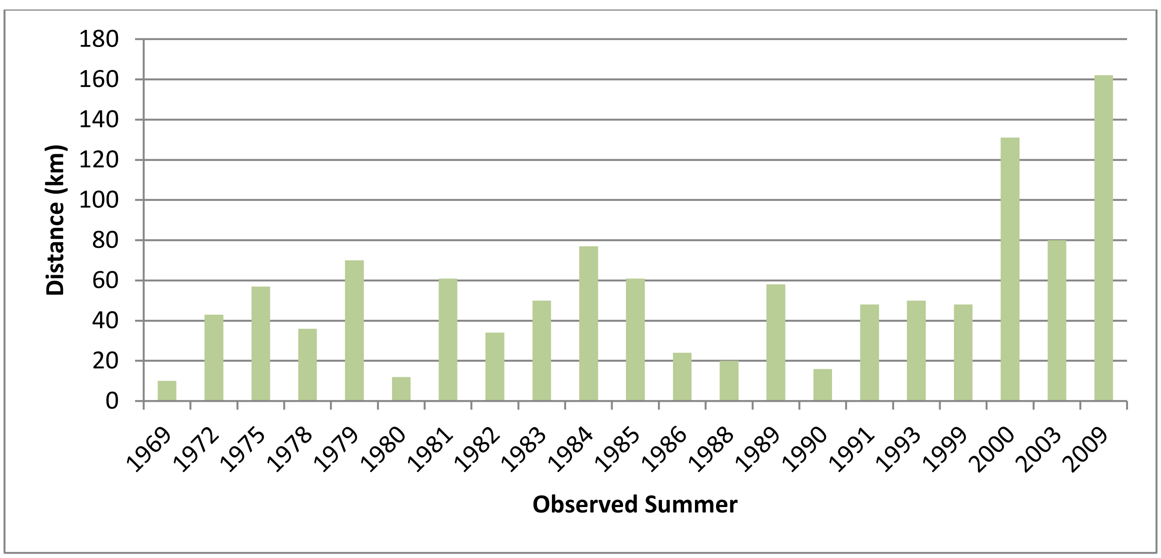


*Figure 15*. Annual variation from summer range geographic mean center

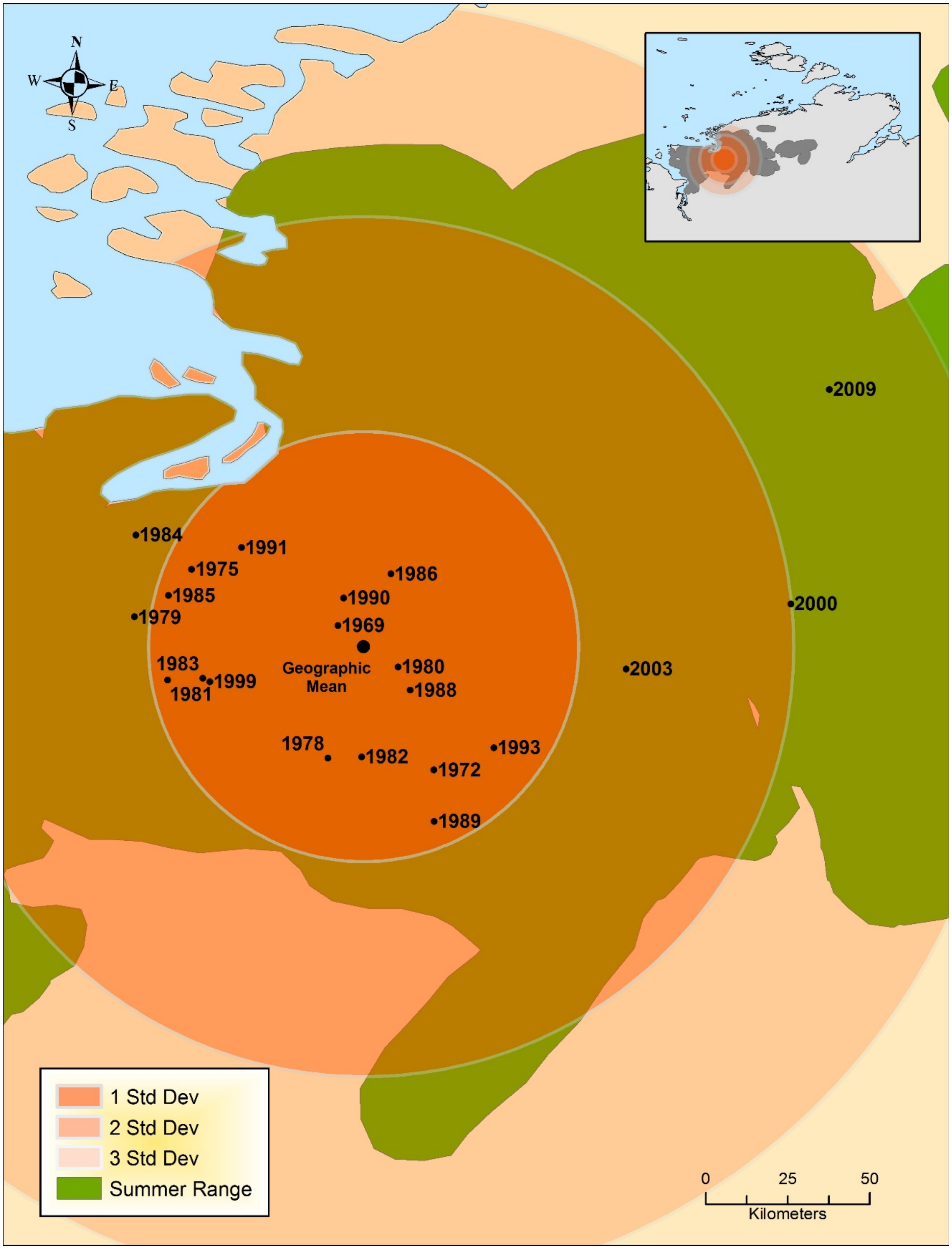


*Figure 16*. TRH annual mean centers

These observations exceeded the statistically necessary 68% of features needed to be within one standard deviation, 95% within 2 standard deviations, and 99% within 3 standard deviations that would be found in a normal distribution. The spatial distribution of annual summer concentration mean centers revealed a statistically more compact *concentration of range* than a normal distribution. A spatial distribution of features that is more compact than a normal distribution of features is statistical and empirical evidence of spatial fidelity (Gunn et al., 2009; Petrov et al., 2012).

Another method used to assess TRH spatial fidelity and or spatial shift was calculating the percentage of *range overlap*. The *range overlap* is the amount of area observed to be reused as summer concentration grounds from year to year (Figure 18). If the herd was not revisiting previously used areas at all, it would have been difficult to make an argument that spatial fidelity influences Taimyr reindeer in their selection of annual summer grounds. This study found substantial fluctuations in amounts of overlapping grounds from year to year when only consecutively observed summers were considered. The measurements of *range overlap* varied from as little as 2.6% from 1999 - 2000 to as much as 43.7% from 1990 - 1991 (Figure 17). The average annual range overlap was 20.7% for the 21 years of observations.

This study has utilized the geospatial technique of spatial overlay to measure the *temporal variation* of all 21 years of observation simultaneously. After the process of rasterization, summer concentration areas were overlaid on top of one another and added together using map algebra. Annual observations consisted of anywhere from 3 to 7 polygons which were rasterized using ArcGIS and then reclassified to represent presence

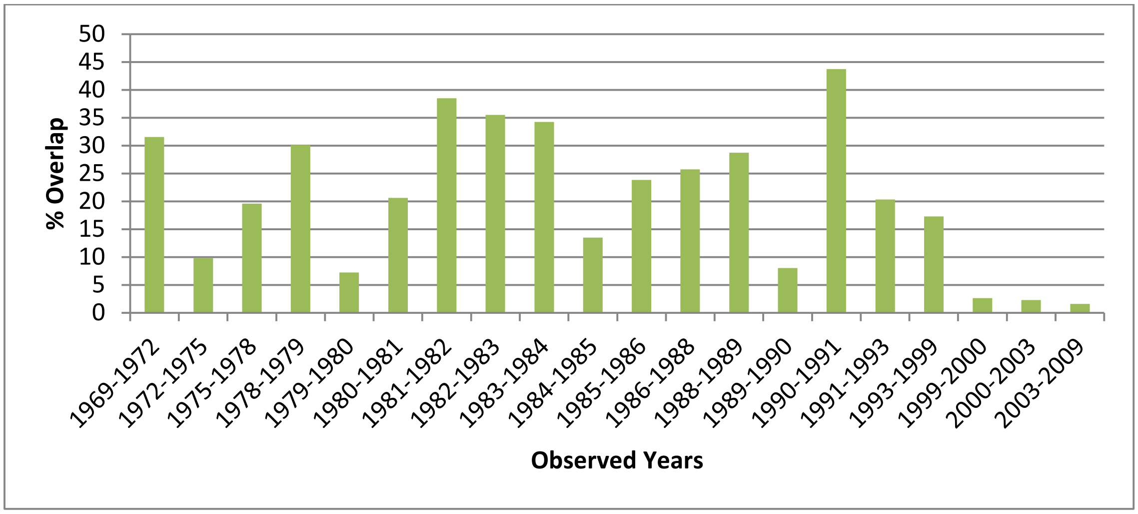


*Figure 17*. Percent of range overlap

(1) of deer or absence (0) of deer. A value of zero was given to the areas outside of the polygons for a given year and a value of one was given to the areas within the polygons.

The map of areas frequently used contained values ranging from 0 to 13. All areas of this raster with value zero signified that the TRH was not observed to use that area as a place of summer concentration. Within ArcMap 10.2 these areas were considered areas of no data and were not symbolized in any way on a map. Combined areas of the map having values of 1 - 13 made the area referred to as the TRH summer range (Figure 19). Raster cells which had a value of one represented areas of the summer range that reindeer were observed during one, and only one summer. A raster cell value of two indicated that the herd was observed in the areas during two of the 21 summer surveys, or said to have two years of occurrence. Areas of the raster which had a value of 13 represented areas in the Taimyr Peninsula where the TRH were observed during 13 different summer surveys, or areas having 13 years of occurrence.


*Figure 18*. Observation of range overlap

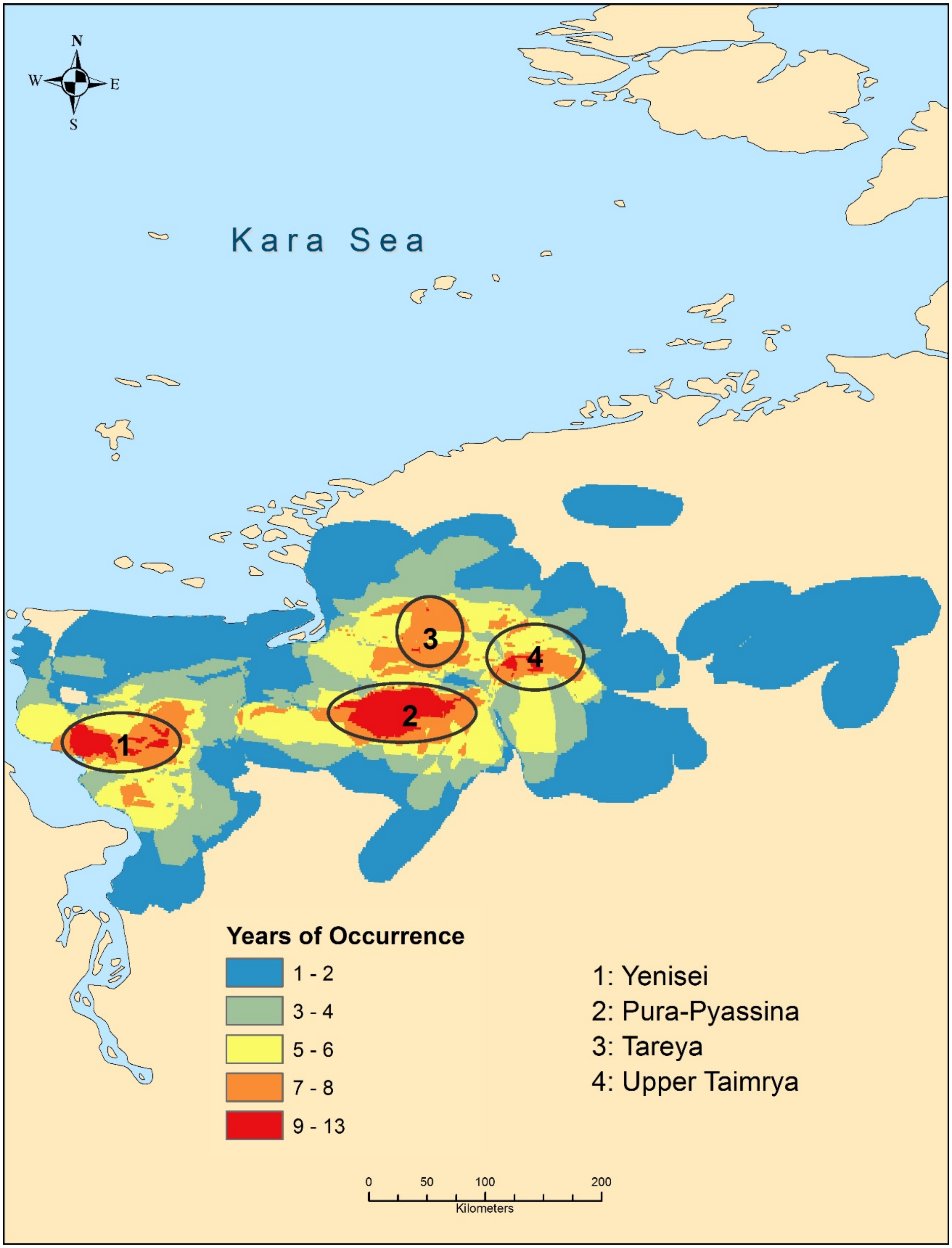


*Figure 19*. TRH summer range and frequency of use

As previously described, spatial fidelity is the tendency of animals to return to a particular space (White & Garrot 1990; Schaefer, Bergman & Luttich, 2000). The reindeer of Taimyr demonstrated their tendency to return to a particular place by revisiting areas on a regular basis. Of 21 summer surveys, seven years recorded the same areas being used, and this area accounted for 11.4% (14,900 km$^2$) of the entire summer range. Within this area, the TRH were documented revisiting even smaller areas more frequently; up to 61.9% of the time, or 13 out of 21 summer observations. The most frequently inhabited areas were found in central and western Taimyr along Pyassina and Tareya rivers and the eastern shore of the Yenisei Gulf. Wild reindeer gathered here 10 - 13 times out of 21 surveys (in 47.6 - 61.9% of all surveyed years).

Analysis of two-dimensional spaces has established evidence that the herd did frequent specific areas over 50% of summers and that annual summer concentrations clustered around the summer range geographic mean. The exploratory analysis of three-dimensional spatial trends accounted for varying *elevation characteristics* by calculating one mean elevation for the multiple deer concentrations that occurred annually. The TRH have a large summer range both two and three dimensionally spanning over 280,000 km$^2$ and rising some 640 meters from the shores of the Kara and Laptev Seas to the rocky foothills of the Byrranga Mountains (Figure 20).

The average elevation for 21 years of summer observations was 90 meters above sea level and measurements ranged from 57 meters in 1972 to 158 meters in 2009 (Figure 21). The results showed annual variations rising and falling throughout the 1970s, 1980s, and 1990s. There were almost identical measurements for 1988 and 1989 followed by a

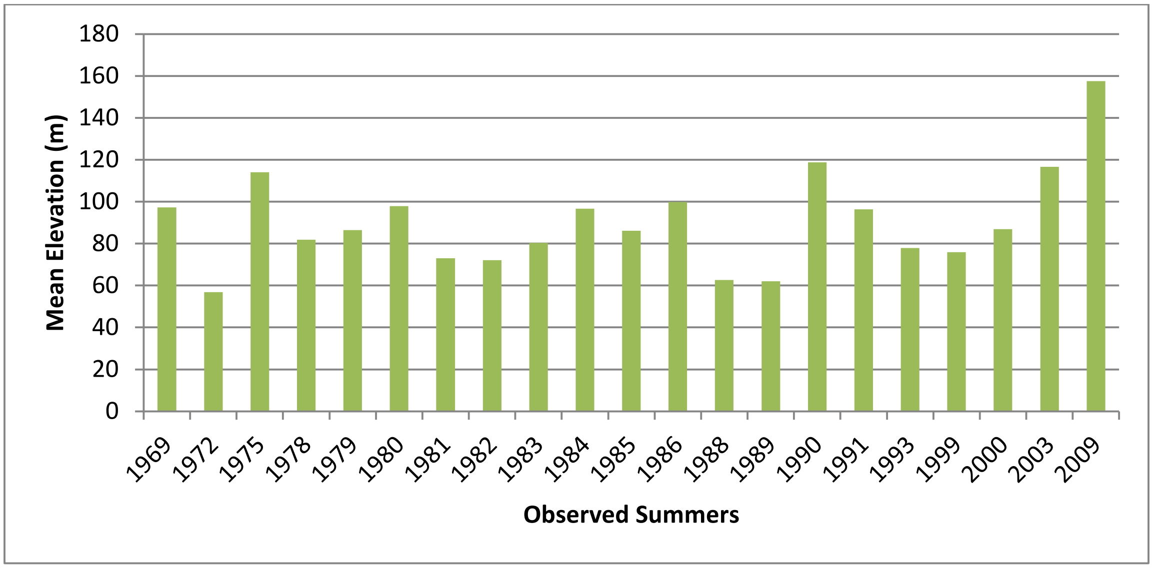


*Figure 20*. Annual mean elevations of TRH summer concentration

nearly 60 meter rise in 1990. There was a consistent and sharp rise in elevation from 76 - 158 meters during the 1999 census to the observations made in 2009. There were multiyear gaps in the 2000 data that made it difficult to declare the trend was consistently maintained; however, no other decade of measurement showed anything similar to+ this pattern of sharp and steady rise in elevation. More so, two out of the three highest mean elevations measured occurred during the 2000s.

Applying a similar method to data accumulated as to the TRH's frequently used summer range areas, it was determined that a trend in elevation existed within the areas most frequently utilized (Figure 22). Areas used for summer concentration grounds least frequently, 1 - 3 observations, had the highest mean elevations ranging from 98 - 113 meters, areas observed to have been used 4 - 8 maintained a fairly consistent mean elevation ranging from 79 - 85 meters, and the areas detected to be used most often,

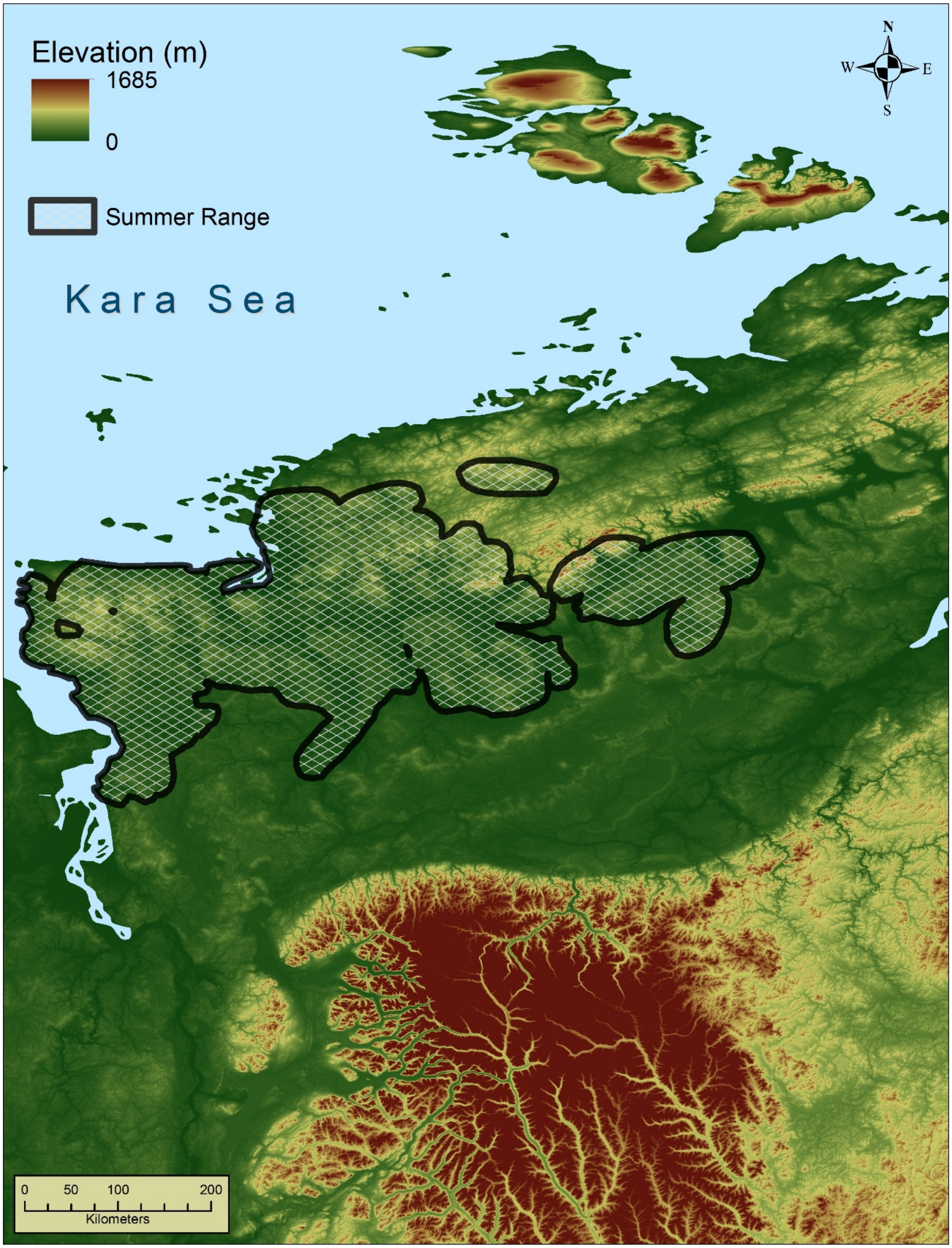


*Figure 21*. Topography of TRH habitat

nearly 50 % or more of the years observed, had the overall lowest and most compact range of mean elevations at 67 - 71 meters above sea level. It was found that Taimyr reindeer tend to select areas that are lower in elevation more often and selection of higher elevation areas occurs less often.

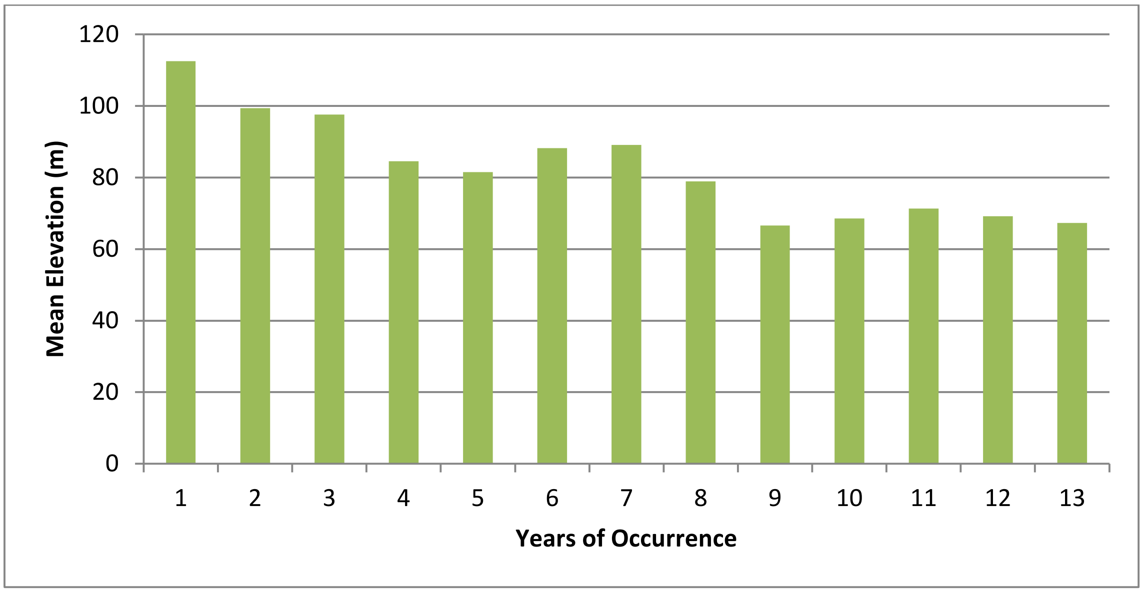


*Figure 22*. Mean elevations of frequently used areas

To further illustrate the Taimyr Reindeer Herd's tendencies of spatial shifting and fidelity, the method of analyzing *decadal concentration distribution* was developed and employed. The plotting of centroids of reindeer concentrations by decade was overlaid on areas of frequent use (Figure 23). There was a persistence of wild reindeer presence in certain areas, but also small and large scale shifts. The western and central areas of the TRH summer range were consistently utilized by the herd since the 1960s, as they frequented these areas up to 62% of observed years, and a significant amount of area was

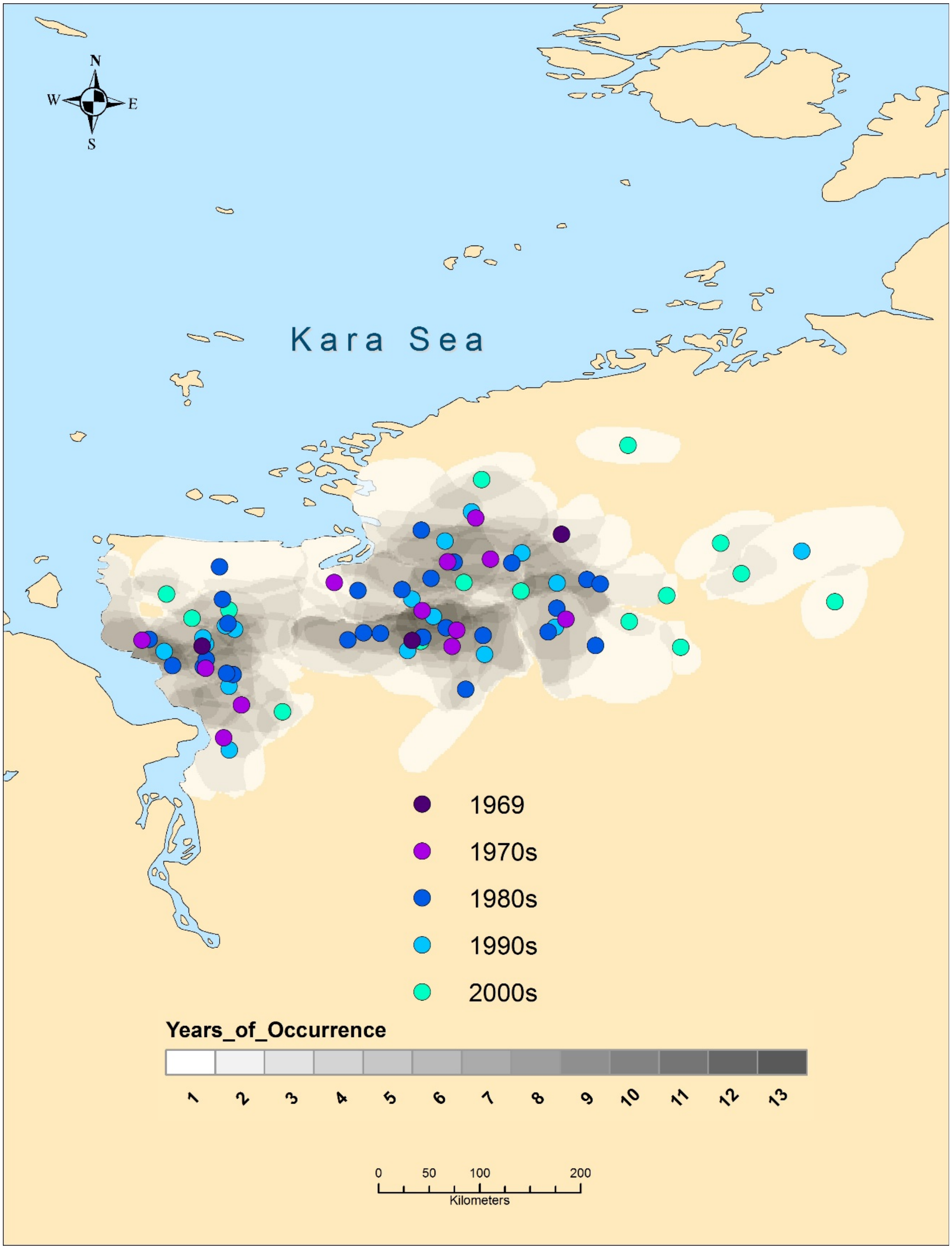


*Figure 23*. Summer concentration mean centers and frequently used areas

used more than 50% of observed years. These small-scale shifts were observed throughout the 1970s, 1980s, 1990s, and in some areas during the 2000s. The large-scale shifts showed the formation of new concentrations which had expanded the summer range to the north and east. Examination of concentration mean centers symbolized proportionally according to population and year, the *dynamic population and frequently used areas method,* revealed the emergence of new and larger summer concentrations during the 2000s to the east of the most frequently used habitat and declining populations in the regularly utilized area of western Taimyr (Figure 24). In the 1960s the majority of animals formed concentrations in western Taimyr.

The results of spatiotemporal analysis have identified that observations made since the 2000 census revealed six trends: (1) population of the Taimyr wild reindeer was decreasing as a whole, (2) western concentrations were losing animals while central and eastern concentrations were developing and getting larger, (3) summer concentrations were shifting to the east and to the north expanding the summer range to areas not previously observed to have been utilized, (4) TRH were reusing smaller percentages of their range from year to year, (5) summer concentrations were becoming more compact and densely populated, and (6) habitat utilized for summer concentration grounds was rising in elevation.

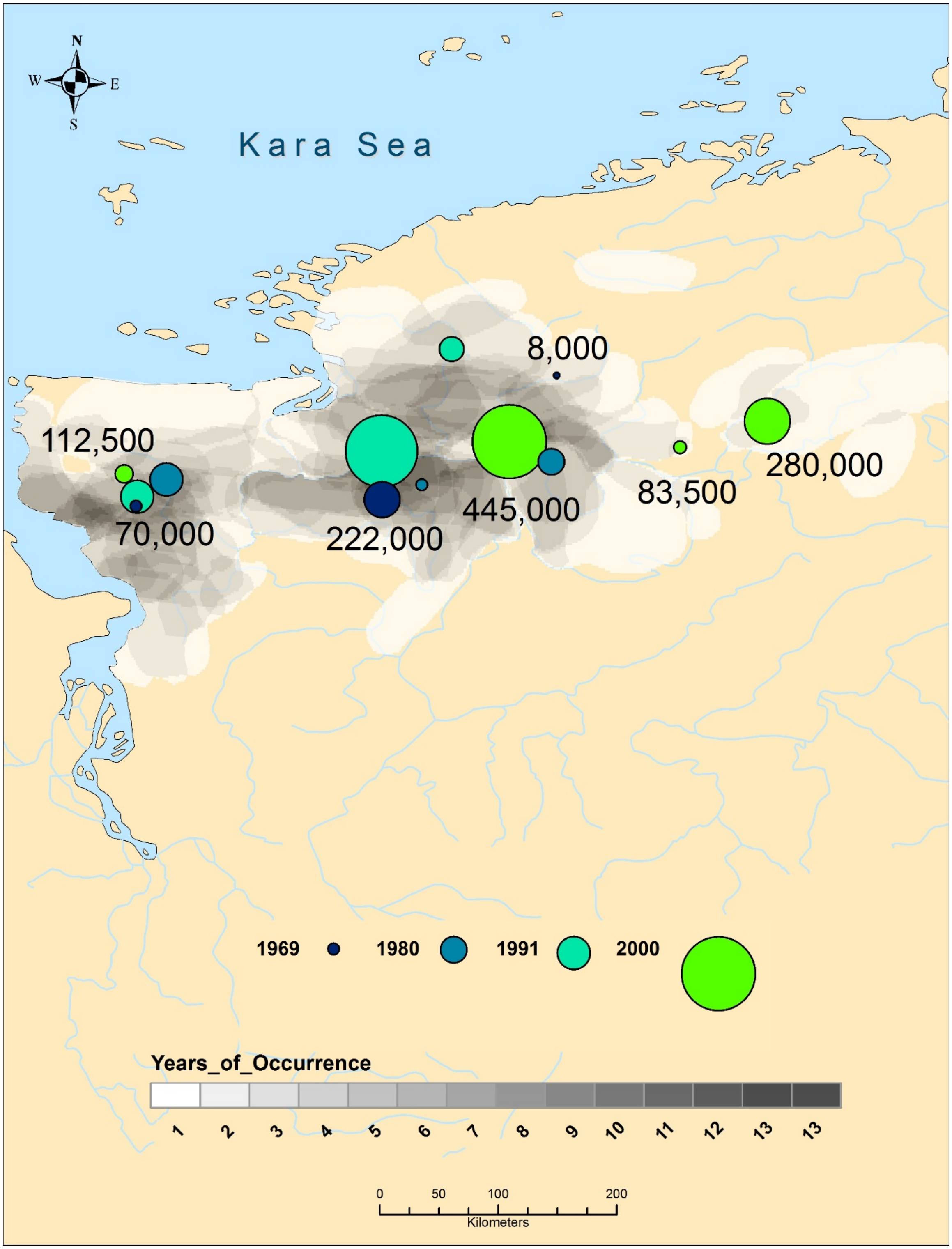


*Figure 24*. Populations shifting within frequently used areas

## 4.2 Identification of Habitat-wide Factors and Their Influence

### 4.2.1 Habitat-wide model for 1985

Pearson correlation analysis conducted on the candidate variables produced a spectrum of relationships ranging from strongly negative to strongly positive as climate variables tend to be highly correlated. Temperature was strongly (< -0.700 or > 0.700) correlated with humidity (-0.994), total clouds (-0.904), and low clouds (-0.708) and all correlations were statistically significant and in a negative direction indicating that a rise in temperature led to lower humidity and less clouds. Temperature had a moderate {[-0.699 - (-0.300)] or [0.300 - 0.699]} correlation with wind (0.308) in a positive direction which suggested that increased temperatures indicated fractionally higher wind speeds. In July 1985 wind and precipitation (0.790) were strongly and positively correlated, and wind shared a moderate positive correlation with low cloud cover (0.405). Strong positive correlations were found between humidity and both cloud cover variables, and correlations between precipitation and cloud cover were found to be positive as well (Table 2).

Multicollinearity diagnostics were performed to further understand the results of correlation analysis. Very strong correlations in both positive and negative directions as well as preliminary logistic regression models with very high standard error values required this addition assessment. As a result of collinearity diagnosis, the variables humidity, total clouds, and low clouds were identified as being multicollinear through tolerance and variance inflation factors and therefore removed from both logistic regression and ENM in the 1985 habitat-wide models.

Table 2. *Correlation of habitat-wide variables 1985*

| | Temperature | Wind | Precipitation | Humidity | Total Clouds | Low Clouds | Elevation | Previous Areas | Presence |
|---|---|---|---|---|---|---|---|---|---|
| Temperature | 1 | | | | | | | | |
| Wind | 0.302** | 1 | | | | | | | |
| Precipitation | -0.091** | 0.790** | 1 | | | | | | |
| Humidity | -0.994** | -0.234** | 0.175** | 1 | | | | | |
| Total Clouds | -0.904** | 0.074** | 0.506** | 0.937** | 1 | | | | |
| Low Clouds | -0.708** | 0.405** | 0.758** | 0.763** | 0.937** | 1 | | | |
| Elevation | -0.234** | -0.260** | -0.148** | 0.209** | 0.130** | 0.027 | 1 | | |
| Previous Areas | 0.203** | -0.026 | -0.001 | -0.204** | -0.183** | -0.161** | -0.046 | 1 | |
| Presence | -0.054 | -0.001 | -0.158** | 0.031 | -0.022 | -0.060* | -0.052 | -.366** | 1 |

** Correlation is significant at the 0.01 level (2-tailed)   * Correlation is significant at the 0.05 level (2-tailed)

Backwards Wald binary logistic regression was performed to assess the impact of a number of available climate and environmental factors on the likelihood of whether or not wild reindeer would be present. This model contained five independent variables (temperature, precipitation, wind, elevation, and areas previously used). The full model which contained all remaining predictor variables was statistically significant:

$$x^2(5, N = 1149) = 310.713, p < 0.001$$

indicating that the model was able to distinguish between presence points and absence points for wild reindeer. The model as a whole explained between 23.7% (Cox & Snell R Square) and 31.6% (Nagelkerke R Square) of the variance in presence or absence of reindeer. The model was able to correctly classify 70.2% of the cases. All five independent variables used as input were found to make unique and statistically significant ($p < 0.05$) contributions to the model (Table 3). The variables with the highest odds ratios, and therefore the strongest predictors of reindeer presence, were wind and areas previously used. For every increase of one in the value for the wind variable, *R. tarandus* were 140 times more likely to be present in the area, and areas that had been previously used as summer grounds was more than 26 times more likely for reindeer presence. As temperature increased by a value of one, wild reindeer would only be 0.66 times as likely to be in the area indicating their preference for cooler temperatures. Areas with lower precipitation amounts and lower elevations were also more likely areas of reindeer occurrence.

Table 3. *Logistic regression for habitat-wide model 1985*

| **Variables** | **B** | **S.E.** | **Wald** | **Df** | **Sig.** | **Exp(B)** |
|---|---|---|---|---|---|---|
| Temperature | -0.416 | 0.068 | 37.835 | 1 | 0.000 | 0.660 |
| Wind | 4.944 | 0.598 | 68.412 | 1 | 0.000 | 140.289 |
| Precipitation | -0.131 | 0.014 | 85.300 | 1 | 0.000 | 0.877 |
| Elevation | -0.003 | 0.001 | 6.211 | 1 | 0.013 | 0.997 |
| Previous Areas | 3.285 | 0.433 | 57.545 | 1 | 0.000 | 26.715 |
| Constant | -25.820 | 3.238 | 63.588 | 1 | 0.000 | .000 |

4.2.2 Habitat-wide model for 2000

For July 2000, strong correlations were found as were some weaker correlations between variables. As temperatures rose total clouds diminished because they are significantly and strongly negatively correlated (-0.855), and there was significant strong negative correlation between temperature and low clouds (-0.895). The presence of low clouds indicated higher humidity as there was a significant strong positive correlation (0.913). The presence of more total clouds suggested a higher presence of low clouds (0.830). Higher temperatures were strongly negatively correlated with humidity (-0.954), total cloud cover (-0.855), and low clouds (-0.895). Higher temperatures were negatively correlated with elevation (-0.242) and wind (-0.108). As temperature rose, correlation analysis suggested that so did precipitation amounts (Table 4).

Multicollinearity diagnostics were performed to further understand the results of correlation analysis. Very strong correlations in both positive and negative directions as well as preliminary logistic regression models with very high standard error values

Table 4. *Correlation of habitat-wide variables 2000*

| | Temperature | Wind | Precipitation | Humidity | Total Clouds | Low Clouds | Elevation | Previous Areas | Presence |
|---|---|---|---|---|---|---|---|---|---|
| Temperature | 1 | | | | | | | | |
| Wind | -0.108** | 1 | | | | | | | |
| Precipitation | 0.237** | 0.654** | 1 | | | | | | |
| Humidity | -0.954** | 0.364** | 0.052** | 1 | | | | | |
| Total Clouds | -0.855** | -0.407** | -0.457** | 0.701** | 1 | | | | |
| Low Clouds | -0.895** | 0.082** | 0.086** | 0.913** | 0.830** | 1 | | | |
| Elevation | -0.242** | -0.189** | 0.028 | 0.210** | 0.349** | 0.334** | 1 | | |
| Previous Areas | -0.145** | 0.102** | 0.068** | 0.172** | 0.085** | 0.155** | 0.061** | 1 | |
| Presence | 0.222** | -0.255** | -0.263** | -0.308** | -0.096** | -0.289** | -0.125** | -0.160** | 1 |

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

required this additional assessment. As a result of collinearity diagnosis, the variables humidity, total clouds, and low clouds were identified as being multicollinear through tolerance and variance inflation factors and therefore removed from both logistic regression and ENM in the 2000 habitat-wide models.

Backwards Wald binary logistic regression was performed to assess the impact of climate and environmental factors on the likelihood of whether or not wild reindeer would be present. This model contained eight independent variables of temperature, precipitation, wind, humidity, low clouds, total clouds, elevation, and areas previously used. Low clouds and elevation were removed which left all other variables contributing to the model statistically significant. The full model that contained all predictor variables was statistically significant:

$$x^2(4, N = 2039) = 372.061, p < 0.001$$

indicating that the model was able to distinguish between wild reindeer presence and absence points. The model as a whole explained between 16.7% (Cox & Snell R Square) and 22.2% (Nagelkerke R Square) of the variance in presence or absence of reindeer, and correctly classified 79.3% of the cases. All variables were found to be significant ($p < 0.05$) and uniquely contributed to the model after the second step. The variable wind was removed from the model as it was not found to be statistically significant. The variable with the highest odds ratios of predicting TRH presence was the categorical variable areas previously used (9.338). As temperature increased, the likelihood of reindeer occurrence increased by 1.643 times, and the likelihood of reindeer occurrence was reduced as elevation (0.998) and precipitation (0.865) rose (Table 5). Higher amounts of precipitation were indicative of lower probabilities of reindeer presence, and so, too, were areas of higher elevations; however, it had only negligible impact.

Table 5. *Logistic regression for habitat-wide model 2000*

| **Variables** | **B** | **S.E.** | **Wald** | **Df** | **Sig.** | **Exp(B)** |
|---|---|---|---|---|---|---|
| Temperature | 0.496 | 0.043 | 130.166 | 1 | 0.000 | 1.643 |
| Precipitation | -0.145 | 0.011 | 182.820 | 1 | 0.000 | 0.865 |
| Elevation | -0.002 | 0.001 | 10.334 | 1 | 0.001 | 0.998 |
| Previous Areas | 2.234 | 0.598 | 13.973 | 1 | 0.000 | 9.338 |
| Constant | -0.065 | 0.352 | 0.034 | 1 | 0.854 | 0.937 |

## 4.3 Identification of Regional Factors and Their Influence

### 4.3.1 Regional model for 1985

In the correlation analysis of the predictor variables at the regional scale, temperature was strongly negatively correlated with humidity (-0.998), total clouds (0.970), and low clouds (-0.780). Temperature and wind shared a moderate positive correlation (0.581), and temperature was weakly, yet still positively correlated with precipitation (0.316) and NDVI (0.169). Temperature was weakly negatively correlated with elevation (-0.216). Temperature correlations with all variables were statistically significant ($p < 0.01$). Wind was strongly positively correlated with precipitation (0.891), and weakly positively correlated with NDVI (0.204) and low clouds (0.023). Wind was weakly negatively correlated elevation (-0.326) and total clouds (-.383). Wind and humidity shared a moderate negative correlation (-0.529). Wind correlations with all variables other than low clouds were statistically significant ($p < 0.01$). Humidity is strongly positively correlated with total clouds (0.984) and low clouds (0.821) and both variables were statistically significant ($p < 0.01$). NDVI and elevation shared only weak correlations with all other variables (Table 6).

Multicollinearity diagnostics were performed to further understand the results of correlation analysis. Very strong correlations in both positive and negative directions as well as preliminary logistic regression models with very high standard error values required this addition assessment. As a result of collinearity diagnosis, the variables humidity, total clouds, and low clouds were identified as being multicollinear through tolerance and variance inflation factors and therefore removed from both logistic regression and ENM in the 1985 regional models.

Backward Wald binary logistic regression was performed to assess the impact of nine climate, environmental, and spatial factors on the probability of reindeer occurrence. The model contained three independent climate variables (temperature, wind, and precipitation), two independent physiographic variables (elevation and NDVI), and one independent spatially and temporally lagged variable (previously used areas). The full model containing all predictors was statistically significant:

$$x^2(5, N = 1466) = 301.084, p < 0.001$$

Table 6. *Correlation of regional model variables 1985*

| | Temperature | Wind | Precipitation | Humidity | Total Clouds | Low Clouds | Elevation | NDVI | Previous Areas | Presence |
|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 1 | | | | | | | | | |
| Wind | 0.580** | 1 | | | | | | | | |
| Precipitation | 0.319** | 0.892** | 1 | | | | | | | |
| Humidity | -0.998** | -0.528** | -0.255** | 1 | | | | | | |
| Total Clouds | -0.970** | -0.381** | -0.078** | 0.984** | 1 | | | | | |
| Low Clouds | -0.778** | 0.028 | 0.342** | 0.819** | 0.907** | 1 | | | | |
| Elevation | -0.222** | -0.332** | -0.282** | 0.203** | 0.156** | 0.017 | 1 | | | |
| NDVI | 0.146** | 0.276** | 0.240** | -0.128** | -0.088** | 0.033** | -0.493** | 1 | | |
| Previous Areas | 0.181** | 0.199** | -0.055** | -0.186** | -0.206** | -0.190** | -0.019** | 0.119** | 1 | |
| Presence | -0.340** | -0.122** | -0.024 | 0.338** | 0.345** | 0.291** | 0.139** | -0.165** | -0.245** | 1 |

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

indicating that the model was able to distinguish between reindeer presence and pseudo-absence points. The model as a whole was able to explain between 18.6% (Cox & Snell R Square) and 24.8% (Nagelkerke R Square) of the variance in reindeer presence. The model was able to correctly classify 67.0% of the cases when these independent variables were used. The strongest predictor of reindeer presence was wind, and as wind increased the likelihood of reindeer presence increased by 1314 times (Table 7). Higher elevations (1.005) were also indicative of higher odds of reindeer occurrence, but it should be carefully interpreted as it is only marginally affecting the odds of reindeer presence. The NDVI variable was not found to be significant in the construction of the model and was removed in the second step. Increases in temperature (0.387), precipitation (0.806), and areas more often used (0.656) were all indicators of a lesser likelihood of reindeer presence.

Table 7. *Logistic regression for regional model 1985*

| **Variables** | **B** | **S.E.** | **Wald** | **Df** | **Sig.** | **Exp(B)** |
|---|---|---|---|---|---|---|
| Temperature | -0.950 | 0.080 | 142.802 | 1 | 0.000 | 0.387 |
| Wind | 7.181 | 1.056 | 46.228 | 1 | 0.000 | 1314.313 |
| Precipitation | -0.216 | 0.041 | 27.566 | 1 | 0.000 | 0.806 |
| Elevation | 0.005 | 0.001 | 23.649 | 1 | 0.000 | 1.005 |
| Previous Areas | -0.421 | 0.045 | 85.719 | 1 | 0.000 | 0.656 |
| Constant | -33.765 | 5.644 | 35.789 | 1 | 0.000 | 0.000 |

The NDVI variable was removed from the regional logistic regression model for 1985 since it was not significantly contributing to the explanation of reindeer presence and pseudo-absence cases. It was still of interest, however, to analyze the variable in order to understand the relationship of biomass and probability of reindeer presence more fully (Table 8). When NDVI was the only independent variable used in logistic regression, the model was able to correctly classify 58.3% of cases and could explain between 1.6% (Cox and Snell R Square) and 2.2% (Nagelkerke R Square) of the variance in reindeer presence. The odds ratio (ExpB = 0.089) for NDVI was less than one and indicated that the TRH was less likely to be present in areas with a higher abundance of biomass.

Table 8. *Influence of biomass on reindeer presence in 1985*

| **Variables** | **B** | **S.E.** | **Wald** | **Df** | **Sig.** | **Exp(B)** |
|---|---|---|---|---|---|---|
| NDVI | -2.424 | 0.584 | 17.232 | 1 | 0.000 | 0.089 |

An independent-samples t-test was conducted to compare the NDVI values (range of 0 - 1 after masking out of water and clouds) for 731 reindeer presence points and 726 reindeer pseudo-absence points. The mean values between utilized reindeer habitat (mean = 0.6046, SD = 0.08741) and non-utilized habitat (mean = 0.6323, SD = 0.0775) was found to be significant which indicates the differences did not occur just by chance (Table 9):

t (1436.508) = 6.401, p = 0.000 (two-tailed)

Table 9. *Independent-samples t-test for equality of NDVI mean values*

| Equal variance not assumed | T | Df | Sig. | Mean difference | Std. error difference | 95% Confidence Interval of the difference | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper |
| NDVI | 6.401 | 1436.508 | .000 | .0276924920 | .0043262660 | .0192060160 | .0361789680 |

The degree of magnitude of difference in the mean was calculated using Eta squared which represented the proportion of variance in NDVI that was explained by presence and pseudo-absence. Eta squared was 0.027 which indicated the magnitude of difference in the mean NDVI values between presence and pseudo-absence was very small.

4.3.2 Regional model for 2000

Results of the correlation analysis on environmental variables at the regional scale for 2000 reflected trends seen in the similar analysis conducted for 1985 (Table 10). Temperature was strongly negatively correlated with total clouds (-0.985), humidity (-0.979), and low clouds (-0.970), as well as being strongly positively correlated with precipitation (0.783). Temperature had a moderate positive correlation with wind (0.578) and all correlations were significant ($p < 0.01$). Wind was strongly positively correlated with precipitation (0.939) and strongly negatively correlated with total clouds (-0.706). In 2000, precipitation was strongly negatively correlated with total clouds (-0.866), and moderately negatively correlated with humidity (-0.642) and low clouds (-0.616) all of

Table 10. *Correlation of regional model variables 2000*

| | Temperature | Wind | Precipitation | Humidity | Total Clouds | Low Clouds | Elevation | NDVI | Previous Areas | Presence |
|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 1 | | | | | | | | | |
| Wind | 0.578** | 1 | | | | | | | | |
| Precipitation | 0.783** | 0.939** | 1 | | | | | | | |
| Humidity | -0.979** | -0.404** | -0.642** | 1 | | | | | | |
| Total Clouds | -0.985** | -0.706** | -0.866** | 0.933** | 1 | | | | | |
| Low Clouds | -0.970** | -0.397** | -0.616** | 0.995** | 0.927** | 1 | | | | |
| Elevation | -0.234** | -0.108** | -0.132** | 0.244** | 0.229** | 0.253** | 1 | | | |
| NDVI | 0.362** | 0.372** | 0.410** | -0.313** | -0.389** | -0.305** | -0.247** | 1 | | |
| Previous Areas | -0.074** | -0.020 | -0.081** | 0.070** | 0.061* | 0.050 | -0.022 | 0.131** | 1 | |
| Presence | -0.005 | -0.309** | -0.307** | -0.087** | 0.055* | -0.125** | -0.434** | -0.143** | 0.091** | 1 |

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

which are statistically significant ($p < 0.01$). Humidity, total clouds, and low clouds were strongly positively correlated with one another. Elevation shared weak correlations with all variables, and NDVI was weakly correlated with all variables other than a moderate positive correlation with precipitation (0.410) which was statistically significant ($p < 0.01$). Multicollinearity diagnostics were performed to further understand the results of correlation analysis. Very strong correlations in both positive and negative directions as well as preliminary logistic regression models with very high standard error values required this addition assessment. As a result of collinearity diagnosis, the variables humidity, total clouds, and low clouds were identified as being multicollinear through tolerance and variance inflation factors and therefore removed from both logistic regression and ENM in the 2000 regional models.

Backward Wald spatial lag logistic regression was performed to assess the impact of six independent variables on the probability of reindeer occurrence. The model contained three climate variables (temperature, wind, and precipitation), two physiographic variables (elevation and NDVI), and one spatial variable (areas previously used). Multicollinearity existed between wind and temperature variables. A preliminary model was constructed omitting temperature, but there was still evidence of multicollinearity seen in the standard error values higher than two for nearly all variables, and wind was omitted from the model after the first step as it was not found to be statistically significant. On this basis a second model was constructed which omitted the wind variable, which eliminated the presence of any multicollinearity issues, and the full model contained all the predictors as uniquely contributing and statistically significant variables:

$$x^2(5, N = 1510) = 851.393, p < 0.001$$

This indicated the model was able to successfully distinguish between reindeer presence and pseudo-absence points. The model as a whole explained between 43.1% (Cox & Snell R Square) and 57.5% (Nagelkerke R Square) of the variance in reindeer presence and pseudo-absence. When these independent variables were added to the model 84.9% of presence and pseudo-absence cases were classified correctly. The best predictor of reindeer presence was temperature and wherever temperature values were higher, reindeer were more than 17 times more likely to be there. If the areas had been previously used for summer concentration grounds, then there was a small increased likelihood of reindeer presence, and areas that had higher NDVI values, precipitation amounts, and elevations were all less likely to be places of reindeer occurrence (Table 11).

It was of interest to analyze the NDVI variable in order to understand the relationship of biomass and probability of reindeer presence more fully. When NDVI was the only independent variable used in logistic regression, the model was able to correctly classify 56.8% of cases and could explain between 2.0% (Cox and Snell R Square) and 2.7% (Nagelkerke R Square) of the variance in reindeer presence. The odds ratio (ExpB) of .025 for NDVI was less than one, which indicated that where there were higher values of biomass reindeer were 0.025 times as likely to occur (Table 12). This was a slightly weaker relationship than seen when modeled with other variables, yet it remained in the negative direction.

Table 11. *Logistic regression for regional model 2000*

| **Variables** | **B** | **S.E.** | **Wald** | **Df** | **Sig.** | **Exp(B)** |
|---|---|---|---|---|---|---|
| Temperature | 2.846 | 0.242 | 138.246 | 1 | 0.000 | 17.227 |
| Precipitation | -1.035 | 0.072 | 204.702 | 1 | 0.000 | 0.355 |
| Elevation | -0.038 | 0.002 | 240.253 | 1 | 0.000 | 0.963 |
| NDVI | -8.054 | 1.140 | 49.925 | 1 | 0.000 | 0.000 |
| Previous Areas | 0.139 | 0.041 | 11.358 | 1 | 0.001 | 1.149 |
| Constant | 7.636 | 1.064 | 51.478 | 1 | 0.000 | 2071.448 |

Table 12. *Influence of biomass on reindeer presence 2000*

| **Variables** | **B** | **S.E.** | **Wald** | **Df** | **Sig.** | **Exp(B)** |
|---|---|---|---|---|---|---|
| NDVI | -3.682 | 0.673 | 29.963 | 1 | 0.000 | 0.025 |

An independent-samples t-test was conducted to compare the NDVI values (range of 0 - 1 after masking out of water and clouds) for 761 reindeer presence points and 749 reindeer pseudo-absence points. The mean values between presence (mean = 0.3685, SD

= 0.0751) and pseudo-absence (mean = 0.3913, SD = 0.0830) was found to be significant which indicates the differences did not occur just by chance (Table 13):

$$t\ (1487.931) = 5.599,\ p = 0.000\ \text{(two-tailed)}$$

The degree of magnitude of difference in the mean NDVI values between presence and pseudo-absence was calculated using Eta squared. The result of 0.020 is indicative of a very small effect size.

Table 13. *Independent-samples t-test for equality of mean NDVI values (7-26-2000)*

| Equal variance not assumed | T | Df | Sig. | Mean difference | Std. error difference | 95% Confidence Interval of the difference | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper |
| NDVI | 5.599 | 1487.931 | .000 | .0228236040 | .0040766459 | .0148270201 | .0308201879 |

Due to availability of data, a second measure of biomass that was possible as a comparison of the region is on July 26, 2000, to the same region on August 11, 2000 (two consecutive passes over the same area made by Landsat 7 ETM+). An independent-samples t-test was conducted to compare the NDVI values (range of 0-1 after masking out of water and clouds) for 760 reindeer presence points and 747 reindeer pseudo-absence points. The mean values between presence (mean = 0.4509, SD = 0.07912) and pseudo-absence (mean = 0.4694, SD = 0.0920) was found to be significant which indicates the differences did not occur just by chance (Table 14).

Table 14. *Independent-samples t-test for equality of mean NDVI values (8-11-2000)*

| Equal variance not assumed | T | Df | Sig. | Mean difference | Std. error difference | 95% Confidence Interval of the difference | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper |
| NDVI | 4.175 | 1464.267 | .000 | .0184674693 | .0044236155 | .0097901696 | .0271447690 |

## 4.4 Identification of Habitat-wide Niche Requirements

### 4.4.1 Habitat-wide ENM for 1985

This first output of the Maxent model was the graphed receiver operating curve (ROC) which was obtained by plotting sensitivity on the y-axis and specificity on the x-axis (Elith, et al., 2011). Sensitivity was interpreted as the true positive, or presence, rate, and specificity was the true negative rate, or in this case when we had presence-only data it was referred to as a true random rate. Maxent ran tests on random points in which it attempts to accurately classify the point as either positive or negative, and the results of accurately or inaccurately classifying the test point is plotted on a graph. The points were then connected and this curve is the ROC. The area under the curve (AUC) was interpreted as the probability that a random positive or a random negative was correctly classified by the model. Random prediction was capable of predicting an ROC with an

AUC of 0.5. The ecological niche model built using reindeer presence points and the independent environmental variables (temperature, precipitation, wind, total clouds, low clouds, humidity, elevation, and previously used areas) was able to identify full niche requirements for the TRH summer grounds better than a random model as seen by the AUC of 0.966 (Figure 25).

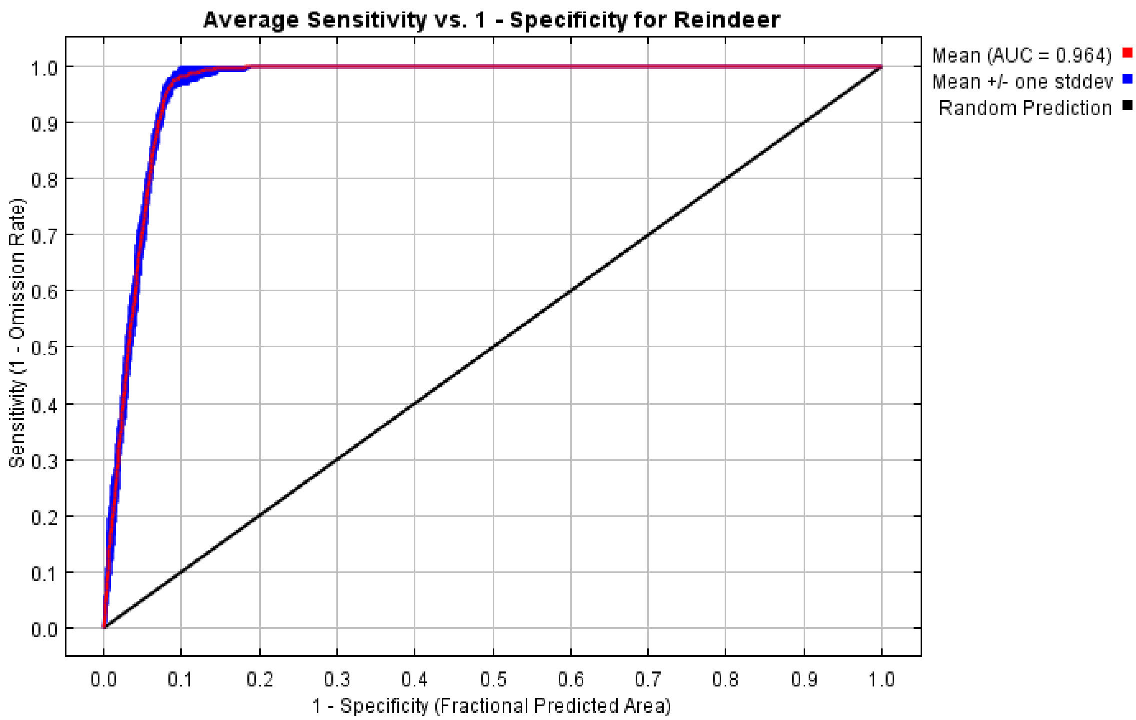


*Figure 25*. Maxent AUC for 1985

Further clarification of the model was provided by marginal response curves generated with the presence records and adjusted only for a select variable and keeping all other variables at their average value. The second set of response curves model the niche environment with only a single variable and the presence records, and these response curves were easier to interpret than similar curves that modeled with all other variables at their average value which suggested that some variables are most likely correlated. Reindeer response ranges that were not easily identified by the marginal response curves were substantially more defined using the latter technique (Figure 26).

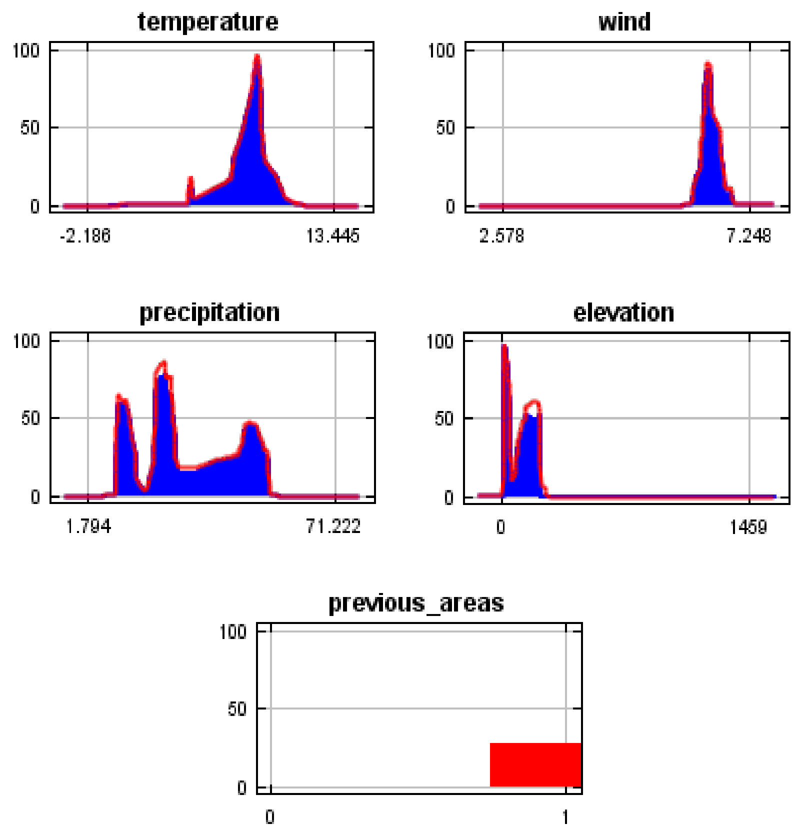


*Figure 26.* Maxent response curves of single variables for 1985

The range of wind speeds for the most probable areas of occurrence ranged from 6.1 - 6.75 m/sec (previously 6.1 - 7.1 m/sec). Areas that had high probability of occurrence when elevation was the single modeled variable were refined from 0 - 250 meters to 0 - 210 meters. When temperature was the only variable in the model, the highest probability areas maintained the same range of 7° - 9° C. The response curve for precipitation contained three peaks of which the first two were the most narrowly defined. This means that although few reindeer responded to precipitation amounts of 10 - 15 mm and 20 - 25 mm, they were responding much more strongly to areas with these characteristics.

Estimates of relative contributions of all variables to the Maxent model were made using training presence locations and background data of climate and physiographic variables. Wind was calculated to be the most significant variable in the model, contributing 57.6% to the explanation of what areas have the highest probability. Temperature (21.1%) and precipitation (18.5%) were also highly contributing variables. Elevation (0.7%) was the least contributing variable in the construction of the niche model (Table 15).

Maxent also created visualizations of the model in order to analyze where the areas of highest probability occurred. The average output of the five replicate models created is shown in Figure 27. The high probability areas of occurrence correlated with the habitat selected by reindeer in the summer of 1985. The area considered to meet the niche requirements for the reindeer was larger than the observed realized niche of 1985, which is often the case (Elith et al., 2011). This indicates the reindeer were not utilizing all available habitats that would have met their requirements in terms of the variables used for the model.


*Figure 27*. Areas of probable reindeer occurrence in 1985

Table 15. *Analysis of variable contributions in habitat-wide model 1985*

| Variable | Percent contribution |
|---|---|
| Wind | 57.6 |
| Temperature | 21.1 |
| Precipitation | 18.5 |
| Previous Areas | 2.1 |
| Elevation | 0.7 |

4.4.2 Habitat-wide ENM for 2000

The area under the curve (AUC) was interpreted as the probability that a random positive or a random negative was correctly classified by the model. Random prediction was capable of predicting an ROC with an AUC of 0.5. The ecological niche model built using reindeer presence points and the independent predictor variables (temperature, precipitation, wind, total clouds, low clouds, humidity, elevation, and previously used areas) was able to identify full niche requirements for the TRH summer grounds better than a random model as seen by the AUC of 0.963 (Figure 28).

The next useful outputs from Maxent were the response curves produced for each variable. The response curves showed how each Maxent prediction was affected by the variable when all other variables remain at their average values. Probability of reindeer occurrence was highest in elevations ranging from 0 - 250 meters, but they were not responding very strongly (less than 9% probability). Reindeer in 2000 responded, although weakly, to the precipitation variable in this modeling framework within the

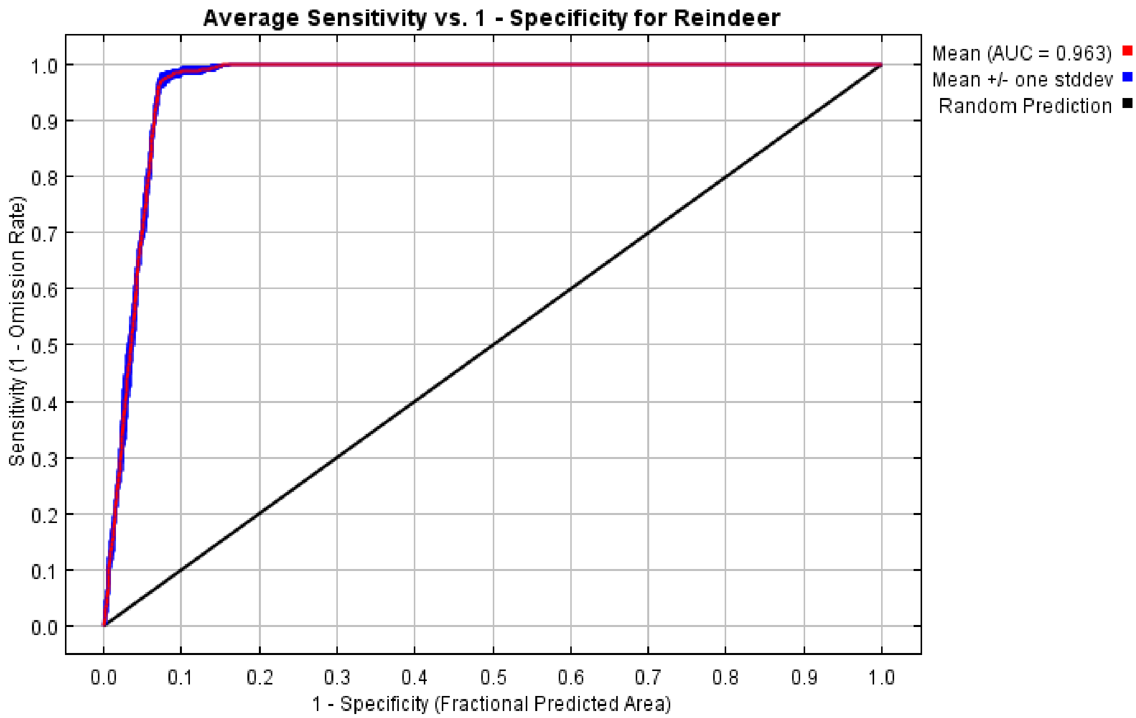


*Figure 28*. Maxent AUC for 2000

range of 18 - 29.5 mm. A weak response of reindeer to temperature was also seen within the range of 6° - 8.5° C. The variable wind produced weak responses by reindeer within the range of 5.5 - 6.75 m/sec.

Response curves generated for reindeer presence using only a single variable at one time in the model produced more interpretable results suggesting that the variables are correlated (Figure 29). The range of elevation with higher probability of occurrence was narrowed from 0 - 250 meters to 0 - 210 meters. The model using precipitation as the only variable was more finely tuned (18 - 24 mm) than model using all variables at their average value while adjusting precipitation values (18 - 29.5 mm). When using temperature in the single variable model, the range maintained the same limits (6° - 8.5° C), and this was also the case when wind is the only variable modeled (5.5 - 6.75 m/sec).

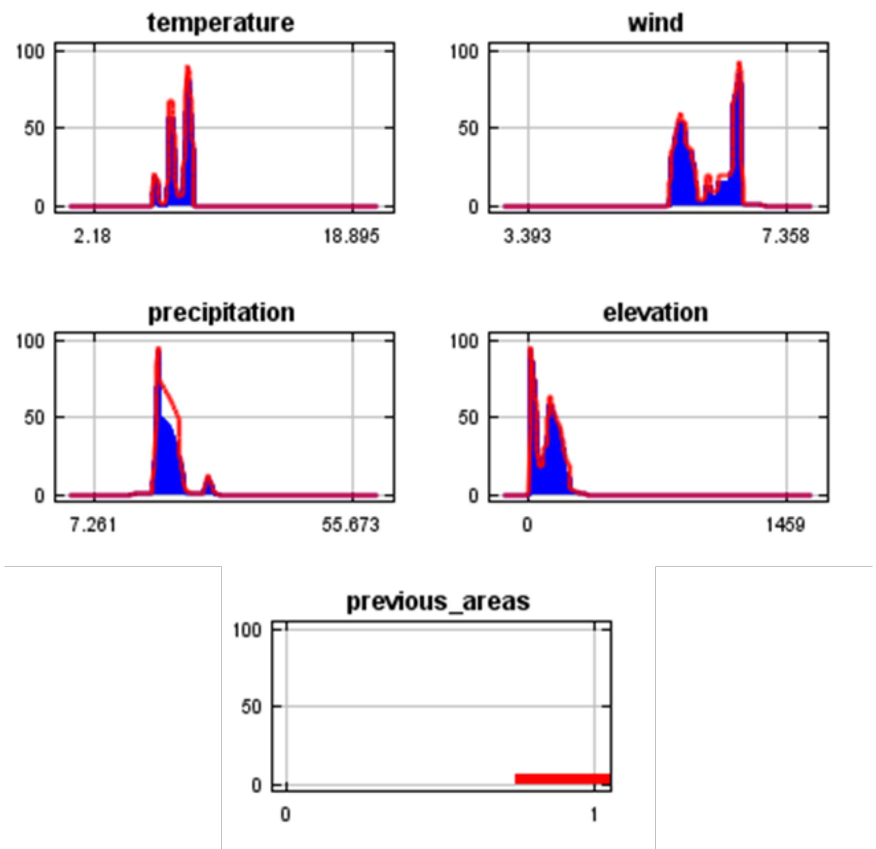


*Figure 29*. Response curves of single variables for 2000

Estimates of relative contributions of all variables to the Maxent model were made using training presence locations and background data of environmental variables. The niche model for 2000 was most contributed to by the variable previous areas (32.4% Table 16). Temperature (18.2%) and total clouds (18.1%) also contributed strongly. The least contributing variables were elevation (0.1%) and humidity (1.3%). Maxent created visualizations of the model (i.e. where the areas of highest probability occurred). The cumulative output of the five replicate models created is shown in Figure 30. The areas of high occurrence probability correlated with the habitat selected by reindeer in the summer of 2000. The area considered to meet the niche requirements for the reindeer was larger than the observed realized niche of 2000, which is often the case (Elith et al., 2011). This indicated the reindeer were not utilizing all available habitats that would have met their requirements in terms of the variables used for the model. Habitat available with higher probabilities of meeting the niche requirements of the TRH were located in between the Puro-Pyassina and Logata/Upper Taimyra concentrations and extends northwards.

Table 16. *Analysis of variable contributions in habitat-wide model 2000*

| **Variable** | **Percent contribution** |
|---|---|
| Previous areas | 35.1 |
| Temperature | 32.2 |
| Precipitation | 16.5 |
| Wind | 15.9 |
| Elevation | 0.4 |

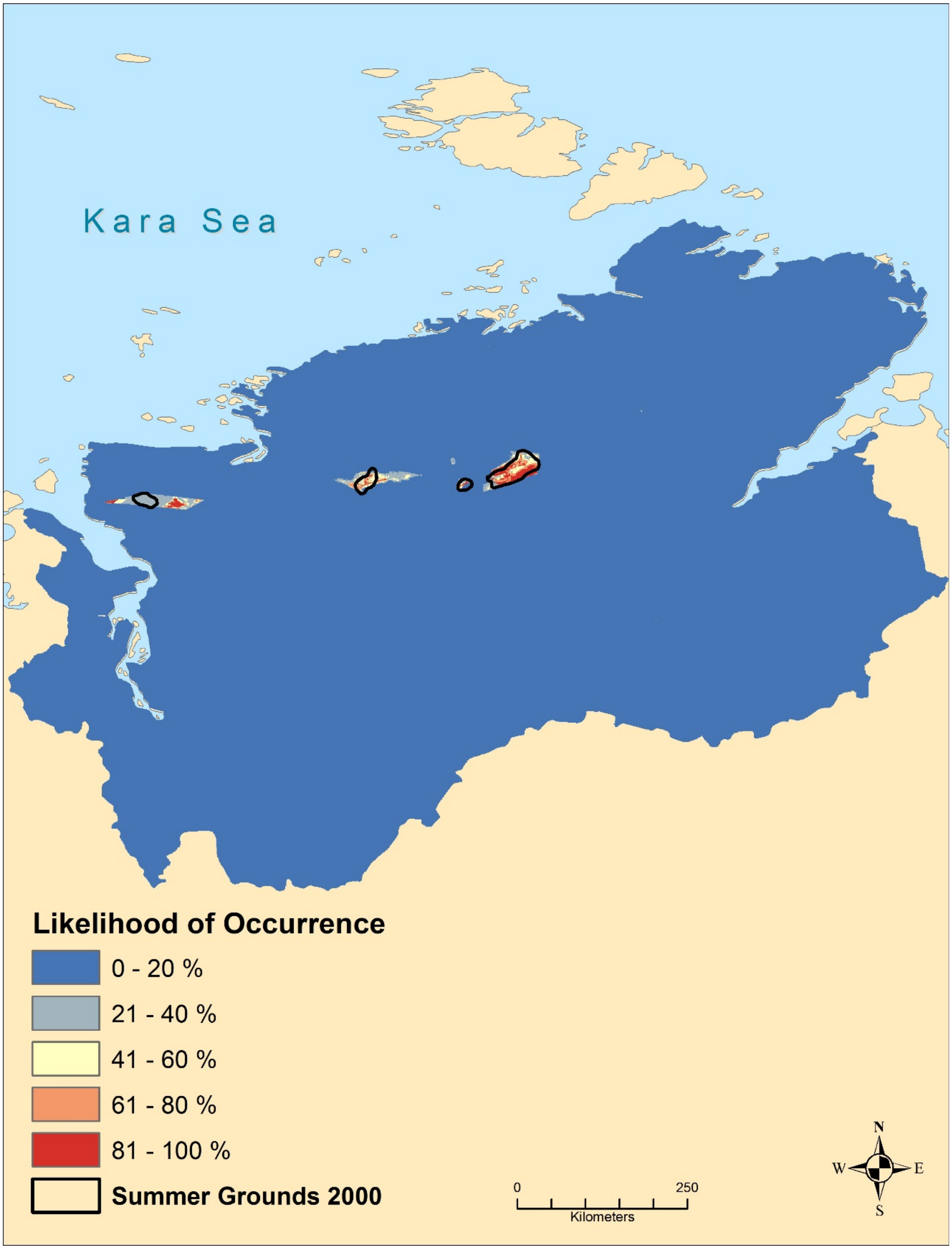


*Figure 30*. Areas of probable reindeer occurrence in 2000

## 4.5 Identification of Regional Niche Requirements

### 4.5.1 Regional ENM for 1985

The area under the curve (AUC) was interpreted as the probability that a random positive or a random negative was correctly classified by the model. Random prediction was capable of predicting an ROC with an AUC of 0.5. The ecological niche model built for 1985 using reindeer presence points and the independent physiographic and climate variables temperature, precipitation, wind, elevation, NDVI and previously used areas, was able to identify full niche requirements for the TRH summer grounds better than a random model as was evident with an AUC value of 0.890 (Figure 31).

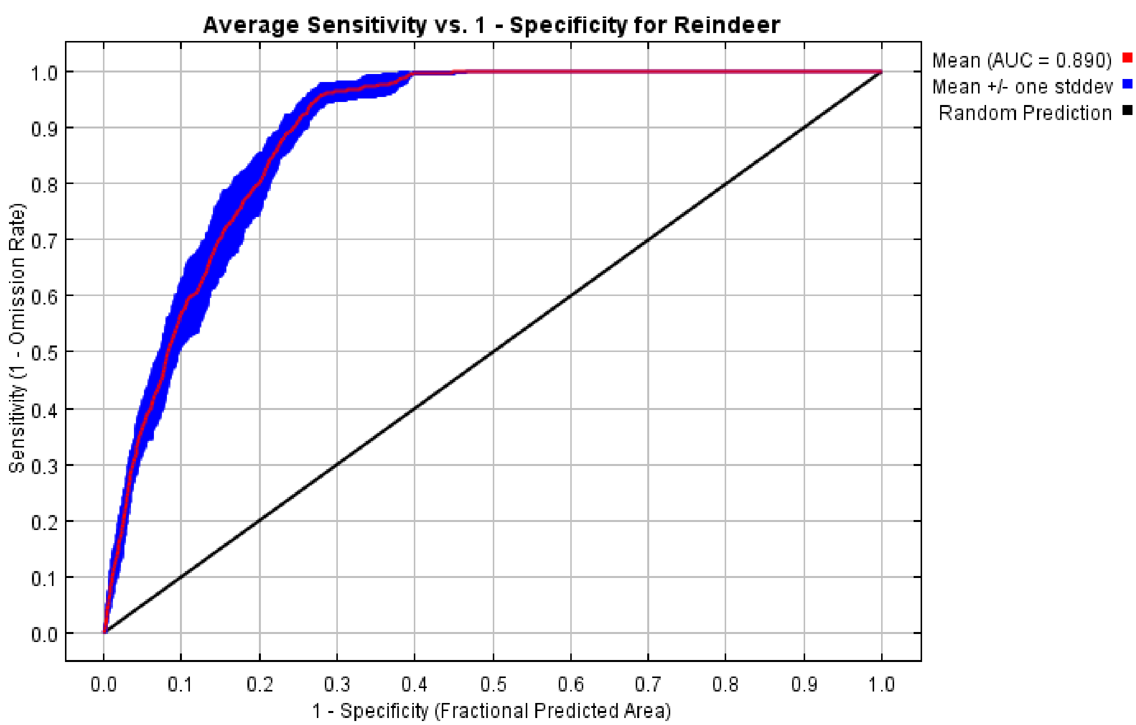


*Figure 31*. Maxent AUC for regional model for 1985

The first set of response curve showed how the logistic prediction changed when a single variable was varied, while all others were at their average value, provided indication that the variables were correlated; these curves are quite broad and multi-peaked. The response curve for reindeer and temperature showed reindeer responding (having a higher probability of being present) to temperatures between 7.25° and 10.75° C. Reindeer were more probable to be occupying areas with wind speeds between 6.3 and 6.7 m/sec. The response curve for precipitation did not provide a defined range, but suggested that areas with less than 25 mm were more suitable for Taimyr wild reindeer in this region during 1985, and reindeer were more likely to be present in areas below 225 meters in elevation. Response curves produced using this method did not provide much insight to the likelihood of reindeer presence for either vegetation or areas previously used.

The second set of response curves modeled the response of reindeer when only a single variable was used at one time which can be more informative when variables are correlated. These models had more definitive ranges as were seen in the response curve generated for reindeer and temperature (Figure 32). It was seen here that the reindeer had a much higher probability of presence in areas within 8° - 8.5° C. Areas with wind speeds of 6.5 - 6.7 m/sec had the highest likelihood of reindeer presence, and areas that received a mean July precipitation of 13 - 16 mm and 20 - 25 mm were more likely utilized areas for the TRH. Reindeer were more likely found in areas below 225 meters, areas with NDVI values between 0.5 - 0.6, and if the area had been used at least twice, and up to five times, by the TRH during previous summers.

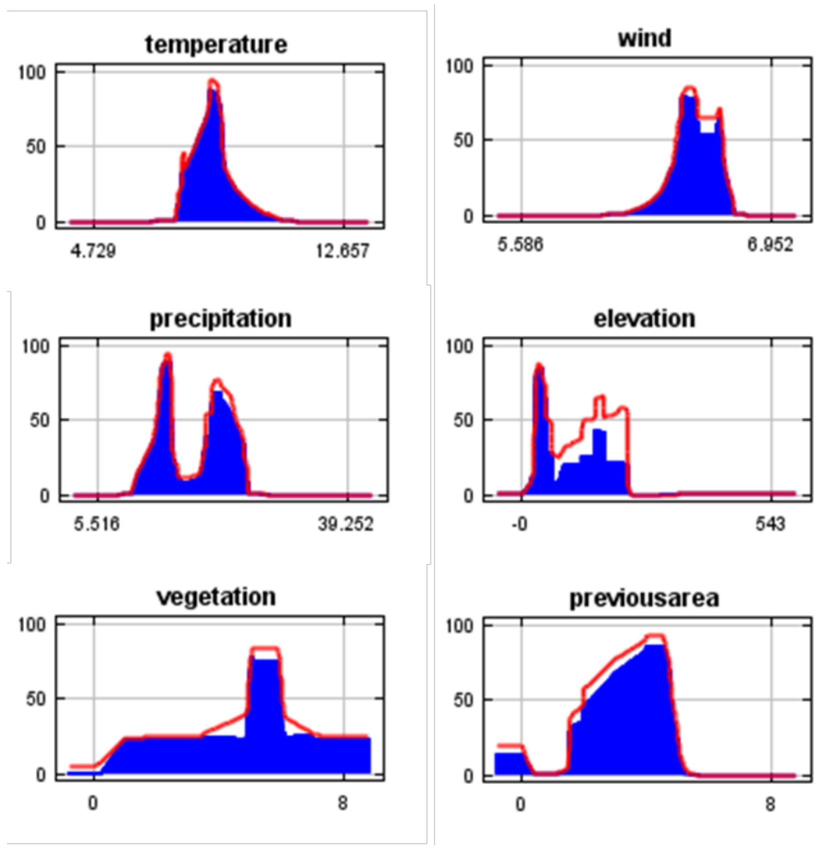


*Figure 32*. Response curves of single variables for regional model for 1985

The analysis of variable contributions table provides estimates of the relative contributions of each variable in the Maxent model (Table 17). Wind (44.4%) and temperature (34.9%) were the most important variables contributing to higher probabilities of reindeer presence. Precipitation (11%), and NDVI (7.9%) had a more limited contribution to the model. Areas previously used and elevation were not found to be a significant variables in the model, and contributed less than a combined 3% to the Maxent model.

Table 17. *Analysis of variable contributions in regional model 1985*

| **Variable** | **Percent contribution** |
|---|---|
| Wind | 44.4 |
| Temperature | 34.9 |
| Precipitation | 11.0 |
| NDVI | 7.9 |
| Elevation | 1.2 |
| Previous Areas | 1.2 |

Maxent created visualizations of the model in order to analyze where the areas of highest probability occurred. The cumulative output of the five replicate models created is shown in Figure 33. The high probability areas of occurrence correlated with the areas selected by reindeer in the summer of 1985, but the area considered to meet the niche requirements for the reindeer was smaller than the observed realized niche of 1985 which is not often the case (Elith et al., 2011). This was especially seen in the area used by the Tareya concentration where low probabilities were predicted by Maxent. This indicated that the reindeer were concentrated on grounds in 1985 that did not meet their ecological niche requirements or that there was not enough habitat available to meet the niche requirements for the number of reindeer that concentrated here during 1985.

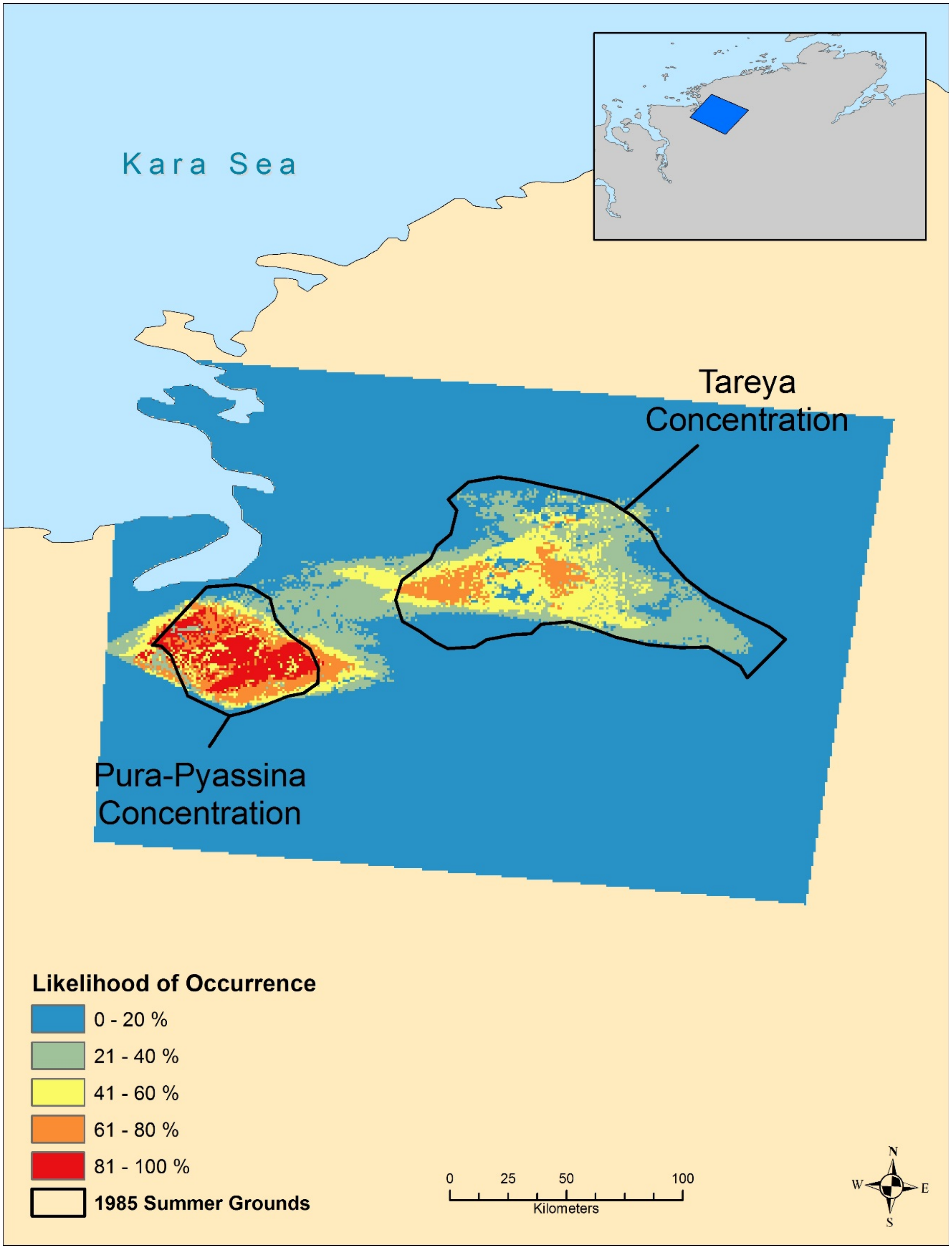


*Figure 33*. Regional areas of probable reindeer occurrence for 1985

4.5.2 Regional ENM for 2000

This first output of the Maxent model was the graphed receiver operating curve (ROC) which was obtained by plotting sensitivity on the y-axis and specificity on the x-axis (Elith et al., 2011). Random prediction was capable of predicting an ROC with an AUC of 0.5. The ecological niche model built for 2000 using reindeer presence points and the independent physiographic and climate variables temperature, precipitation, wind, elevation, NDVI and previously used areas, was able to identify full niche requirements for the TRH summer grounds better than a random model as seen by the AUC value of 0.978 (Figure 34).

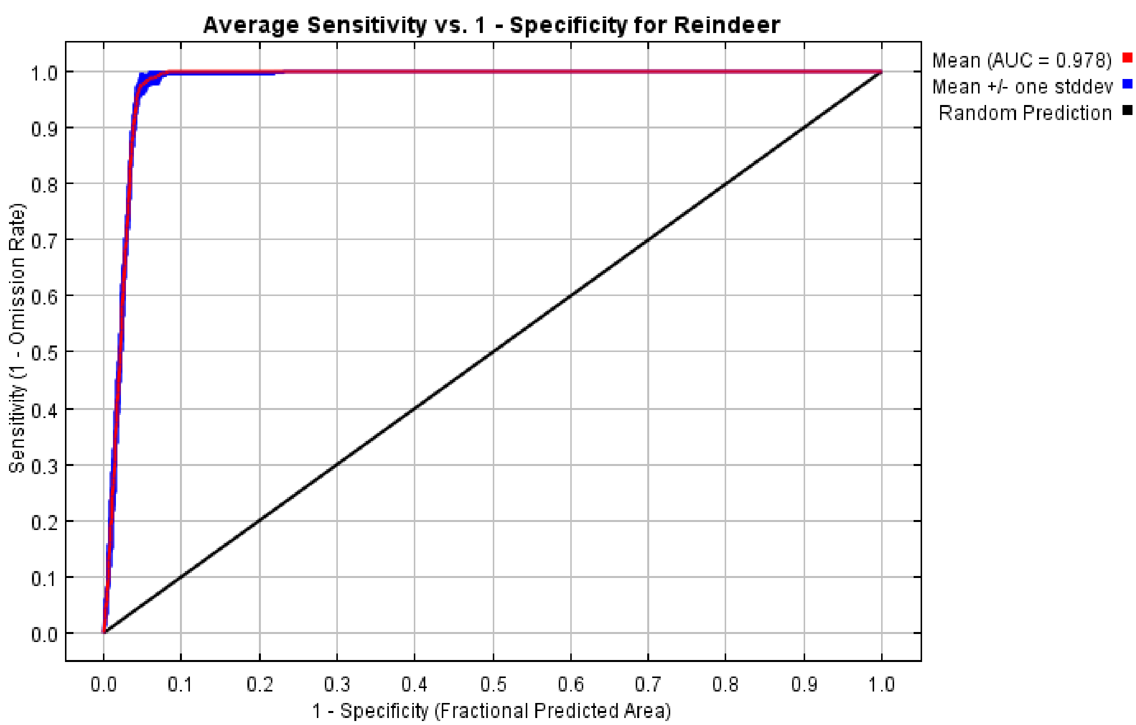


*Figure 34*. Maxent AUC for regional model for 2000

As with previous models built using similar physiographic and climate variables, the first set of response curves indicated that the variables were correlated generating response curves that were fairly difficult to interpret. The response curve generated by varying a single variable and keeping all others at their average for reindeer response to temperature was signifying that reindeer were more likely found in areas with temperatures below 7.5° C, but the lower end of the range was indeterminable. When the variable wind was adjusted, the response curve had a range of higher probability of reindeer occurrence between 6.5 and 6.7 m/sec. Areas that received a mean July precipitation amount of 24 mm or less were likely utilized areas. When all variables were kept at their average values and elevation was varied, the response curve indicated that reindeer most likely opted for areas below 150 meters, and the response curve for NDVI when this method was utilized was unable to indicate any discernable range.

The next set of response curves were generated by using only a single variable in the construction of the model. As a result of some existing correlation between variables, these response curves were more easily interpreted and provided more refined ranges within the variables wherein higher probabilities of reindeer occurrence can be seen (Figure 35). In July 2000, areas with mean temperatures of 7° - 7.25° C and mean wind speeds of 6.55 - 6.65 m/sec were the most probable areas for the Puro-Pyassina to inhabit. A much more informative response curve was generated for reindeer response to precipitation when precipitation was the only variable used, and the most probable areas for reindeer presence were between a July mean of 22 - 23 mm. The TRH Puro-Pyassina concentration had a higher probability of occupancy in areas below 50 meters elevation, in areas with NDVI values between 0.3 - 0.4, and in areas previously observed as summer ground habitat ranging from 6 - 8 times.

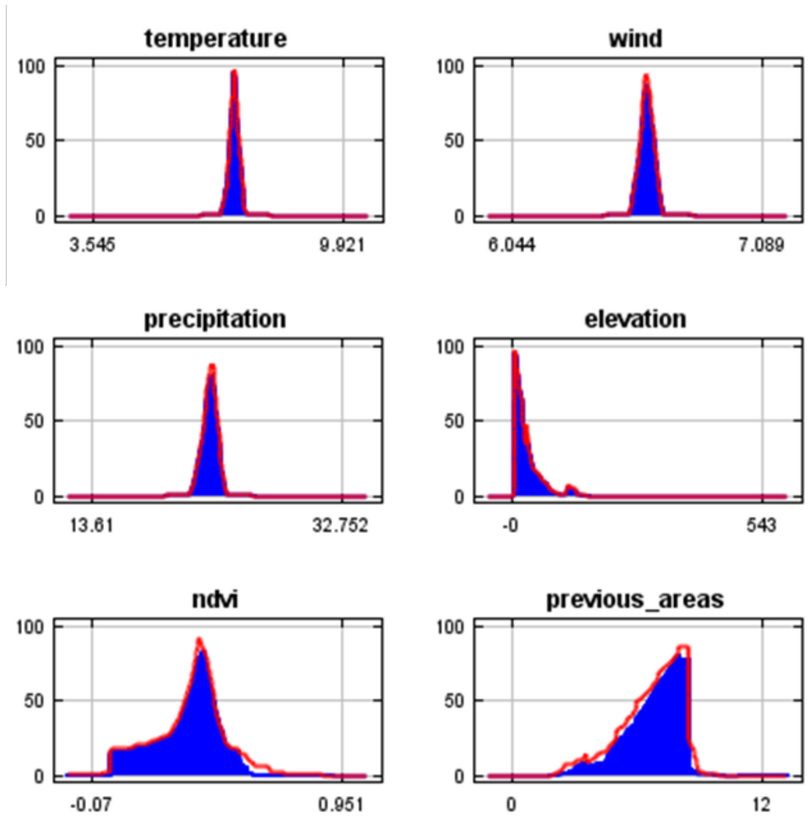


*Figure 35*. Response curve of single variables for regional model for 2000

The results of analysis of variables' contributions to the regional model for 2000 showed that temperature (38.0%), wind (31.5%), and precipitation (28.7%) were the most significantly contributing variables (Table 18). In fact, these three variables accounted for 98.3% of the model's ability to identify the ecological niche requirements for the TRH. The least significant contributions to the model were made by areas previously used, elevation, and NDVI which combined for less than 2% of all variable contributions to the model.

Table 18. *Analysis of variable contributions in regional model 2000*

| **Variable** | **Percent contribution** |
|---|---|
| Temperature | 38.0 |
| Wind | 31.5 |
| Precipitation | 28.7 |
| Elevation | 1.3 |
| Previous Areas | 0.4 |
| NDVI | 0 |

The visualized average output of the 5 replicate models created is shown here (Figure 36). The high probability areas of occurrence correlated with the habitat selected by the TRH in 2000. The area considered to meet the niche requirements for the reindeer was smaller than the observed realized niche of Pura-Pyassina/Tareya in 2000, which is most often times not the case when implementing Maxent modeling (Elith et al., 2011). This ecological niche habitat was then very small and the Pura-Pyassina concentration was extremely large at this time (445, 000), and thus indicated they were utilizing areas during 2000 that did not meet their requirements. There was very little existing area outside of where they did aggregate that had climate and physiographic conditions meeting more than 50% of their niche requirements given these variables.

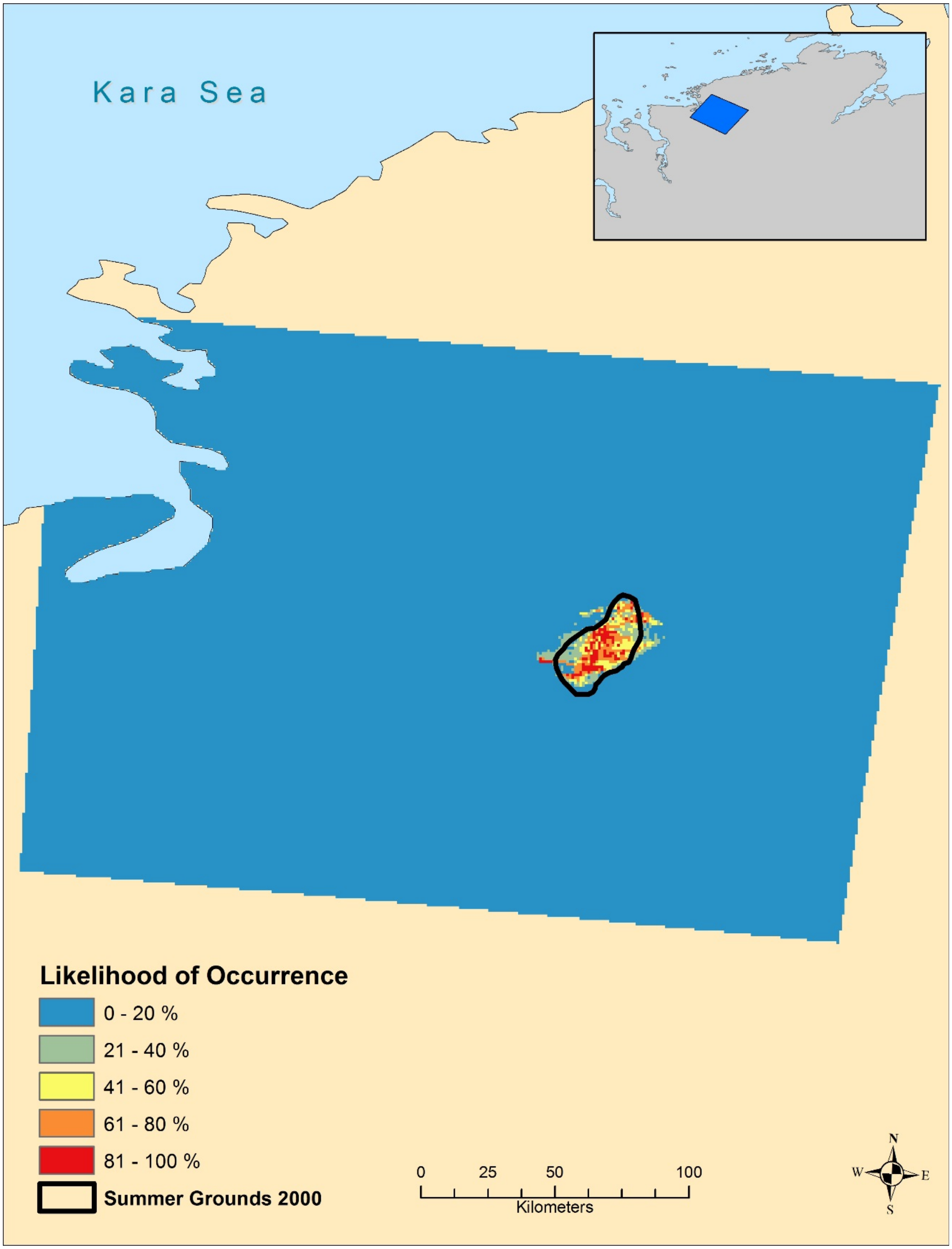


*Figure 36*. Regional areas of probable reindeer occurrence 2000

# CHAPTER 5

# DISCUSSION AND CONCLUSIONS

The final chapter provides discussions of all findings resulting from spatioanalytic methods and modeling techniques, and summary tables of model outputs are presented. This study has added to the existing knowledge base through the accomplishment of mapping and analyzing the spatial dynamics of TRH summer concentrations between 1969 and 2009 using various spatioanalytic methods, identifying environmental factors and their significance that influence the TRH's selection of summer grounds, and creating a regional model for a frequently utilized area of summer concentration grounds that incorporates climate, elevation, vegetation, and spatially and temporally lagged variables. The chapter also states conclusions and discusses the limitations encountered during the research process. Finally, this chapter includes suggestions made as to the direction of future TRH research.

## 5.1 Discussion

The population of reindeer/caribou has been declining in 80% of the herds throughout the circum-Arctic region (Gunn et al., 2009). It is estimated that the TRH has lost more than 30% of its population since the comprehensive survey of 2000 (Petrov et al., 2012; Kolpashchikov et al., 2009) as numbers dropped from an observed high of 1 million animals to below 700,000. As their population plummets, *R. tarandus* are utilizing less overall area for summer concentration grounds compared to years prior to 2000. Evidence of this trend is observable in the increased population density during the summer of 2000 and for both of the following observed years (2003 and 2009).

Empirical evidence has revealed that along with smaller areas being utilized during a single summer that smaller areas are being revisited from year to year. Range overlap percentages drastically reduced in 2000, 2003, and 2009 from the higher rates seen during the three decades prior indicating a reduction in spatial fidelity displayed by the TRH (Figure 17).

The percentages of *range overlap* calculated for summer concentration grounds from 1999 – 2000, 2000 – 2003, and 2003 – 2009 were well below the mean value calculated for all years of observation and represented the lowest three values calculated (i.e. 2.6%, 2.3 %, and 1.6% respectively). Although there were multi-year gaps in the data, the low values should not be considered less indicative of spatial trends and simply dismissed. We have similar gaps of three years between 1972 – 1975 and 1975 – 1978 but have observed range overlap to be almost 10% and 20% respectively. We also see a six year gap from 1993 – 1999 and have observed the TRH reusing the same 17% of land despite the substantial multi-year gaps in observations.

Results of centrographic spatioanalytics have confirmed that spatial distribution of summer concentration mean centers does have properties of a concentrated distribution, indicative of spatial fidelity, similar to observations for spring calving grounds (Meerdink & Petrov, 2012). The mapping and analysis of annual concentration centroids reveals that not only is there clustering around the overall geographic mean center of the summer range (Figure 16), but it also identifies concentration mean centers of 2000, 2003, and 2009 as the most dispersed points. The mean centers for these summers are clearly moving to the east and north of the summer range geographic mean center. This is an important revelation as it is in partial disagreement with hypothesis of ENARI researchers maintaining that the summer grounds are moving to the east and south (Petrov et al., 2012). Researchers should take this trend into consideration in order to most accurately identify and predict future habitats of the TRH as management strategies are formulated.

Summer concentration ground expansion is clearly occurring to the north and east of areas detected to be those areas most frequently used by wild reindeer (Figure 23). The semi-regular summer surveys have observed that the Yenisei concentration, forming regularly in far western Taimyr, has been losing population since 1991 and the populations of the Puro-Pyassina, Tareya and Upper Taimyra concentrations experienced growth throughout the 1990s and 2000s (Figure 24). Furthermore, the eastern summer habitat has seen the development of new concentrations throughout the 1990s and 2000s approaching the western side of Lake Taimyr. This spatiotemporal shifting populous is evidence that the summer grounds and a great percentage of the TRH are in fact shifting to the east. When this evidence is coupled with evidence derived from centrographic spatioanalytics, it is clear that shifting is also happening towards the north (Figure 16).

With growing population in the 1970s - 2000s, concentrations were distributed further east and north. Kolpashchikov, Yakushkin, and Kokorev (2003) concluded that eastern concentrations now constitute the majority of TRH population amounting to about 70% of the total. Historically, the largest concentrations were the Puro-Pyassina in central Taimyr. Together with the Yenisei concentrations they are consistently present in the record since the first aerial survey in 1969. Whereas western TRH concentrations were the largest in 1969 (about 300,000), their population declined to 150,000 by 2000, and to just over half that amount only nine years later to become surpassed by central and eastern concentrations. The Tareya in central Taimyr was also first observed in 1969 and included up to 200,000 reindeer in 1986, but later declined to 180,000 - 190,000 in 2003 and 2009. The Upper-Taimyra concentration was first identified in the mid-1980s, and the Logata concentration was first surveyed in 2000, both in central-eastern Taimyr. The Upper-Taimyra had a population of roughly 200,000, and the Logata contained over 60,000 animals in 2009.

Exploratory analysis of spatial distributions of the TRH summer grounds across varied elevations has provided a valuable starting point from which future methods may be developed. These initial observations revealed that the TRH selected areas lower in elevation more often (Figure 22), and a trend that the TRH selected summer grounds with higher elevations in the most recent past (i.e. the 2000s; Figure 20). This can be attributed to the shifting of summer grounds towards Lake Taimyr in the east. As the TRH move east, they utilize more area near and within the Byrranga Mountains more frequently. Perhaps an indirect cause of the utilization of grounds higher in elevation is increased insect harassment as was stated by scientists during the 2000 census (Kolpashchikov, Yakushkin, & Kokorev, 2003). Due to a lack of existing data, it is not yet fully known why this trend exists and further analysis by future studies may provide more detailed understandings.

Quantitative results derived from spatioanalytic methods have established that significant spatial fidelity has been exhibited by the TRH over 40 years of observations.

Four unique areas have been identified as areas the TRH have the tendency to return to form summer concentrations (Figure 19). Historically the concentrations were identified by the major rivers they formed near; however, each year the TRH utilized slightly different areas and no specific area could ever be pointed to on a map and said this is the Logata, the Yenisei, the Tareya, or the Pura-Pyassina. The results of spatioanalytics performed in this study have established these frequently used areas and identified them by name.

The results obtained in this study through multiple spatioanalytic methods have also identified that observations made since the 2000 census reveal six trends: (1) population of the Taimyr wild reindeer herd is decreasing as a whole, (2) western concentrations are losing animals while central and eastern concentrations are emerging and getting larger, (3) summer concentrations are shifting to the east and to the north expanding the area of utilized habitat to areas not previously observed to have been utilized, (4) TRH are reusing smaller percentages of their range from year to year, (5) summer concentrations are becoming more compact and densely populated, and (6) the areas being utilized for summer concentration grounds are rising in elevation.

The most recent comprehensive aerial survey conducted on TRH summer distribution and population was done in 2000, which has proven to be a pivotal year in herd dynamics as previously demonstrated (Kolpashchikov, Yakushkin, & Kokorev, 2003; Petrov et al., 2012). The data accumulated during this census has been of great utility as we address the *factors* that have contributed to this pivotal time of population dynamics and spatial distribution of wild reindeer. A regional focus area has been selected from the four identified areas of most frequent use. The Pura-Pyassina region (Figure 19), within the central portion of the summer range, was selected due to the herd's tendency to summer here and the occurrence of regional population growth despite overall TRH population decline. Logistic regression and ecological niche modeling of reindeer presence/pseudo-absence data, climate data and physiographic characteristics of the summer range and the Pura-Pyassina regional area identified what specific variables influence the TRH's selection of summer grounds and to what degree these variables do so.

Habitat-wide modeling conducted for TRH summer grounds and reindeer locations provided empirical evidence never before established for factors impacting the world's largest wild reindeer herd (Table 3 & 19). In July 1985, the most predictive factor of high probability of reindeer occurrence was higher wind speed. Areas with increased wind speeds were 140 times more likely to be summer concentration areas, and these conditions would provide relief from insect harassment. Another strong predictive factor of high probability of reindeer presence was whether or not the area had been previously utilized as summer concentration ground. In addition, logistic regression modeling with the spatial lag variable was able to confirm spatial fidelity, indicating that the TRH was 26 times more likely to be present in areas previously used for summer grounds than in areas that had not before been observed to be summer habitat during previous years. Lower temperatures also indicated higher probability of occurrence as *Rangifer* move to find relief from summer heat.

Table 19. *Summary of logistic regression models' odds ratios (expB)*

| | **Habitat-wide** | | **Regional** | |
|---|---|---|---|---|
| **Variables** | **1985** | **2000** | **1985** | **2000** |
| Temperature | 0.660 | 1.643 | 0.387 | 17.227 |
| Wind | 140.289 | n/a | 1314.313 | n/a |
| Precipitation | 0.877 | 0.865 | 0.806 | 0.355 |
| Elevation | 0.997 | .998 | 1.005 | 0.963 |
| NDVI | n/a | n/a | 0.089* | 0.025* |
| Previous Areas | 26.715 | 9.338 | 0.656 | 1.149 |

*NDVI modeling was conducted using it as the sole variable

The identification of environmental and climate factors of July 2000, that best predicted high probabilities of reindeer occurrence were similar to and different from those of 1985 (Table 5 & 19). Similarly, a predictor of high probability of reindeer occurrence in 2000 was whether the area had been previously used by the TRH as summer concentration habitat. This is interesting because according to spatioanalytic measures, during the summer of 2000, the TRH exhibited more spatial shift rather than fidelity. There was substantial shift to the east that summer, but it is also important to remember that over 445,000 reindeer were densely populating the Pura-Pyassina and Tareya regions which has been frequently used since ENARI observations began. This meant at least half of the presence points used in the model would have been from this one concentration, and would have been classified as being in previously used areas which is perhaps reflected in the logistic regression output.

Different from the 1985 habitat-wide model, the 2000 model did not find wind to be significant, and found that increased temperature had an opposite effect than in 1985. Warmer temperatures indicated higher probabilities of reindeer occurrence. Kolpashchikov, Yakushkin, and Kokorev (2003) state that the summer of 2000 was exceptionally warm and this may have been incorporated into the model. Wind was not found to be a significant variable to the model explanation, and it is not fully known why this was the case. It is possible that the extremely small areas of summer concentrations during 2000 provided a very limited range of wind speeds, thereby limiting its ability to make a significant impact on the probability of reindeer occurrence.

The ENM constructed for July 1985, using the same variables presented a very similar scenario to that described by logistic regression (Table 15 & 20). Wind was found to be the most significant variable in the modeling framework contributing 57.6% to the overall performance, and temperature (21.1%) was the second most significant variable to model performance. The major difference seen in this type of model was the difference in contribution made by the variable previous areas (2.1%) to the overall model. A key difference in logistic regression modeling and ENM is that logistic regression requires absence, or in this case pseudo-absence, data to be an input in the model, and this is perhaps an explanation of the different magnitudes of importance of spatial fidelity in the output of the models. Even so, the contribution of wind, temperature, and areas previously used combined explains over 79% of the models ability to accurately predict niche areas of summer concentration grounds.

Table 20. *Summary of variable contributions in ENM*

| | **Habitat-wide** | | **Regional** | |
|---|---|---|---|---|
| **Variables** | **1985** | **2000** | **1985** | **2000** |
| Temperature | 21.1% | 32.2% | 34.9% | 38.0% |
| Wind | 57.6% | 15.9% | 44.4% | 31.5% |
| Precipitation | 18.5% | 16.5% | 11.0% | 28.7% |
| Elevation | 0.7% | 0.4% | 1.2% | 1.3% |
| NDVI | n/a | n/a | 7.9% | 0% |
| Previous Areas | 2.1% | 35.1% | 1.2% | 0.4% |

Table 21. *Summary of ENM variables' optimal ranges*

| | **Habitat-wide** | | **Regional** | |
|---|---|---|---|---|
| **Variables** | **1985** | **2000** | **1985** | **2000** |
| Temperature | 7° - 9° C | 6° - 8.5° C | 8° - 8.5° C | 7° - 7.25° C |
| Wind | 6.1 - 6.7 m/sec | 5.5 - 6.7 m/sec | 6.5 - 6.7 m/sec | 6.5 - 6.6 m/sec |
| Precipitation | 10 - 25 mm | 18 - 24 mm | 13 - 25 mm | 22 - 23 mm |
| Elevation | 0 - 210 m | 0 - 210 m | 0 - 225 m | 0 - 50 m |
| NDVI | n/a | n/a | 0.5 - 0.6 | 0.3 - 0.4 |
| Previous Areas | n/a | n/a | 20 - 50% | 33 - 44 % |

Examination of the ENM outputs for July 2000, showed whether or not reindeer visited the area during previous years made the highest contribution (35.1%) to the overall model (Table 16 & 20). The reason for this is perhaps twofold: first, the areas previously used occupies a larger area than those used previous to 1985, and second, the concentrations formed in 2000 were substantially smaller and more densely populated in 2000 than in 1985. In 1985, summer concentrations occupied 6.2% of the overall TRH summer habitat, while in 2000, summer concentrations occupied a mere 1.2% of the overall summer habitat. This may indicate the model was, in a way, backed into a corner where it could only narrowly define (spatially) niche areas, and therefore the magnitude of influence by areas of previous use was amplified. Another variable contributing significant amounts to the model's explanatory power was temperature (32.2 %), and temperature was seen to be an important variable in 1985 as well. Other significant variables in the ENM were precipitation (16.5%) and wind (15.9%), and although not having near the magnitude it did in 1985, wind speeds do help explain why reindeer are likely or unlikely to be in a particular space.

The variables wind, temperature, and previous areas (i.e. spatial fidelity) have been identified as having the highest degrees of influence on the spatial distribution of TRH summer concentrations in both model frameworks and for both years studied. The conditions provided to the reindeer when there are cooler temperatures and higher wind speeds create a more comfortable environment for them during the warm summer months. Their coats are made out of hollow hairs that trap heat in, and relief must and can be found where wind speed is higher and temperatures are cooler. These conditions also provide greater relief from mosquitos as described in previous literature. However, unlike previous literature this study has empirically found these three variables and their magnitude of influence relative to other physiographic and climate variables, to be drivers of TRH summer migration on a habitat-wide scale.

The construction of regional models for the area lying between the Pura, Pyassina, and Tareya rivers first entailed a correlation analysis of variables. Like the analysis of variables for the habitat-wide models, there was significant correlation among the variables as often found when using climate variables and similar correlation strengths and directions were found when analyzing at the regional level. Multicollinearity diagnostics identified humidity, total clouds, and low clouds as variables that must be removed from the list of independent variables in logistic regression and ENM. NDVI was an added environmental variable, and areas previously used was incorporated as both a spatially and temporally lagged variable as it represented both whether or not the reindeer had been in an area during a previous summer and if so, how many summers the TRH had been observed in that area.

Logistic regression modeling of TRH summer concentrations at the regional scale during 1985 was able to classify 67.0% of presence and pseudo-absence cases correctly. Model optimization involved the removal of the NDVI variable after the first step. Reindeer were much more likely to be present in areas with higher wind speeds, and slightly higher odds of occurring in areas of higher elevations (Table 7). In areas where temperatures were higher, the TRH were 0.387 times as likely to be present which indicates their opting for cooler temperatures. As modeled in the habitat-wide approach, areas with higher wind speeds and cooler temperatures had higher probabilities of reindeer presence. For every increase in number of years that an area had been previously visited reindeer were 0.656 times as probable to be used as regional summer grounds in 1985, meaning that areas where reindeer had been more frequently in the past were less likely to be used.

NDVI was added in order to explore the role of vegetation abundance in spatial distribution patterns of the TRH (Tables 8 & 9). Independent-samples t-test showed that NDVI values within the summer concentration were in fact significantly different than those values found outside of the concentration area. The statistically significant different mean values indicates that the difference did not occur by chance and thereby implying the reindeer did not select this area by chance. Mean values within the concentration area (0.605) were lower than those outside the area (0.632) indicating that there was greater vegetation abundance where the reindeer were not. Some research on feeding strategies of Arctic reindeer found that the ungulates follow the wave of new vegetation that is rich in protein during spring (Baskin, 1990). As the snow melts gradually from south to north, vegetation emerges providing the protein rich shoots that some Arctic reindeer feed upon. This could explain why the reindeer were in an area with less abundance, as more abundance does not necessitate more available protein. Reindeer survive on carbohydrate-rich lichens all winter long, but they seek out green, protein-rich vegetation in the spring and summer months building strength for the ever approaching winter season.

The regional model constructed using spatial lag logistic regression for the Pura-Pyassina concentration during 2000, was able to correctly classify 84.9% of the cases of presence and pseudo-absence. Model results confirmed that as temperature increased, so too did the probability of reindeer occurrence (Table 11 & 19). It was an unusually hot summer that year according to researchers and the TRH formed very dense concentrations as they sought relief from the intense harassment of mosquitoes (Kolpashchikov, Yakushkin, & Kokorev, 2003). It is possible that the reindeer were not able to find locations that were both cooler and windier which could have resulted in the collinearity of the wind and temperature variables. If that was the case, then it could be the reindeer were in windy places, but these windy places were also warmer than the surrounding area. This possible explanation would be why wind was not found to be a significantly contributing variable to the logistic regression model, but the ENM for the region offers some further clarification.

ENM corroborated results from logistic regression modeling for the regional scale model for 1985 (Table 17 & 20). Wind (44.4%) and temperature (34.9%) were the highest contributing variables to the model construction, and here, too, it is seen that previous areas did not contribute a significant amount (1.2%). For the first time, research has quantitatively identified that wind and temperature are important explanatory variables of TRH spatial distribution, and quantified the degree to which the variables contributed to distribution patterns.

A very interesting visual output from Maxent is the mapped areas of probability of reindeer occurrence (Figure 33). Most often, Maxent over-estimates the area that constitutes the niche environment. This can be seen clearly in the results of the habitat-wide model where red swaths sweep across the concentration areas. In this regional model, there is little area found with near 100% likelihood, most of which was identified as the area where the Pura-Pyassina aggregated. The area used by the Tareya concentration is speckled with probabilities of near 0% and has only limited area above 50% likelihood. This means either the reindeer did not select concentration grounds which fulfilled their niche requirements based on conditions of the environment and climate, or that there was not enough area meeting their full niche requirements available to select from. If the former is the case, then it can be said that the influence of spatial fidelity was driving the herd more than satisfying environmental requirements. Perhaps the same land in previous years was cooler, windier, and had more protein-rich sprouting green vegetation. If the latter is true, then this is evidence of changing vegetation and climate conditions. The TRH have regularly utilized this same ground, more than 50% of the observed summers researchers located concentrations here, and it is assumed they would not migrate over 1000 km from their winter grounds to find sub-prime habitat as a result of ineptitude in the selection process.

The regional ENM for July 2000, identified temperature (38.0%) and wind (31.5%) to be the most contributing variables to the model construction (Table 18 & 20). Temperature has been a strong predictor and model contributor at other scales and years, and this trend continues in July 2000, at the regional scale. Previous areas and NDVI did not contribute significantly to the model. Thresholds refined through the construction of single variable model response curves makes it clear that the TRH were more stringent in the selection of their summering grounds in 2000 compared to 1985; interpreted through very prominent, narrowly defined peaks in the response curves and little margins on either side of the peak that reindeer were responding to in 2000. Much broader curves and some variables had multiple peaks in 1985, indicating that reindeer were found inhabiting areas with wider ranges of climate and environmental conditions within the region.

The map of likelihood of occurrence created by Maxent predicted areas of 50% or higher to be an area smaller than that observed to be utilized by the Pura-Pyassina in 2000 (Figure 36). This unlikely outcome is similar to that of the regional scale model for 1985. Both regional models identified probable niche environments to be smaller than the areas actually utilized, while both 1985 and 2000 habit-wide models identified swaths larger than all of the areas utilized as summer habitat.

Mean NDVI values were lower in 2000 than in 1985, and this is perhaps a result of the early onset of green vegetation that year in conjunction with the very dry summer months of 2000 (Kolpashchikov, Yakushkin, & Kokorev, 2003). What is very interesting, however, is that not only were the mean values outside of the utilized area higher than mean values of utilized areas for both 1985 and 2000, but the mean differences between utilized and unutilized areas for both years was nearly identical (0.0277 in 1985 and 0.0228 in 2000). Independent-samples t-test determined that differences in mean values within and outside utilized areas were statistically significant and therefore indicative of the reindeer not selecting these areas by chance. It follows that these areas of lower biomass provide a condition that the reindeer sought out in their concentration habitat selection process. Logistic regression analysis conducted with NDVI as the sole independent variable reinforces the findings that low NDVI values are better predictors of reindeer presence as the have odds ratios of less than one (Tables 8 & 12).

The availability of cloud-free satellite imagery for August 11, 2000 provided a unique opportunity to identify changes in biomass abundance from a time when the *Rangifer* were known to be in the area (July 26, 2000) to 16 days later. Independent-samples t-test was used to determine that the differences in mean values for areas within and outside of the area utilized were statistically significant (Tables 13 & 14). Both areas within and outside of the summer grounds had higher NDVI values in August than in July indicative of higher abundance of biomass. The NDVI mean value for areas within the concentration in July was 0.0228 lower than areas outside of the concentration grounds, and the NDVI value mean difference between areas within and outside of the concentration grounds for August was 0.0185. This is evidence that vegetation within the area of concentration became more abundant at a faster rate than did the vegetation outside the area where the Pura-Pyassina concentration formed.

Kolpashchikov, Yakushkin, and Kokorev (2003) documented the TRH forming concentrations from July 22 - July 25 in summer of 2000, and the Landsat image was captured on July 25 while the reindeer were there. This could provide understanding as to the difference in NDVI values within and outside of the concentration areas. It is possible that the reflectance of the biomass was significantly reduced because 445,000 reindeer were obscuring the light reflected to the satellite. This is not verifiable, however, as the Landsat imagery spatial resolution is 30 meters, therefore, no reindeer were visible in the image.

Another plausible explanation of the lower NDVI values within the concentration areas could be a result of nearly half a million wild reindeer foraging for three days on leafy, green vegetation, and thereby drastically reducing the abundance of biomass. The pruning of plants may have triggered a growth spurt which was then detectable by the time of the next Landsat image acquisition. Another scenario for the lower NDVI values could be that with such a large number of animals, densely concentrated for three or four days, is that the NDVI values are indicating the post-presence evidence of vegetation trampling.

One reason for this could be that the area within the concentration grounds was covered by more immature green vegetation which provided more protein for the wild reindeer. The shoots of green leafed plants are known to be attractive to wild reindeer for this reason. Another reason that could explain this finding is a result of the reindeer being in a particular place for 3 - 5 days as they were in July 2000. If they aggregated in such dense formations for multiple days, it would have been necessary for them to consume a significant amount of vegetation. It would have then been necessary for the reindeer to expel their waste and to have hypothetically provided a source of nitrogen-rich fertilizer that would be an excellent source of nutrients to vegetation, especially while in a drought-like environment.

Any one of these scenarios could be explanatory of the lower NDVI values within the concentration area becoming higher at a faster rate than the values outside of the concentration area. This study maintains that all of these scenarios are useful to examine further, and more so, maintains that this could provide an initial basis for innovative, and cost-reducing monitoring efforts whereby the TRH may be monitored by way of knowing where they were via effects on vegetation.

Utilization of spatioanalytic methods, bolstered with spatial lag logistic regression analysis and ecological niche modeling, has enabled this study to quantify the magnitude of impact given variables have on TRH summer ground selection. Researchers have been convinced that higher wind speeds and cooler temperatures were factors known to keep *R. tarandus* more comfortable and therefore drivers of reindeer migration and aggregation, but this work provides a valuable component that can describe to *what degree* these factors are influencing the TRH's selection of grounds.

These findings may prove useful to future research and development of survey methods that are less costly than aerial surveys. Satellite imagery is becoming more widely available, at a reduced cost, and at finer spatial resolutions that would enable scientists to track the reindeer indirectly. The lack of availability of historical satellite data, and the lack of available cloud-free images were challenges this study had to work around. This study has established that vegetation abundance is a significant variable in the systematic process of *R. tarandus* monitoring, and that a higher abundance of biomass is not indicative of a higher probability of reindeer presence.

Geospatial analysis has been employed to quantify and assess hypotheses formulated by Russian scientists over the past 40 years as they have regularly monitored the TRH. These geoanalytical methods have been successful in the identification of spatial trends, and the variability within the trends, during the past 40 years. Spatial fidelity has been innovatively and scientifically established, documented, displayed and will prove to be valuable as guidelines for future monitoring efforts. It is increasingly important that these trends are identified in order to assist researchers in locating where the herd is more likely to be, therefore making summer surveys more efficient and affordable. The need for annual surveys to continue becomes more and more important as the population of the TRH is declining rapidly.

## 5.2 Conclusions

This study found that visual observations made over the past 40 years are generally in agreement with empirical results derived from spatial statistical analysis. Both visual observations and statistical analysis agree that the TRH are declining in population in Yenisei region of western Taimyr, and that populations are growing in the Pura-Pyassina, Tareya, and Logata regions in central Taimyr. Visual observations have led to claims that the TRH do exhibit spatial fidelity, and this study has conducted statistical analysis able to confirm the hypothesis. Visual observations have maintained that during the late 1990s and 2000s, the TRH summer grounds were shifting to the east and to the south, reflecting what has been statistically analyzed and visually observed for calving grounds. This study has shown through the utilization of reviewed statistical methods that the summer grounds are moving to the east and to the north.

The notion that the TRH returned to the same summer grounds over time was originated through many years of visual observations. These observations now have supporting statistical evidence of TRH summer ground fidelity and multi-year patterns have been identified. This study found that the TRH exhibit both spatial fidelity and spatial shift, and spatiotemporal analysis has revealed unique patterns unfolding: (1) The population of the Taimyr wild reindeer herd is decreasing as a whole, (2) Distribution of summer concentration grounds forms a compact, statistically normal distribution, (3) Distances between concentration grounds for consecutively observed summers is increasing, (4) The Taimyr reindeer are reusing smaller percentages of their range from year to year, (5) Four distinct areas have been identified as areas frequently used (i.e. more than 50% of observed summers, (6) Summer concentrations are becoming more compact and more densely populated, (7) Habitat utilized for summer concentration grounds is rising in elevation, (8) Western concentrations are losing animals while central and eastern concentrations are emerging and getting larger, and (9) Summer concentrations are shifting to the east and to the north and thereby expanding the area of utilized habitat.

In order to identify which factors the TRH are sensitive to when selecting summer concentration grounds, this study employed spatially lagged logistic regression modeling and ecological niche modeling at two scales for two different years. The factors that were most effective in the modeling were higher wind speed, cooler temperatures, and whether or not the areas had been previously used as summer concentration grounds. These findings corroborate previous observations, but have added a valuable empirical component that provides understanding as to what degree the variables affect the selection of summer grounds. The July optimal ranges of variables' for reindeer ecological niche requirements have been amassed for future research and modeling techniques: (1) Temperatures from 6° - 9° C, (2) Wind speeds ≈ 6 m/sec, (3) Precipitation amounts of 10 – 25 mm, (4) Elevations less than 225 meters, (5) NDVI reflectance of 0.4 – 0.6, and (6) Areas observed to have been utilized as summer concentration grounds 20% - 50% of all summer observations made.

## 5.3 Limitations

This study encountered difficulties as most studies do, and one of the difficulties was concerning the quality and quantity of reindeer location data. The only available dataset is that which was made by hand drawn maps that were only GPS verified starting in the 1990s, however, only limited corrections were needed to be made to the digitized versions of summer concentration locations. Precise tracking collar data would have made spatial statistical analysis equally as precise. Multiyear gaps in between summer surveys presented a limitation as well, especially during the 1990s and 2000s.

Another limitation of this study was that of climate data availability. The Arctic is not a well-monitored region of the world even when taking into consideration the technological advances made in terms of satellite acquired or reconstructed climate data. Working with only a limited number of operating meteorological stations in Taimyr, coupled with them only maintaining monthly mean values for all variables, created the necessity to interpolate relatively few values over an extremely large area. Although mean climate values were used, they were not the exact conditions existing when the reindeer were in their summer concentration grounds and, therefore, we cannot say for certain what the exact conditions were like that they were reacting to. It could be useful in the future to have data on wind direction as well, as the TRH move in directions to avoid biting insect harassment. It is also unknown the abundance of mosquitos that were present at the time of concentration, which, too, would prove useful in modeling spatial shifts.

When doing remote sensing, acquiring cloud-free imagery is most always a challenge, but it is even a larger obstacle when timing of the image acquistion is of great importance. The historical availability of satellite acquired imagery is also a problem, as one can only go back so far in time. It was of great fortune that relatively cloud-free data was available for the time and location of summer concentrations for two years, and perhaps even more fortunate that the next pass of Landsat 7 ETM+ in 2000 (the August 11th image) was cloud-free. Without such fortune, valuable analysis of condition of biomass post-concentration would not have been possible.

## 5.4 Future Directions

A more complete understanding of *R. tarandus* spatial distribution and temporal patterns is needed to fully analyze if and how migration routes or seasonal concentration grounds are shifting. The analysis of spatiotemporal dynamics of the TRH has now been conducted on two out of three seasonal ranges, calving (spring) and summer, therefore making winter grounds a probable next step. Limitations on availability of data for winter grounds is a substantial obstacle due to the TRH being more dispersed in winter and far fewer winter surveys are conducted to the dangerous Arctic environment.

North American herds have been equipped with GPS tracking collars for up to 30 years in some places, and this has provided scientists an unparalleled dataset from which to model spatiotemporal dynamics of *R. tarandus*. In September 2013, ENARI and TREC researchers from Russia deployed satellite tracking GPS collars on 13 wild reindeer in southeast Taimyr. These collars will provide near hourly location data that will add to the richness of historical data already compiled on the herd. Data is downloaded and mapped here at UNI and then shared with Russian colleagues. Future research and modeling will have an added advantage of knowing precisely the routes and length of time travelled. This information will also enable summer surveys to become more efficient, as *a priori* knowledge of where to look saves both time and money. Exploratory analysis of abundance of biomass has shown that reindeer in Taimyr select summer concentration grounds with lower amounts of biomass than surrounding areas. This finding may provide groundwork for a future satellite monitoring technique that is developed in stride with the GPS tracking data to monitor reindeer by assessing where they have recently been.

Currently there is a method being developed by some of those who made this study possible (Dr. Vladimir Mikhailov, Dr. Leonid Kolpashchikov, and Anna Pestereva) that simulates and models environmental, climate, and weather factors and how they affect *Rangifer* body thermoregulation mechanisms. The model includes metabolic heat production, mechanical work heat production, fur and coat characteristics, skin characteristics, and radiant temperature of the atmosphere. Their research is unveiling a value range of weather and climate factors, in which temperature and stability is provided by the physiological thermoregulation system called the “bioclimatically neutral zone,” (Mikhailov & Mordovin, 2005). It is with great hope they will find the research conducted here of utility in their efforts to better understand the spatiotemporal dynamics of the Taimyr Reindeer Herd.

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