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Movement Ecology of the Qamanirjuaq Caribou *(Rangifer tarandus groenlandicus)* Herd with focus on their Wintering Grounds

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UNIVERSITY OF TROMSØ

ABSTRACT

With a rapidly changing climate in the arctic there is concern that specialized species, such as caribou (Rangifer tarandus), may not be able to adapt. Currently, the importance of climatic changes for North-American caribou herds is unclear. In an effort to reduce this knowledge gap I have analysed the movement behaviour of caribou in the Qamanirjuaq herd, in the central Canadian Arctic, in relation to data regarding the presence/absence of snow and snow depth.

Using collar data (n=69) from female caribou over a 16 year period (1993-2008) and snow data from the climate model described by Liston and Hiemstra (2011), I identified where the caribou spent each winter and how long they remained in an area. First, I investigated the relationship between the presence/absence of snow and seasonal migration movements. Second, I investigated the relationship between snow depth and the start of seasonal activity periods, and more specifically whether patterns in the snow melt could explain why the calving area differed between years. Finally, I investigated the movement behaviour during winter, as determined by First Passage Time values (Fauchald and Tveraa, 2003), in relation to snow depth.

My results indicate that the presence/absence of snow as well as snow depth has an impact on the movement rates of caribou cows in the Qamanirjuaq herd. During their fall migration the collared caribou traveled south ahead of accumulating snow. Although there were observational indications that the timing of the annual snow melt might affect their spring migration, my results did not suggest this. Thus it was determined that the presence/absence of snow did not affect the location of calving. It was hypothesized that snow depth influenced the start dates of seasonal activity periods. My results only indicated this to be the case for the Post Rut season, where the start date became later as snow depth increased. Additionally, it was determined that snow depth hampers movement. Increases in snow depth resulted in the caribou cows staying in an area longer.

Key Words

Reindeer, Caribou, Qamanirjuaq, Snow Depth, First Passage Time, Movement

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Nunavut

Building *Nunavut* Together

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1 INTRODUCTION

Arctic climate is in a process of rapid change and the affect of this on species is of major concern (Stien et al., 2012, Post and Stenseth, 1999, Hansen et al., 2011). Global surface mean temperature has increased approximately 0.6^{o}C to 0.7^{o}C between 1951 and 2012 (IPCC, 2013) and heavy precipitation has also likely increased in frequency (IPCC, 2013). Furthermore, the arctic has seen an increase of about 2^{o}C since the mid-1960's (Hodgkins, 2014). The date of snow cover disappearance in spring changed at a rate of 3 to 5 days per decade and the length of snow free summers has also increased by 3 to 6 days per decade (Dye, 2002, Liston and Hiemstra, 2011). The species that live year round in the Arctic have adapted to the harsh weather characteristic of the winter period in the region. As the climate changes there is concern that these specialized species may not be able to adapt to the changes (Post et al., 2008).

With its circumpolar distribution and often large herd sizes, caribou/reindeer (*Rangifer tarandus*) is the most numerous large terrestrial herbivore in the Arctic. The majority of caribou herds in Canada are in a state of decline (Festa-Bianchet et al., 2011), and it has been suggested that a decline in Rangifer populations is a global phenomenon (Vors and Boyce, 2009); though the causes vary (Johnson and Russell, 2014, Chen et al., 2013). In Fenno-scandia socio-ecological factors have also been implicated as the main cause of population change in semi-domesticated herds (Hausner et al., 2011). More generally it has been suggested that increasing industrial development (Johnson and Russell, 2014), overharvesting, predation, disease and climate change have played a role in population declines (Vors and Boyce, 2009, Festa-Bianchet et al., 2011).

Climate can affect Rangifer in numerous ways. Indirect effects influence Rangifer through disease transmission, insect harassment (Witter et al., 2012), and plant forage abundance (Post and Forchhammer, 2008, Kerby and Post, 2013). Whereas direct effects, such as snow and ice conditions, impact food availability and locomotive costs (Hansen et al., 2011). Snow is seen by some to be the most limiting of environmental factors in the Arctic for large wildlife (Richard et al., 2014). Animals are limited in space use (Witt et al., 2012) and resource availability. When movement becomes difficult energy use is increased, which may impact survival rates (Richard et al., 2014). Snow depth impedes the movement of animals (Richard et al., 2014, Ratikainen et al., 2007, Witt et al., 2012) .

Caribou are of great importance to the traditional way of life for indigenous people throughout the arctic (Chen et al., 2013); the Inuit of Canada are no exception. The Kivalliq Inuit rely in particular on the Qamanirjuaq (*Rangifer tarandus groenladicus*) herd (Nicolson et al., 2013). The Qamanirjuaq (QAM) herd is one of six subpopulations of barren-ground herds in the central Canadian Arctic (Nagy et al., 2011). The herd is one of the world's largest wild

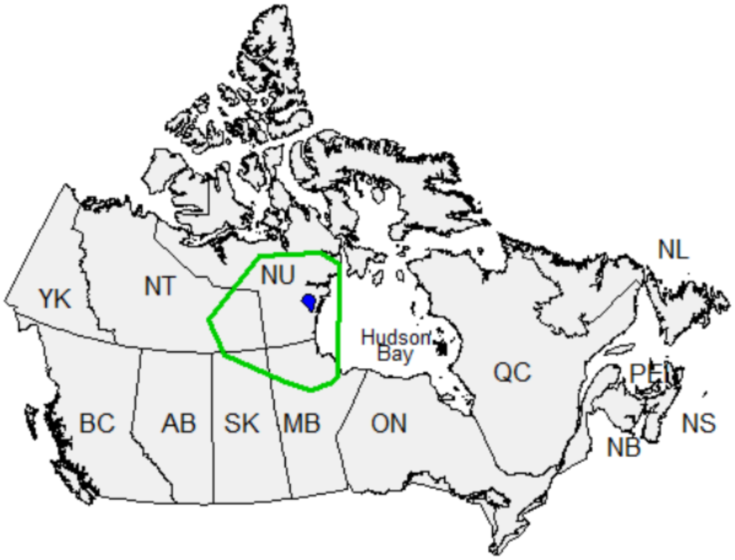

Figure 1: Study Area. The green polygon around the calving ground is the area of study based on the all the collar data. The calving grounds at 50% usage from 1993-2012 for the Qamanirjuaq caribou herd (blue). NU (Nunavut),NT (Northwest Territories), YK (Yukon), BC (British Columbia), AB (Alberta), SK (Saskatchewan), MB (Manitoba), ON (Ontario), QC (Quebec), NB (New Brunswick), PEI (Prince Edward Island), NS (Nova Scotia), NL (Newfoundland and Labrador).

populations of caribou and undertakes a ~600km seasonal migration between the calving grounds in Nunavut (Figure1) and their wintering grounds in Northern Manitoba and Saskatchewan (Campbell et al., 2010, Nagy et al., 2011). The most recent population survey in 2008 estimated the herd size to be 348,661 (SE=44,861, CV=0.129) (Campbell et al., 2010). However, there is concern that the population may be declining as the calf to cow ratio in spring classification counts has been declining in recent years (Figure 2, Campbell et al., 2010). As with other caribou herds, climate change may be one cause of such a decline; although it has been suggested that increased mining and exploration activities within the QAM herd's home range may also play a role (Johnson and Russell, 2014).

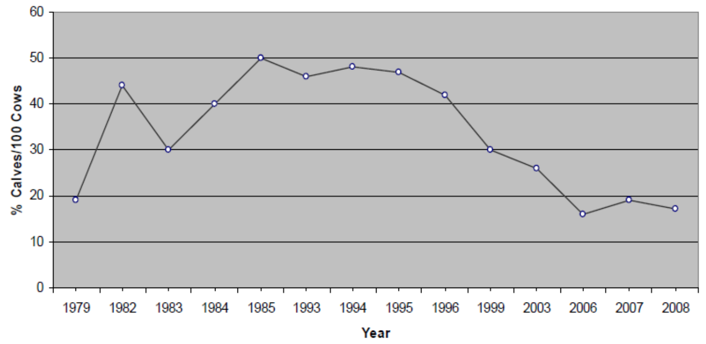

Figure 2: Calf to cow ratio during the spring classification counts displayed as calves per 100 cows. The index for a stable population is 25 calves/ 100 cows (taken from Campbell et al., 2010).

Currently, the importance of climatic changes for North-American caribou herds is unclear. As a first step towards such an evaluation, I have analysed the movement behaviour of caribou in the QAM herd in the central Canadian Arctic in relation to data on the presence and absence of snow as well as snow depth. Using collar data (n=69) from female caribou over a 16 year period (1993-2008) I identify where the caribou spent each winter and how long they remained in an area. First, I examine the relationship between the presence/absence of snow and seasonal migration movements. Second, I examine the relationship between snow depth and the start of seasonal activity periods. Finally, I investigate the movement behaviour during the winter, as determined by First Passage Time (fpt) values (Fauchald and Tveraa, 2003), in relation to snow depth.

2 METHODS

2.1 STUDY AREA AND HERD

The QAM herd itself is determined by its calving ground (Figure 1) around the Qamanirjuaq Lake in the Kivalliq region of Nunavut, Canada. The study area is defined as the year round home range of the herd. The precise location of the study area shifts with the movement of the herd.

Table 1: Seasonal Activity Periods (Nagy et al., 2011)

Seasonal Activity Period	Start and End Dates	
Calving	04-Jun	20-Jun
Post-Calving	21-Jun	03-Jul
Early Summer	04-Jul	07-Aug
Mid Summer	08-Aug	22-Aug
Late Summer	23-Aug	21-Sep
Fall, PreRut	22-Sep	17-Oct
Rut	18-Oct	03-Nov
Post-Rut	04-Nov	25-Nov
Early Winter	26-Nov	25-Jan
Mid/Late Winter	26-Jan	09-Apr
Spring, Spring Migration	10-Apr	03-Jun

The QAM herd is migratory in nature. Using collar data Nagy et al. (2012) identified 11 seasons of activity for the herd based on movement speed (Table 1). Nagy et al. (2012) used a method which included movement rates (km/day), "fuzzy clustering, analysis of variance and Turkey's honest significant difference pair wise comparison to identify 5 day periods with significantly different movement rates". My study primarily uses data collected during winter, which is Early Winter (EW) and Mid/Late Winter (MLW). Spring Migration (SM) and Post Rut (PR) data are also included as these seasons have periods of snow cover on the ground.

Although not all caribou within the QAM herd migrate to the same area within a year, the majority spend the winter in south-eastern Northwest Territories, southern Nunavut, and northern Manitoba and Saskatchewan (Nagy et al., 2012). This results in the QAM herd's home range occupying four jurisdictions. The satellite data revealed that most of the collared cows spend winters below the tree line, however a few spent some winters on the tundra (Nagy et al., 2012, Campbell et al., 2010) .

The winter collar locations of individuals covered a mean area of 36,035 km^2 (min=11,603 km^2 and max=84,122 km^2) during each winter. Nagy et al. (2011) determined that the individual collars between 1993 and 2009 had an annual range around a mean of 208,323 km^2 (min=60,252 km^2 and max=357,389 km^2). However, the QAM herd does not use the entire home range each year (Wakelyn, 1999).

The home range of the QAM herd consists of five Ecozones (Campbell et al., 2010): Northern Arctic Zone, Southern Arctic Ecozone, Taiga Shield Ecozone, Boreal Shield Ecozone, and Hudson Plains Ecozone. Caribou can be found throughout this area at all times of the year although they are concentrated during various seasons. Generally, the South Arctic Ecozone (SAE) occupies the northern limit of the annual home range; though collar data revealed that a few caribou have travelled slightly further north into the Northern Arctic Ecozone. SAE is mainly covered by tundra vegetation such as low shrubs *(Ledum decumbens, Betula nana, Vaccinium spp,* and *Salix spp*). In warm areas tall shrubs (*Betula spp, Salix spp,* and *Alnus crispa*) grow, whereas in wet sites *Salix* spp, *Carex* spp, and moss are dominant. This area is also occupied by continuous permafrost (Campbell et al., 2010).

The majority of the QAM herd's southern portion of the annual range is in the Taiga Shield Ecozone (TSE), though collar data indicated that during some winters caribou used a small portion of the Boreal Shield Ecozone and the Hudson Plains Ecozone. TSE is an ecozone between the tundra and boreal forest and consists of stands of *Picea mariana, Picea glauca,* and *Larix laricina*. Lower canopy layers include *Betula nana, Salix spp,* and ericaceous shrubs: C*arex spp, Eriophorum spp,* lichens and moss. The northern portion of the TSE has continuous permafrost that progresses to mostly discontinuous in the southern reaches (Campbell et al., 2010).

The QAM herd is the largest herd in Nunavut, as such a number of surveys of their calving grounds have been conducted. The first visual survey was carried out in 1968 and obtained an estimate of 63,000. In June 1983 a photographic survey of the calving grounds determined an estimated population of 230,000 (SE=59,000; CV=0.258) (Campbell et al., 2010). Subsequently all surveys were conducted this manner. The population remained relatively stable through the next two surveys carried out in 1985 and 1988. In contrast the survey conducted in June 1994 indicated a population increase as a result of a population estimate of 496,000 caribou (SE= 105,426; CV=0.213) (Campbell et al., 2010). The most current photographic survey was completed in June 2008 and obtained an estimate of 348,661 (SE=44,860; CV=0.129 (Campbell et al., 2010).

2.2 SATELLITE COLLAR DATA

Table 2: The number of active collars per year and the number that were used in this study.

Year	Collars	Used
1993	5	4
1994	5	4
1995	8	8
1996	7	7
1997	12	10
1998	12	10
1999	10	8
2000	9	9
2001	8	7
2002	8	6
2003	7	6
2004	15	14
2005	12	10
2006	25	22
2007	23	21
2008	33	33
2009	29	-
2010	11	-
2011	27	-
2012	24	-
2013	13	-

The satellite collar data was obtained from the Government of Nunavut, Canada. Satellite collars have been deployed on caribou within the QAM herd since 1993. The work began under the directive of the government of the Northwest Territories and was transferred to the government of Nunavut following the creation of the territory of Nunavut in 1999. Despite the transfer in authority over the project the collars were deployed in the same way. Animal care protocols were followed: a net gun (that targeted adult caribou cows) was fired from a helicopter and then the captured caribou cows were fitted with satellite collars. Table 2 shows the number of active collars for the years 1993-2013. During the period from 1993 until 2004 the Model ST collars that were deployed transmitted locations every 4 days. Since 2004 the Model GPSIII and GPSIV collars have been deployed and have transmitted locations daily. Figure 3 indicates the rate of data return for the different collar models that were deployed. Although there are discrepancies between the two recording schedules, by using First Passage Time as my response variable, the discrepancies are minimized.

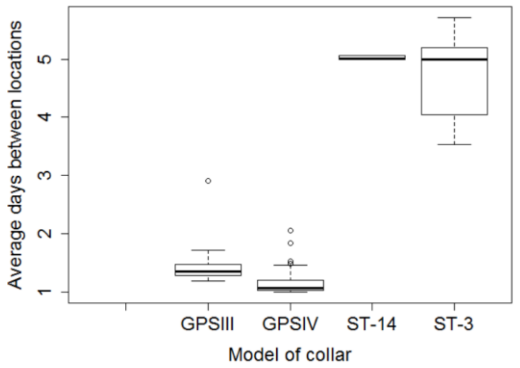

Figure 3: The recording schedules (box plots of days between locations) of the four types of satellite collars that have been deployed between the years 1993-2012. The ST-3 and ST-14 (1993-2004) models were programed to transmit location data every 4 days while the GPSIII and GPSIV models (2004-2012) were programed to transmit every day.

Not all the collars were active for the same amount of time. I decided to only include data from collars that were active for at least one winter. The most any single animal was tracked was over a period of 5 winters (Figure 4). I defined each winter as the dates from August 1 through to July 31 to ensure that the winter included the time between the first snowfall registering snow depth in the weather data, and the beginning of the snow free period registered in the weather data. Some of the locations in the collar data set were erroneous, which led to gaps in data. When these gaps were greater than 15 days and present either as start date of a season or around the time of first snow or snowmelt they were excluded from those analyses. Collar data was also left out of the analysis if there were less than 15 locations within a season for an individual.

Using the R packages stats (R Core Team, 2014) and dplyr (Wickham and Francois, 2015) I obtained the mean first snow fall and the first snow free day for each year. A plot of the dates that each collared caribou started occupying snow covered ground for the remainder of the winter, as well as the date that they were on snow free ground for the first time that year was created.

The collars that were deployed were programmed to send their locations via satellite to Telonics Inc.'s headquarters in Arizona, USA they are then emailed to the Government of

Nunavut, Department of Environment, office of the biologist Mitch Campbell. Locations of the collars are recorded every four days or daily as previously mentioned. However, some signals were not received or an inaccurate location was transmitted resulting in an anomaly. Therefore further refinements had to be made to the raw data before it could be used in this project. In looking at the distance (km) between sequential locations of an individual there were some clearly erroneous points. These points were then looked at while plotted for confirmation. An example of an error would be where in a three point sequence the middle point would be ~75km away from the other two points which were only 10 km apart. The erroneous locations were removed from the data base.

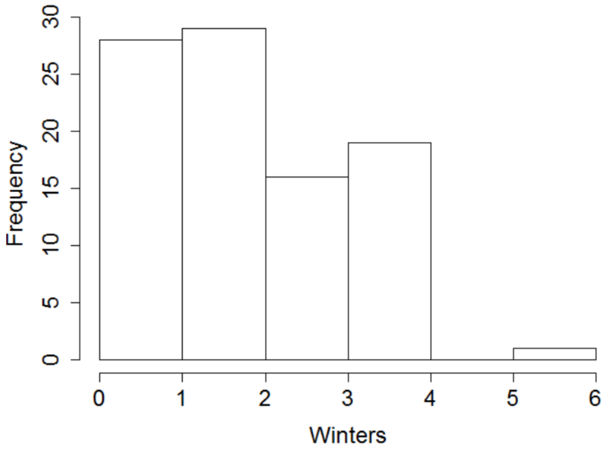

Figure 4: Frequency of winters collars active. Histogram of the number of winters that collars were operational for each individual. The y-axis is the number of collars that were active for the number of winters (x-axis).

2.3 WEATHER DATA

Environment Canada has operated 10 weather stations that are located throughout the study area and years. Unfortunately, their management and measurements are not uniform. Different stations are set up to monitor different weather characteristics and the periods and durations of operation are not consistent. Consequently, the weather data from weather stations, for the purpose of this project, was incomplete and not useable. This is a common issue with weather station data in the Arctic (Wilson et al., 2013). Therefore, it was necessary to use snow data from the model described by Liston and Hiemstra (2011). These data was created using the meteorological model (MicroMet) by Liston and Elder (2006b) and the distributed snow-evolution modeling system (SnowModel) also by Liston and Elder (2006a). The dataset covers the entire arctic and lays on a 10-km grid and at 3 hour time intervals (Liston and Hiemstra, 2011). Due to the size of the study area and computing capabilities a coarser grid size then was desired and what was available from the data set was used. After trying a few different grid sizes it was determined that a 150-km grid was optimal, the larger grid sizes averaged out to many small scale changes whereas going beyond the 150-km grid size would be too much for the commuting capabilities. This grid was overlaid at the study area and the average of the weather parameter (snow depth) on a daily base was obtained for each grid cell.

2.4 MOVEMENT ANALYSIS

First Passage Time (fpt) values as developed by Fauchald and Tveraa (2003) were used to identify seasonal changes in movement and in the analysis of the impact of snow depth on the movement rate of animals in the QAM herd during four seasons (PR,EW,MLW,SM). Fpt was used as it could be used both in determining the response variable of how long a caribou remained in an area as well as to be used in determining the individual seasonal breaks.

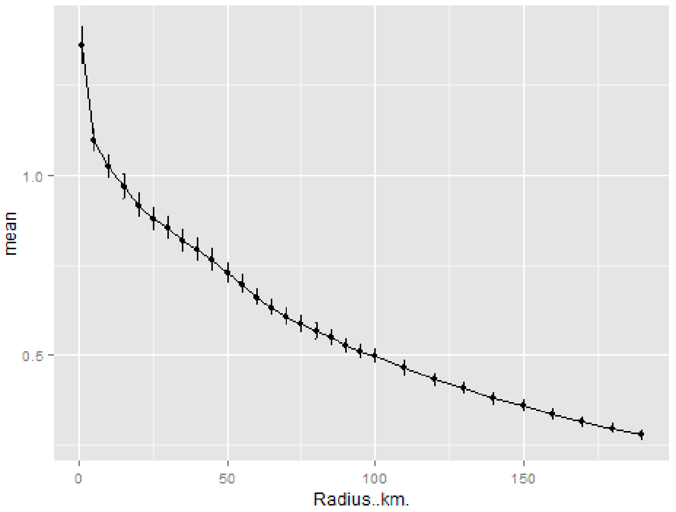

Figure 5: Variance of the mean log(first passage time) with standard error bars by varying radii in km.

Fpt is the time in days an animal remains within a specified radius of its position and has previously been used to determine search effort (Fauchald and Tveraa, 2003) as well as the intensity of use of habitat (Iversen et al., 2014). In this thesis days were used as the time measurement as it is the level of accuracy used in the weather averages. As a radius is increased the time spent within the radius would also increase. Normally to identify the optimal radius the radius with a peak in the variance log(fpt) is used. However, as depicted in Figure 5 there was not a specific peak in the variance of varying radii in the available data. After testing a range of radii values, I determined 20km was a suitable measure. Segments of time with similar fpt values were very short when using a radius below 20km and covered too large a part of the year when the radius was above 20km (Figure 6).

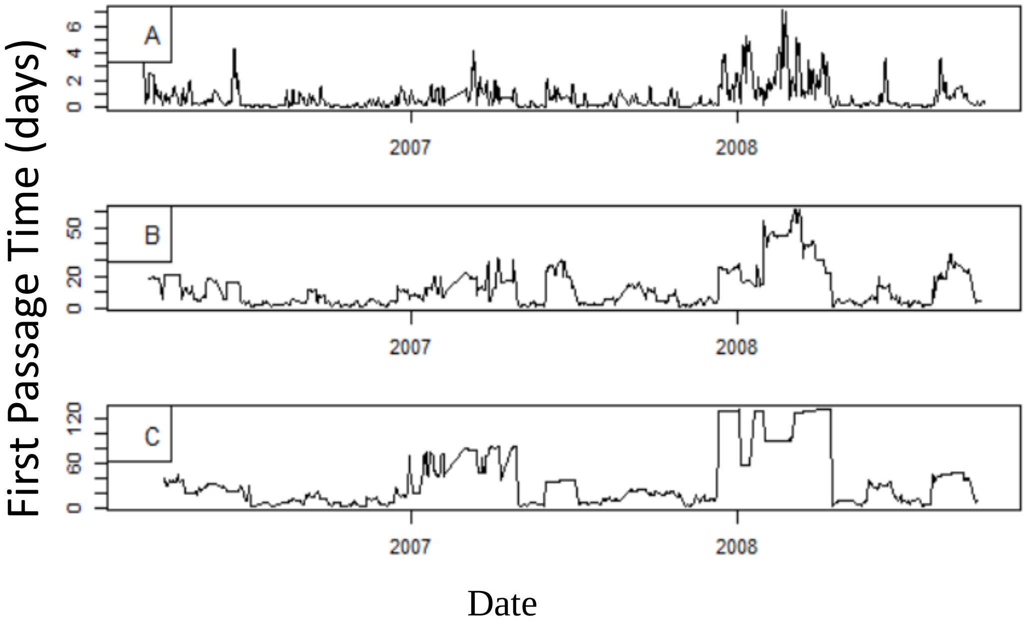

Figure 6: Temporal variation in first passage time (fpt) for a single animal using different radii for the fpt values A) 1km, B) 20km, C) 50km. One km showed too much variation and 50km did not show enough to capture differences during the winter. Y-axis is the number of days a caribou stays within the radius assigned. The portions with the highest fpt value are during the winter season.

The 11 seasonal activity periods that have been identified by Nagy et al. (2012) are listed in Table 1.Nagy's dates are averages and thus it was important to determine the specific start dates for the years in which satellite collar data had been acquired.

To compute the dates, the function lavielle in R package adehabitatLT (Calenge, 2006) was used to create segments using fpt values from a radius of 20km. These segments were then overlaid on the activity season dates that had already been documented by Nagy et al. (2012). Once I had the segments for each individual collared caribou, I then used the segment breaks along with the previously determined average season dates to verify each season. The seasonal activity periods that were used in this thesis were PR, EW, MLW, SM. The season start dates where obtained from 56, 71, 70, and 62 individual caribou cows, respectively. When comparing the segments that I obtained to those that Nagy et al. (2012) obtained, I felt they were sufficiently close that it confirmed my decision that the fpt would be sufficient for the analysis. Therefore the individual and yearly variables were taken into account in the analysis. Box plots were made to give a better visualization of the seasons in relation to each other as shown in the results.

The individuals showed a slight variation in season start dates both within the same year and between years (Figure 7). The SM period showed a pattern of fpt values that was very distinctive when compared with the wintering fpt values, so the start date of the SM period was identified clearly. The MLW season often had higher fpt values that could be distinguished from the EW fpt values. However, the PR values were not clearly distinguished from the Rut values. Also the EW values were not clearly distinguished from the PR values. Consequently, unless there was a clear change in the segmentation, the dates for those activity seasons were taken from Nagy et al. (2012).

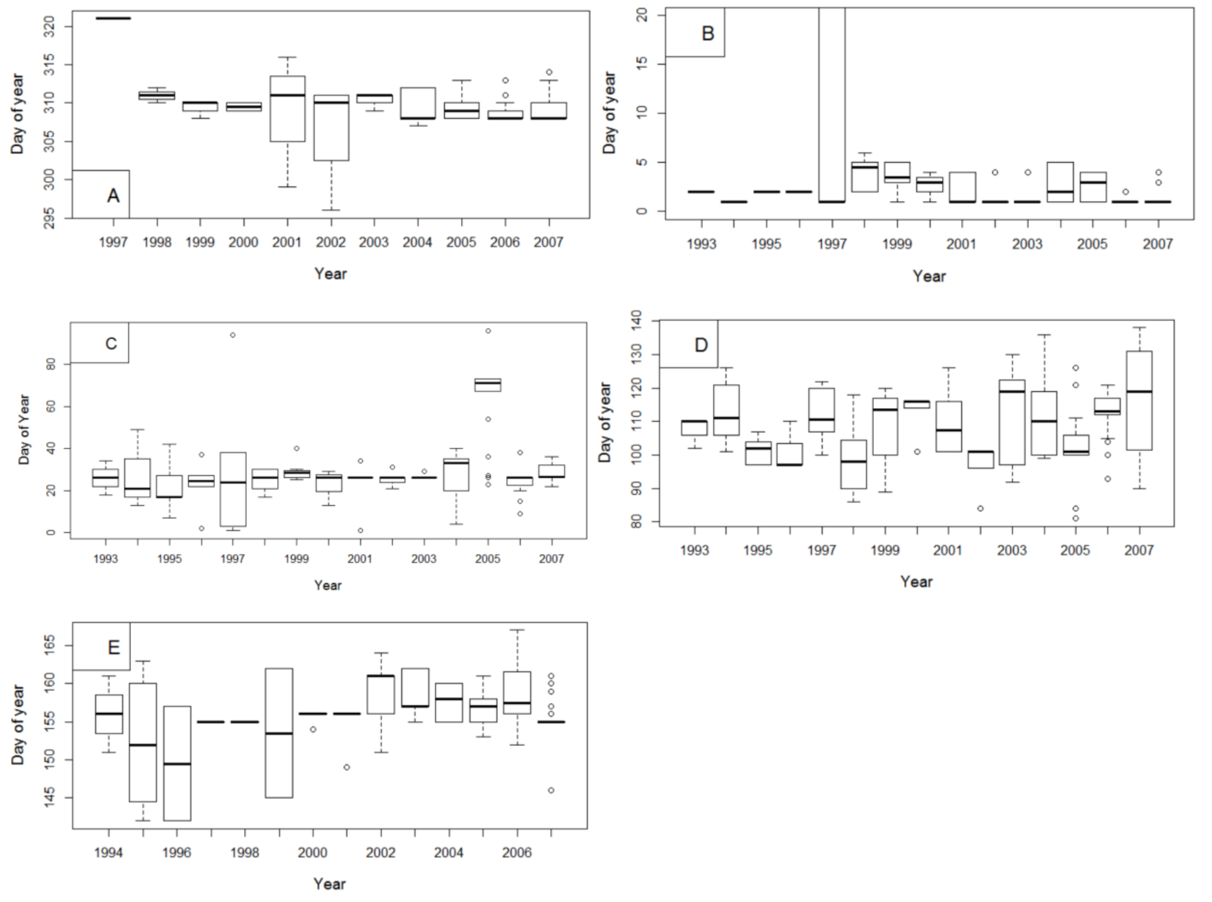

Figure 7: Box plot of the seasonal start dates for each year. A) Post Rut, B) Early Winter, C) Mid/ Late Winter, D) Spring Migration, E) Calving. In plot B for the year 1997 a start date of 328 was left out of the y-axis, as well as one point from 1996 and 2001.

The seasonal start dates used in the linear model (LM) and linear mixed-effect (LME) model analysis for the thesis were PR, EW, MLW, SM, and Calving (Figure 8). The Calving (CLV) was not used in the LME analysis as there were not many collars that had any snow on the ground during the season.

Running LM through the formula lm in the R package stats (R Core Team, 2014) with the start dates of PR, EW, MLW, SM as the response variable with the predictor variable as snow depth and winter (year) to find out if the amount of snow was associated to the differences in start dates of the seasons for individual animals.

The data on snow depth was aggregated at 150 km^2 scale. After aggregating the log(fpt) values by individual animals, season, and winter year using the R package sp (Pebesma and Bivand, 2005), I then ran a linear regression model using the R package stats (R Core Team, 2014). Snow depth was used as the predictor variable and the log(fpt) was the response variable with season as a fixed effect.

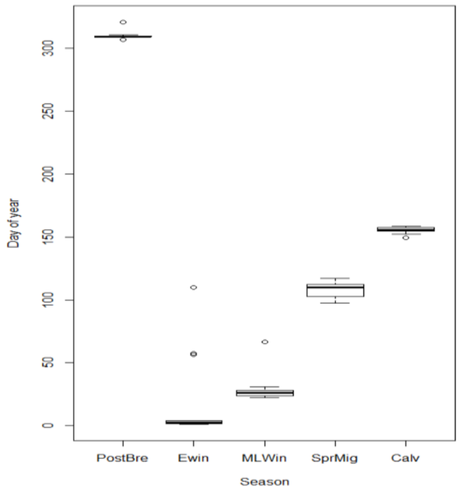

Figure 8: Averaged start date by year for each season then put in a box plot for the day of year. Post Rut (postBre), Early winter (Ewin), Mid/ Late winter (MLWin), Spring Migration (SprMig), Calving (Calv).

Using the collar data and weather data I looked at the first day with snow on the ground as well as the first day that was snow free. These were then plotted to try and understand the relationship between the movement behaviors of the caribou and the first snow /snow free days. A generalized least squares (GLS) model was run with the distance from the centroid of the 50% calving home range when the collar was first on snow free ground as the response variable. The day of year as a variance function of fixed weight.

Finally, I ran the linear mixed-effect model (LME) with the lme4 package in R (Bates et al., 2014) was used to find the impact of the predictor variable (snow depth) has on the response variable (rate of movement using the log(fpt) value with a radius of 20 km), with collar ID and snow depth nested in year and season as random effects and season fitted as a categorical fixed effect variable.

3 RESULTS

3.1 MIGRATION AS RELATED TO PRESENCE/ABSENCE OF SNOW

I identified the mean day of year for the first snow on the ground for each year, and plotting it against the mean first snow for the north and south half of the study area (Figure 9). It is seen that during the fall migration the caribou remain on snow free ground longer than the mean weather data provides (Figure 9). The first snow is usually in the north east portion of the study area, the snow then proceeds to the south west, taking over a month for the entire area to be under snow (Figure 10).

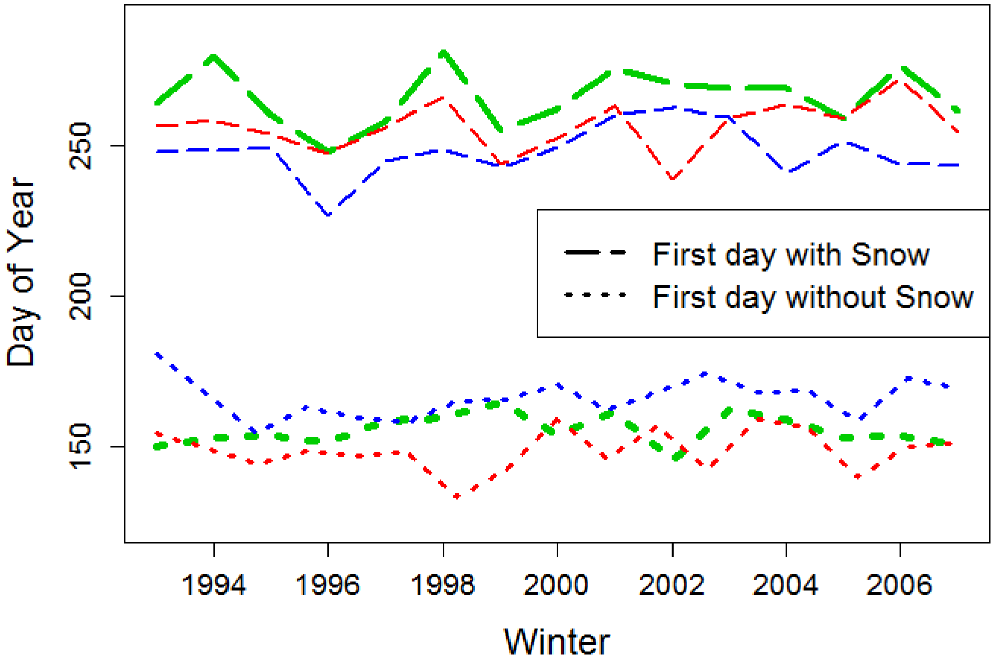

Figure 9: Temporal mean first snow/snow free days. Green line gives the first day of either snow or no snow experienced by collared caribou cows. Blue and red dotted lines gives the average estimates of the same for the northern and southern half of the study area respectively. The top three lines are during the fall, and the bottom three lines are during the spring.

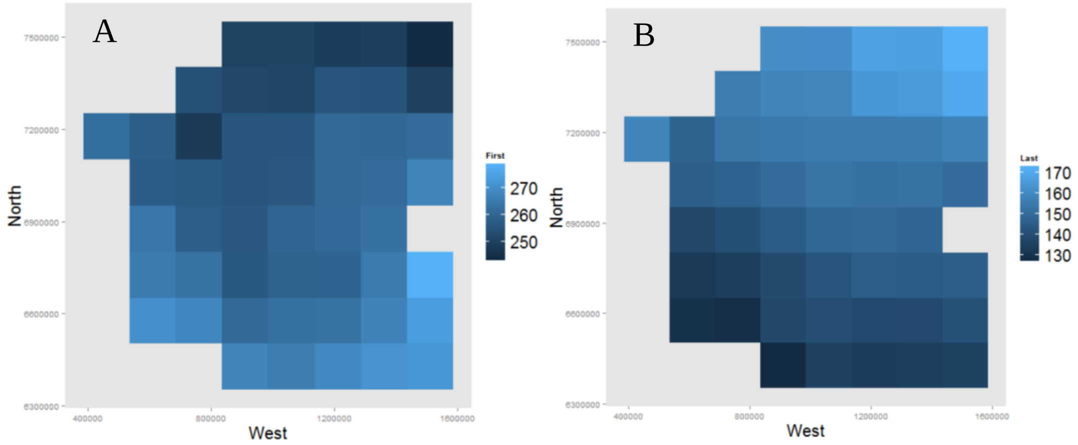

Figure 10: Spatial mean first snow/snow free days. Using the mean from all the years (1993-2008). The days of the year that snow is first on the ground (A) and the first day of the year the ground is snow free (B).

Typically the first snow free day in the south west occurred 46 days before the full study area was snow free (Figure 10). To investigate if the timing of the first snow free period played a role in the spring migration, I calculated the distance from the location of the caribous first snow free day to the centroid of the 50% calving home range. This distance was not related to onset of spring in the calving area, as measured by the average first snow free day in the 50 % calving home range (Figure 11, estimated regression slope 1847, SE = 1532, P=0.23).

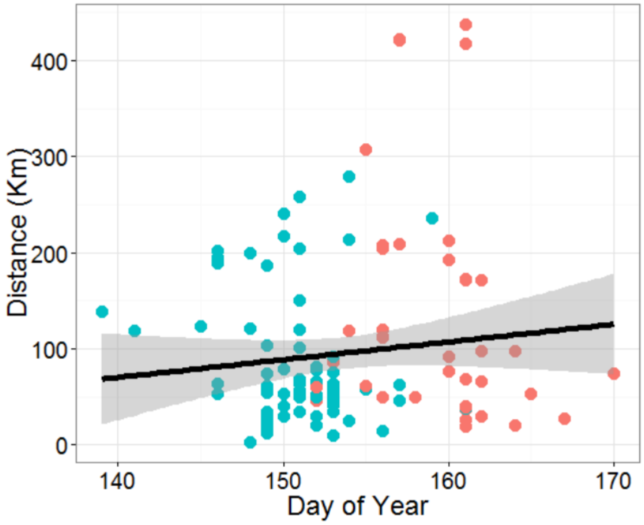

Figure 11: Snow free in relation to distance to the centroid of the 50% calving home range. The points are the first day of snow free ground. Orange is during Spring Migration and Blue is Calving. The peak calving occurs on the 163 day of the year. The black line is the regression line and the shaded portion is the 95% confidence.

3.2 SEASONAL START DATES AS RELATED TO SNOW DEPTH

In determining the effect that snow depth has on the seasonal start dates linear regression model were run. There were some evidence for the onset of the post-rut period to be related to snow depth (Table 3). With an increase in snow depth the start date for PR was delayed (Figure 12). For the other seasons it did not seem to be a consistent relationship with snow depth (Table 3, Figure 12).

Table 3: Estimated parameters of the linear regression model of the start date of each season as predicted by fixed effects snow depth and winter

Variable	Estimate	Std.Err	P value
Post Rut			
Snow Depth	24.7	6.86	0.0006
Winter	-0.26	0.13	0.045
Early Winter			
Snow Depth	-0.86	2.61	0.744
Winter	-0.095	0.033	0.005
Mid/ Late Winter			
Snow Depth	26.62	27.321	0.332
Winter	1.088	0.423	0.011
Spring Migration			
Snow Depth	9.51	13.6	0.49
Winter	0.56	0.26	0.029

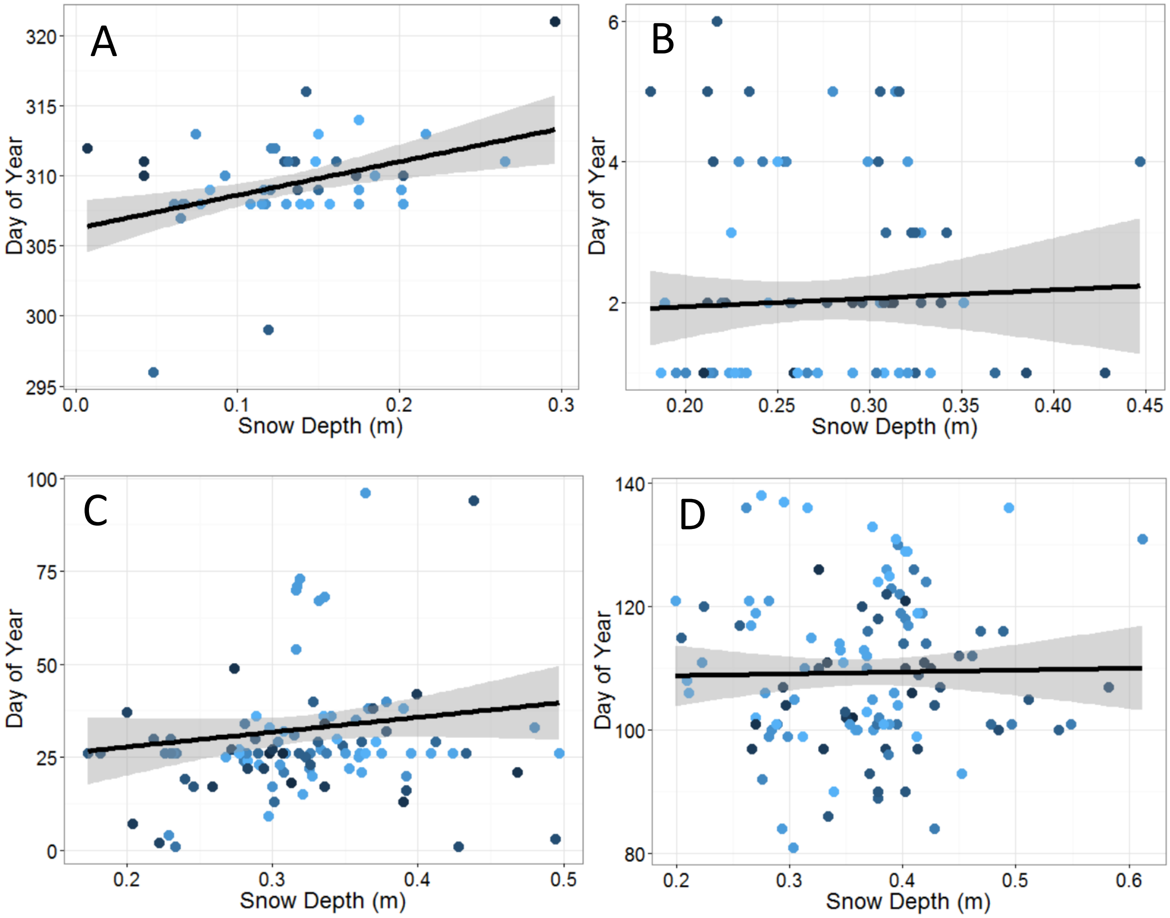

Figure 12: The snow depth on the first day of a season by individual animals and the day of year the season start date occurred. A) Post Rut, B) Early Winter, C) Mid/Late Winter, D) Spring Migration. The coloration is in a gradient representing the years 1993-2007(Dark Blue and Light Blue respectively). The thick black line is the regression line with the shaded grey portion the 95% confidence interval as produced in ggplot2 (Wickham, 2009).

3.3 MOVEMENT IN WINTER RELATED TO SNOW DEPTH

Snow depth had a significant positive overall effect on ftp in the winter seasons. This suggest that snow hampers movement over a range of snow depth (Table 4, Figure 13).

By comparing the 2 graphs in Figure 14 we can see that seasons with the most snow are the seasons with the lowest movement rates. Conversely, seasons with the least amount of snow are the seasons with the highest movement rates. Although the mean movement and snow depth changes from year to year there is no overall temporal trend for either.

Table 4: Estimated parameters of the linear mixed-effect model of Log(fpt) as predicted fixed effects snow depth and season and with the random intercept and slope effects of individuals and snow depths (nested in seasons and years). The Seasons are Post Rut, Early Winter, Mid/ Late Winter, and Spring Migration. The winters from 1993-2007 were included in the model.

Variable	Estimate	Std.Dev	T value
Fixed Effects			
Intercept	1.318	0.18	7.337
Snow Depth	0.99	0.424	2.336
Early Winter	0.648	0.137	4.72
Mid/ Late Winter	1.338	0.139	9.597
Spring Migration	0.152	0.135	1.119
Random Effects	Variance		
Individual Animal	0.146		
Season :Winter	0.452		
/Snow Depth	6.357		
Winter	0.158		
/Snow Depth	0.528		
Residual	0.469		

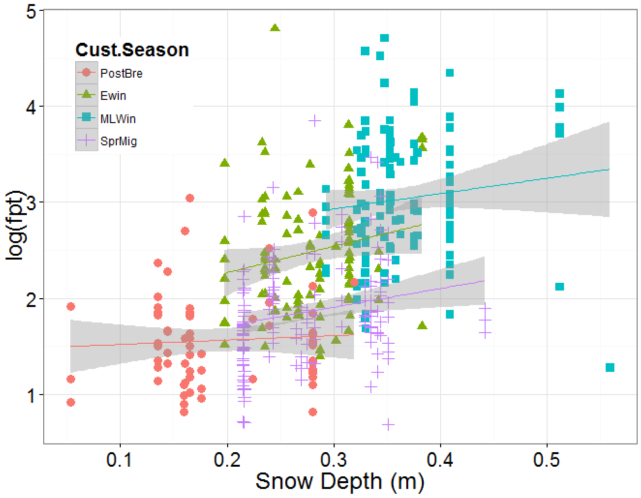

Figure 13: Snow depth and caribou movement. The relationship between snow depth and the rate of caribou movements indicated by log (ftp) in different seasons with snow. Snow depths is mean values predicted from a model based on weather data at a grid with cell sizes of 150km^2 Seasons are Post Rut (PostBre), Early Winter (Ewin), Mid/ Late Winter (MLWin), and Spring Migration (SprMig). Lines are derived from season specific regression analyses.

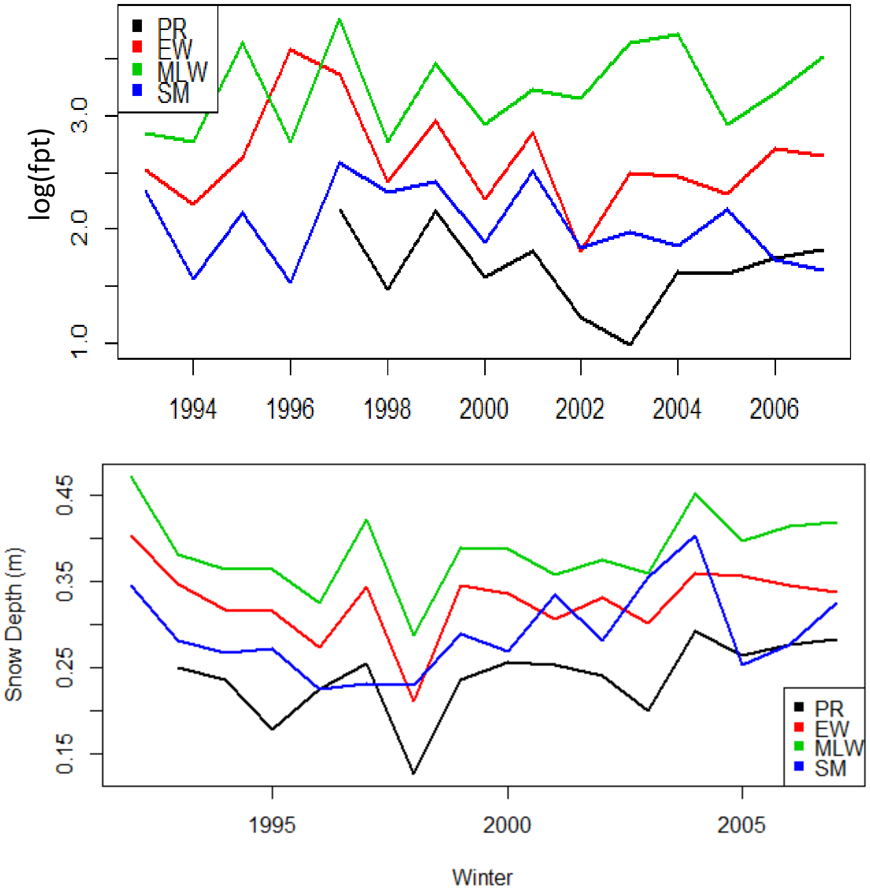

Figure 14: Yearly and seasonally means for log(first passage time) and snow depth. The upper plot has the log(fpt) with a radius of 20km on the y-axis. The lower plot is the mean snow depth on the y-axis. The x-axis is the winter the measurements were recorded. The snow depth is the snow depth at the location of the collared caribou. Post Rut (PR), Early Winter (EW), Mid/Late Winter (MLW), and Spring Migration (SM).

4 DISCUSSION

My results show that during their fall migration the collared caribou traveled south ahead of accumulating snow. The mean day of the year that the collared caribou were on snow covered ground was later than the mean day of year that the southern half of the study area received first snow on the ground. A potential reason for this behavior is that snow depth negatively impacts movement rates, as shown in Section 3.3.

An unexpected result of my analysis of the presence/absence of snow in relation to the spring migration was that the timing of the spring melt does not impact the location of calving. The satellite collar data showed that in 2005 the snow melt was delayed enough to prevent the caribou cows from reaching their traditional calving grounds (Figure 15 in Appendix). As a result they ended up calving further south. In contrast the early spring melt of 2006 allowed the caribou cows to make it to their calving grounds (Figure 16 in Appendix). The observational data suggests that the collared QAM caribou seem to migrate in accordance with snow cover. Migratory animals use the environment to guide their movements (Winkler et al., 2014). The purpose of staying ahead of the melt is probably to time their arrival on the calving grounds to maximize the onset of, and thus their consumption of, highly nutritious plants (Post et al., 2008). The peak calving dates are relatively static with a mean of June 12 (SD=3.) (Nagy et al., 2012).

I hypothesized that snow depth influenced the start dates of seasonal activity periods. My results only indicated this to be the case for the Post Rut season. With an increase in snow the start date of PR was delayed. This result seems counter intuitive, as later in the year there is typically more snow on the ground in the arctic. So the relationship determined by the analysis may be coincidental.

I have determined that snow depth has an impact on the movement rates of caribou cows in the QAM herd. Increases in snow depth resulted in the caribou cows staying in the same area longer. Conversely, caribou cows moved out of areas with shallower snow depths in less time. This is a general finding that happens throughout the winter as well as within each season. Migratory caribou at an individual level can show a low fidelity to seasonal use of some areas including the winter home range (Le Corre et al., 2014, Nagy et al., 2012), and variation in snow depth between years may be a reason that there is so little overlap between years of seasonal home range.

The significance of these results is that they have examined an area that does not have a lot of published research. The Government of the Northwest Territories and the Government of Nunavut over the years have continued to monitor the Qamanirjuaq herd and produce valuable technical and status reports used in the management of this herd. Unfortunately, the potential impact of a changing arctic climate has not been evaluated in depth. These gaps in knowledge are of vital concern to the local communities that rely on the herd for subsistence. My project has begun to fill in this knowledge gap by analyzing how presence/absence of snow and snow depth impacts this herd.

The QAM herd collar data obtained for this thesis gives a representation of the activities and ranges that are used by the cows. The data, covers a period of 16 years, however, in 1975 and 1976 observations were made that the QAM herd wintered north and northwest of Baker Lake (Campbell et al., 2010). This is in stark contrast to the home range data results found in this project (Figure 17 in Appendix). This suggests that the seasonal range use of the herd may have shown changes previous to the study period covered by the available data.

My results could be understood to a greater degree if Inuit traditional ecological knowledge (TEK) of snow and climate conditions from the area were available to be incorporated. Riseth et al. (2011) understood that there is great potential if scientific data is collected and analyzed alongside of TEK. There is some TEK that has been documented from the area however, it is often difficult to obtain and not readily used in scientific reports. One piece of Inuit TEK that I came across in my research was a statement by an Inuit elder Nutaraluk in a paper by Ferguson et al. (2001). Nutaraluk stated that “snow cover is not usually a problem for caribou because they adjust their distribution within a given winter range”. Although such a shift would require that there are undisturbed areas available to move to. This option of moving to another area is very understandable with a herd like QAM that vary their seasonal home ranges from year to year.

A possible avenue for future research would be to use the research concept of Richard et al. (2014). When researching mountain goats (*Oreamnos americanus*) they used a finer scale than this thesis did. The study showed that mountain goats are impacted greater by recent snow fall then by cumulative snow depth, although cumulative snow depth plays a role in determining the overall winter range used between years. I see the study by Richard et al. (2014) as a potential direction for further research on the QAM herd. A major obstacle is, that the observational weather data available for the QAM home range is of poor quality. In addition to more accurate weather data, satellite collars with more frequent recording schedules and accuracy would also be needed. This potential research would go beyond the impacts at a seasonal scale and increase the understanding of the daily impacts of snow fall on movement.

As climatic conditions in the arctic change a possible future issue for the QAM herd is rain-on-snow (ROS) events. These events are currently an area of interest to many arctic researchers (Hansen et al., 2011). The ice barrier that is created over vegetation during an ROS event is detrimental to caribou (Stien et al., 2010, Lee et al., 2000). It has been documented in Svalbard that reindeer are impacted by ROS events (Stien et al., 2010). At present the significance of these ROS events on the QAM herd are unknown. Unfortunately my interest in this area of research was impeded. As I discovered, obtaining the necessary data to perform such a study is not currently possible. As previously mentioned the data recorded at the weather stations in the QAM herd’s home range is inconsistent and incomplete. Nunavut hunters observed that there was an icing event with the home range of the QAM herd. It occurred along the coast of Hudson Bay in the southern portion of Nunavut and was up to 2 inches thick and extended 100km inland (Campbell, 2005). However this event was not picked up in the weather data available for this thesis. I see this as a potential area of research, with arctic temperatures rising the frequency of these events could greatly affect the QAM herd and those that rely on it for subsistence.

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7 APPENDIX

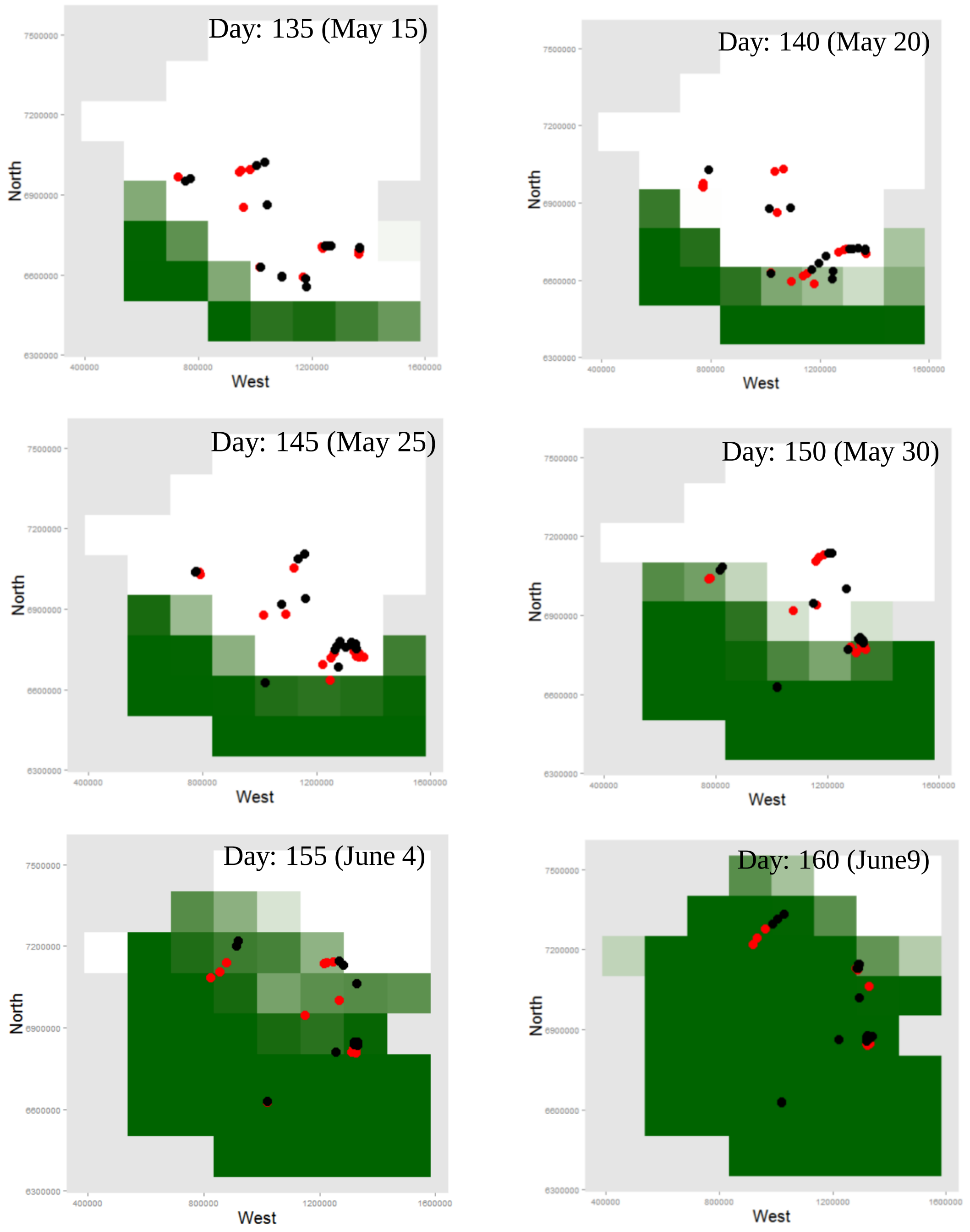

Figure 15: Progression of a late spring melt. The advancement of snow free ground during the spring of 2005. This is the mean snow depth from all years on each day of year (Day) in the 150 Km^2 grid. Dark Green is for snow free Ground and white is for snow cover with a mean of >0.2 meters depth. The gradient from dark to light green is between 0 and 0.2 meters of snow depth. The Black dots are for the 2 days preceding and including the Day, red dots are the previous 1-5 days before Day (for Day 140 black is Day 138,139, and 140; red is Day 135, 136, and 137).

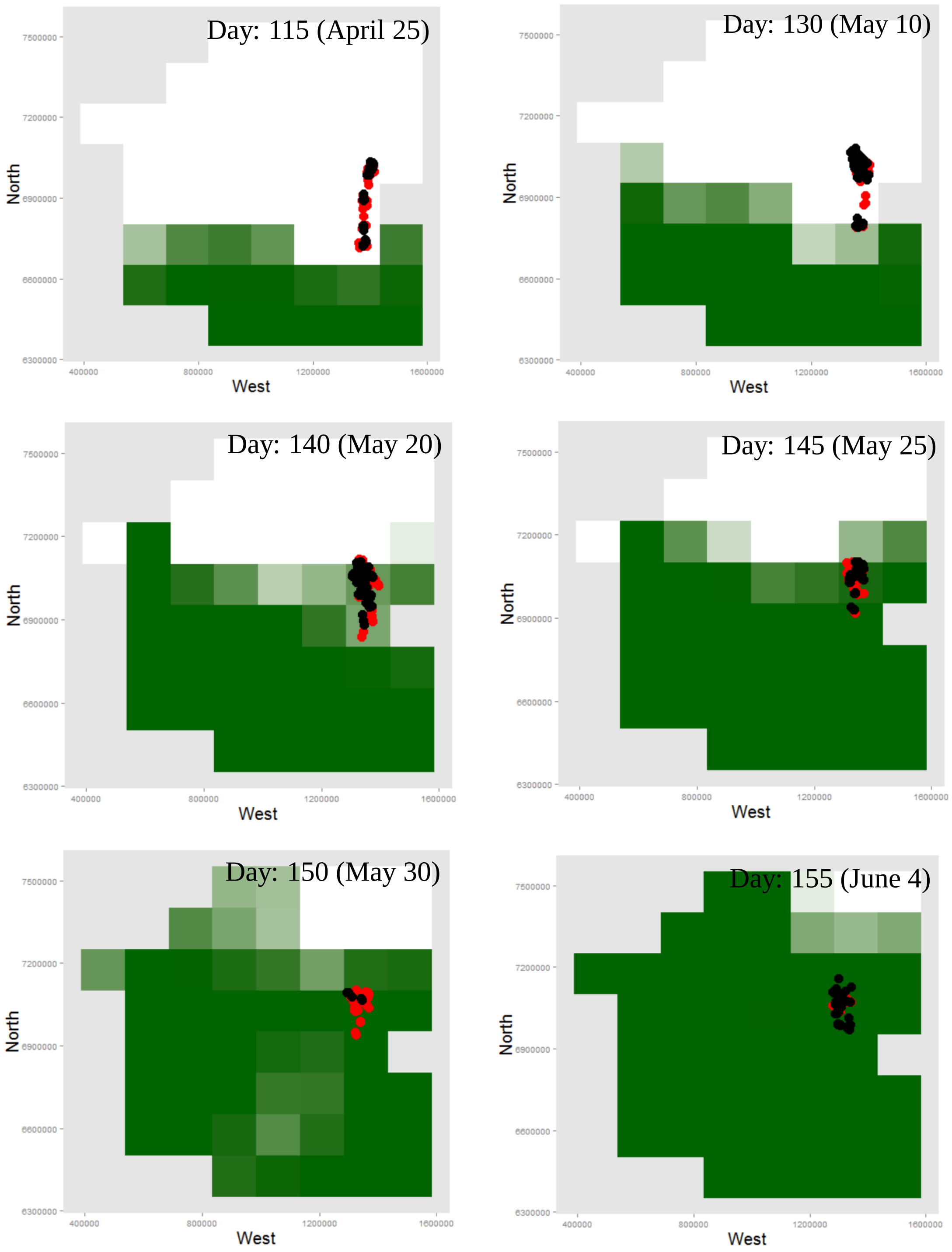

Figure 16: Progression of an early spring melt. Same as Fig 12 but for spring 2006

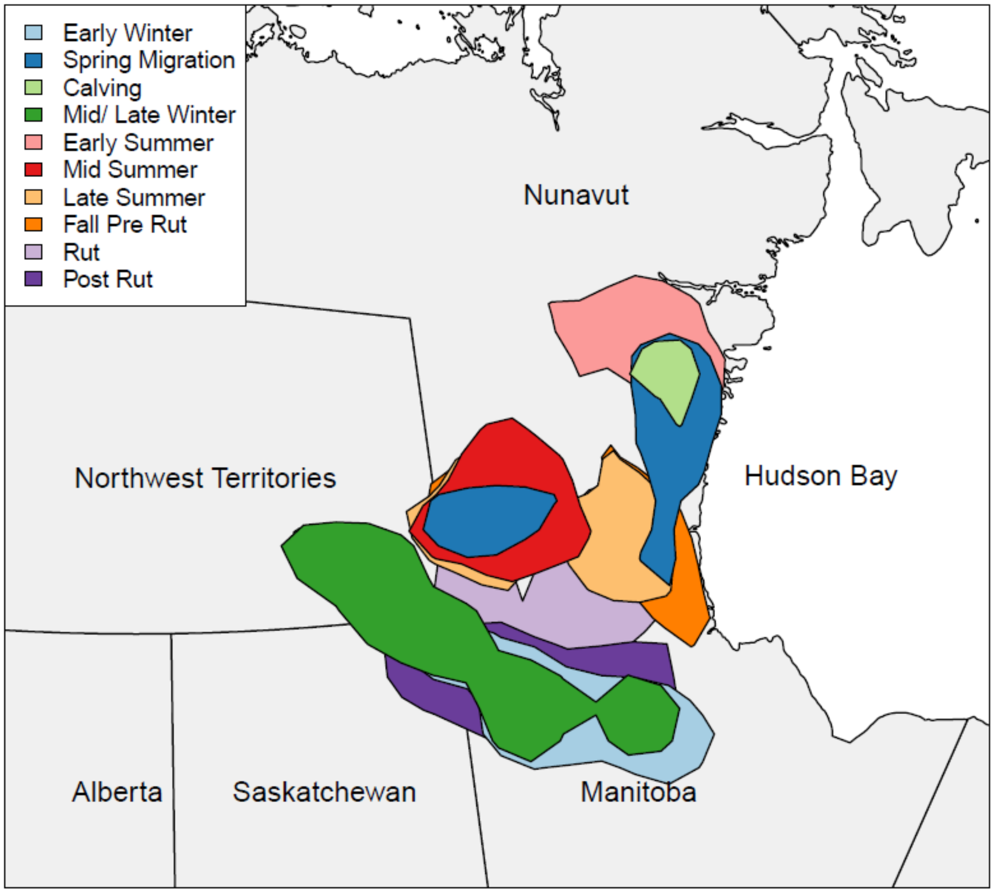

Figure 17: Qamanirjuaq herd seasonal home range for all years and collars at 50% usage.