Long-Term Habitat Trends in Barren-ground Caribou

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General Abstract

Global and local climate patterns may affect barren-ground caribou (*Rangifer tarandus groenlandicus*) populations. I predicted global climate changes to be correlated with periods of population decline, and local changes to be more pronounced on the habitat of caribou with a declining population. In chapter 1, the Arctic Oscillation (AO), changes in normalized difference vegetation index and phenology were used as measures of global and local climate. In chapter 2 environmental variables and caribou presence points were used to build Maxent habitat models. There was no consistent correlation with the positive AO phase and periods of population decline, or phenology trends and the habitat of caribou with a declining population. Maxent models underestimated the amount of suitable habitat spatially and failed to model suitable habitat temporally. This thesis is the first to look at a range of density-independent variables over a long time period and model suitable habitat for multiple herds.

Résumé général

Les changements climatiques globaux et locaux peuvent affecter les populations de caribous de la toundra (*Rangifer tarandus groenlandicus*). J'ai prédit que les changements globaux sont corrélés avec les périodes de déclin des populations de caribous, et que les changements climatiques locaux ont des effets davantage prononcés sur les habitats des caribous en situation de déclin. Dans le chapitre 1, j'ai examiné l'oscillation Arctique. Les variations temporelles significatives de l'indice différentiel normalisé de végétation (IDNV), et la phénologie, ont été utilisées comme mesures de climat mondial et local. Au chapitre 2, les variables environnementales locales et des points de présence de caribous ont été utilisés comme intrants dans les modèles d'habitats de Maxent. J'ai constaté qu'il n'y a pas de corrélation consistante entre la phase positive de l'oscillation arctique et les périodes de déclin des populations, ou de tendance phénologique dans l'habitat des caribous en situation de déclin. Les modèles de Maxent sous-estiment la quantité et la dimension des habitats convenable, et n'ont pas réussi à modéliser les habitats adéquats sur une base temporelle. Cette thèse est la première à regarder une vaste gamme de variables locales et globales indépendantes, sur une longue période de temps, et à modéliser l'habitat adéquat pour de multiples hordes de Caribous.

Table 1.1: Acronyms and abbreviations for thesis overview

Acronym	Definition
AO	Arctic Oscillation
AVHRR	Advanced Very High Resolution Radiometer
Bath	Bathurst herd
Bev	Beverly herd
BIOCLIM	Bioclimatic Modeling
BNE	Bluenose-east herd
BNW	Bluenose-west herd
Cape B	Cape Bathurst herd
GARP	Genetic Algorithm for Rule Set Production
INDVI	Integrated Normalized Difference Vegetation Index
NDVI	Normalized Difference Vegetation Index
Qam	Qamanirjuaq herd
Tuk P	Tuktoyaktuk Peninsula herd

Chapter 1: Thesis Overview

Caribou Natural History: A Brief Summary

Barren-ground caribou (*Rangifer tarandus groenlandicus*) have the largest number of subspecies of caribou in Canada (Mallory & Hillis, 1998). These caribou are associated with areas north of the tree-line (hence, 'barren-ground"), such as in the Southern Arctic ecozone (Banfield 1954; Calef & Heard 1981; Gunn et al., 2011). There are eight barren-ground caribou herds living in Nunavut and the Northwest-Territories: Tuktoyaktuk Peninsula (Tuk P), Cape Bathurst (Cape B), Bluenose-east (BNE), Bluenose-west (BNW), Bathurst (Bath), Beverly (Bev), Qamanirjuaq (Qam), and Ahiak. The herds are classified based on the location of their calving habitat (Zalatan, 2006).

Barren-ground caribou migrate large distances each year to take advantage of the most nutritious sources of vegetation available, and thus have distinct seasonal habitats (Figure 1.1). Most herds spend winters below the tree-line in the forest; except for the Tuktoyaktuk Peninsula, Cape Bathurst and Ahiak, whose winter range is located on the tundra (Russell et al., 2002; Nagy et al., 2005). Lichen, which is high in energy, is the caribou's main source of food during the winter months. Caribou select their winter range by balancing the amount of lichen available and snow conditions (Gunn et al., 2009). Caribou search out areas where they can easily dig through the snow and use their hooves to create "craters" to access lichen (Fancy & White, 1985). In the summer, barren-ground caribou switch their diet to vascular plants, which provide high quantities of protein during the calving and summer months (McNeil et al., 2005).

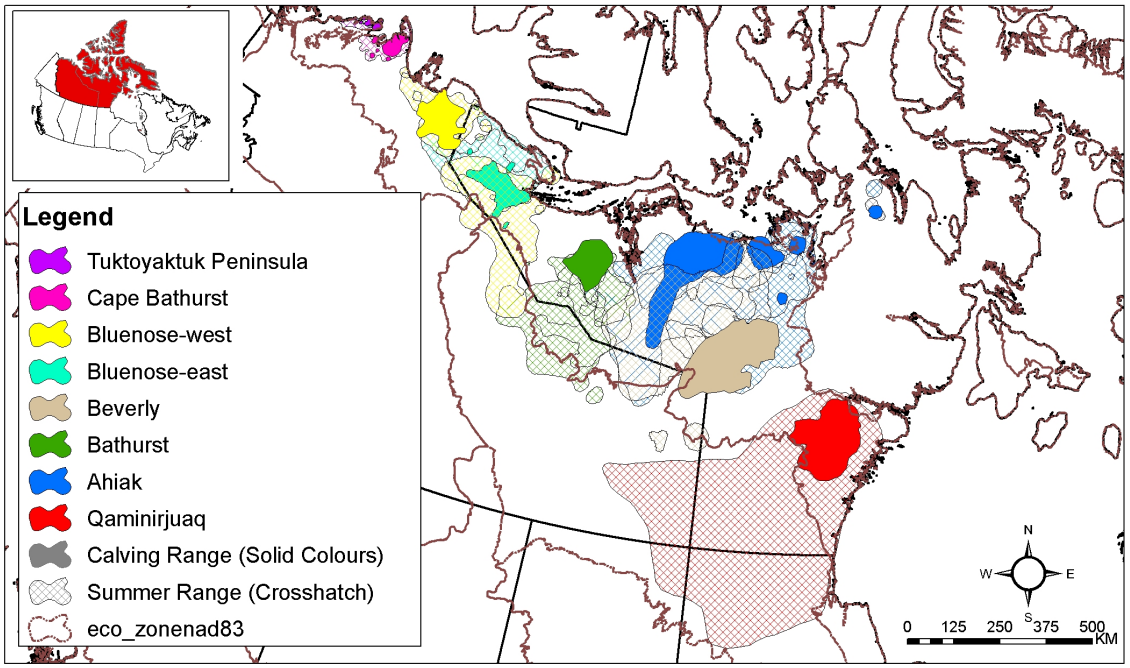

Figure 1.1: Map showing the locations of migratory North American caribou and their calving grounds (Russell et al., 2002).

Seasonal migration is initiated by pregnant cows (Chan-McLeod et al., 1994; Heard et al., 1996). Caribou time their arrival on the calving grounds with the onset of the growing season, so that when calves are born they can take advantage of the highest quality vegetation, and in turn produce more milk (Chan-McLeod et al., 1994), which results in higher calf survival (McNeil et al., 2005). The body condition of adult caribou also improves from the winter at a faster rate (Adamczewski et al., 1987; Chan-McLeod et al., 1994). While on the summer range, caribou forage as much as possible to replenish their energy and body fat so they will have a greater success during the mating season, and a higher survival rate the following winter (Cameron & VerHoef, 1994; Gerhart et al., 1997; McNeil et al., 2005).

Caribou populations fluctuate naturally over decadal time scales (Gunn, 2003; Russell et al., 2008). Barren-ground caribou populations have reached low numbers in the past, and have rebounded to a healthy population size (Gunn et al., 2009; Nesbitt & Adamczewski, 2009). For example the majority of barren-ground caribou populations were low in the late 1960's and early 1970's, then rebounded to peak numbers in the late 1980's and 1990's (Gunn et al., 2009).

Recent barren-ground caribou population cycles may be more extreme than their previous population fluctuations. Barren-ground caribou herds in the past have generally followed the same population cycle, but recent estimates indicate inconsistencies among herds in population trends. The BNE herd increased from 66 186 (95% confidence limits, CI= 62 625 – 69 747) in 2006 to 98 600 in 2010 (The Bluenose Caribou Management Plan Working Group, 2011), while most of the other herds declined. The Porcupine herd population (not included in this study) increased more slowly and decreased faster compared to other herds (PCMB, 2012). In addition, the population fluctuations of the Porcupine herd

are believed to be greater than in the past (PCMB, 2012). The Bathurst, Cape Bathurst and Bluenose West herds all experienced a slow decline in the 1990's, but a rapid decline in the mid to late 2000's (Nesbitt & Adamczewski, 2009).

Aerial surveys have been used to estimate caribou population estimates since the 1970's (Zalatan, 2006). Population estimates used in this thesis were based on the photocensus method, which is thought to be the most accurate (McLean & Russell, 1992). This technique estimates caribou populations from a plane, when they have formed a large post-calving group that enables caribou to avoid insect harassment (McLean & Russell, 1992). However, such aerial surveys are expensive, and their effectiveness is reduced if weather conditions hamper visibility, or if caribou herds are dispersed over broader areas. The lack of consistent, temporal population estimates makes it difficult to fully understand past and present caribou population cycles. Nevertheless it is critical to attempt to understand, and make management decisions based on the data available to help monitor their populations.

Both density-independent and density-dependent factors affect caribou populations (Siether, 1997; Gaillard et al., 1998; Tews et al., 2007; Joly & Klein, 2011). Populations are density-dependent when their growth rate decreases while their density increases (Tews et al., 2007). Caribou populations may decline (lower survival, and/or reproduction rates), as a result of density-dependent variables (Patterson & Power, 2002). For example, the amount of forage declines, while population density increases. Over-grazing (Nellemann, 1997), intra-specific competition (Skogland, 1985), trampling vegetation (Morneau & Payette, 1998) and disease are all density-dependent factors that can have a negative impact on caribou populations (Joly & Klein, 2011). Density-independent variables have the same proportional effect on population regardless of population densities (Tews et al., 2007).

Density-independent factors influencing caribou populations include climate variability, insect harassment, predation, habitat modifications, and human activities. Climate, both directly and indirectly, is believed to have the largest influence on caribou population ecology (Joly & Klein, 2011). Components making up the climate system such as snow, ice, temperature, wind, rain and clouds, vary regionally and seasonally, thus may not affect all caribou herds the same (Joly & Klein, 2011). Because there are so many factors that could affect caribou population dynamics, it is difficult to determine the exact impact each is having (Figure 1.2).

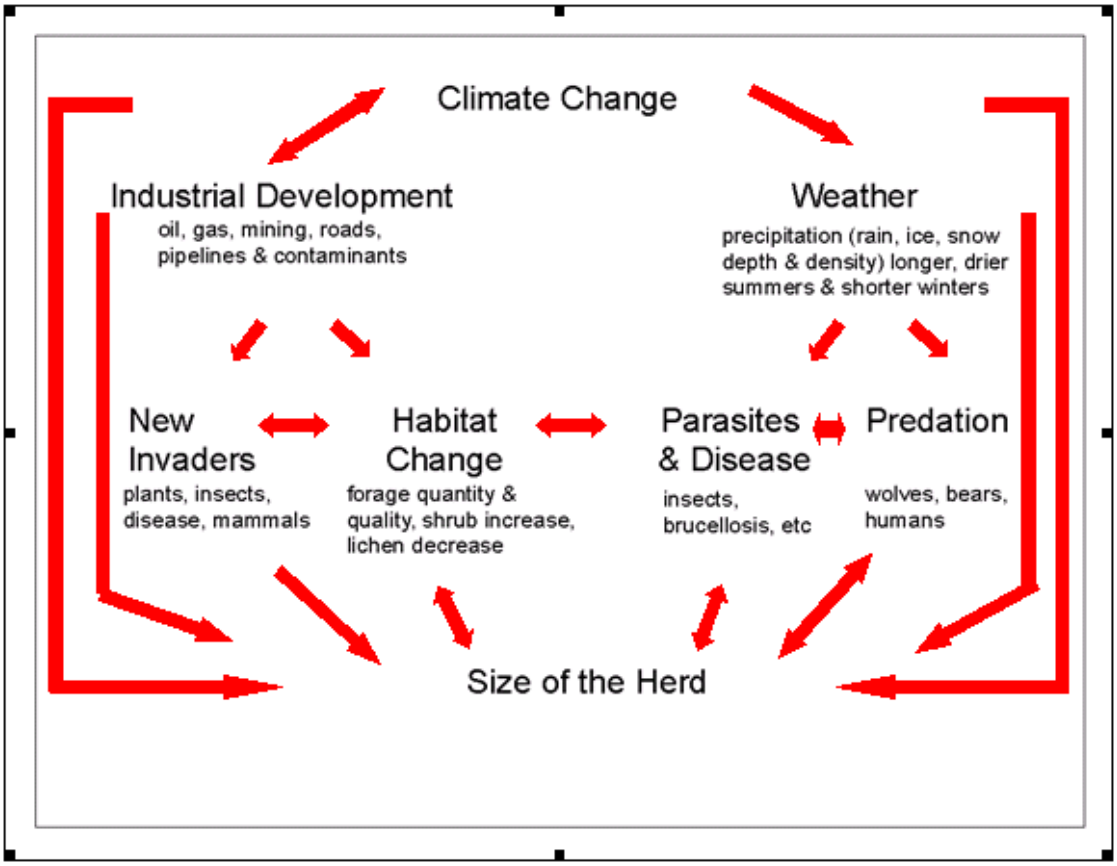

Figure 1.2: A model representing the complexity of the many factors affecting caribou populations (Based on the design of L. Weaver from Joly & Klein, 2011).

The Arctic Oscillation (AO) is a large-scale climate pattern centered over the Arctic (Thompson & Wallace, 1998) that may play a role in density independent regulation of ungulate populations (e.g. Post & Stenseth, 1999). The AO consists of two phases, the positive (low pressure in polar regions), and negative phase (high pressure in polar regions), with each phase lasting years or even decades (Mantua et al., 1997, Hartmann & Wendler, 2005). More than half of the warming in the eastern Arctic is related to the AO (Rigor et al., 2000).

Links between large-scale climate patterns (such as the Arctic Oscillation), and ungulate population fluctuations have been widely documented (e.g. Post & Stenseth, 1999; Post & Forchhammer, 2002; Aanes, et al., 2002; Hebblewhite, 2005; Zalatan, 2008). The negative phase of the AO is associated with cold, dry winters, which in turn leads to easier forage accessibility, and a decrease in predation, because caribou have a better chance of escaping predators when there is less snow (Zalatan, 2006). In contrast the positive phase of the AO has warm, wet winters, and cold, wet, cloudy summers. These conditions are not desirable for caribou because an increase in snow causes a reduction in available forage and may make it more difficult for caribou to evade predators. During summers affected by the positive phase of the AO, biting insect numbers increase and poorer growing conditions for vegetation may reduce forage quality (Zalatan, 2006). When caribou spend relatively greater amounts of time and energy to escape insects rather than feeding, their body masses can decline (Helle & Kojola, 1994; Weladji et al., 2003), which can lead to lower survival rates (Festa-Bianchet et al., 1997) and reproductive success (Festa-Bianchet et al., 1998; Sand, 1996). In addition, unfavourable growing conditions for forage can also reduce caribou body mass, by reducing the quality (Boelman et al., 2005), quantity (Jonasson et al., 1986) and accessibility of forage (Barrette & Vandal, 1986).

Forest fires are likely to increase in dry, warm conditions resulting from climate change (Overpeck et al., 1990). More forest fires in turn reduce the amount of available lichen, and cause caribou to change their migration routes (Scotter, 1969; Festa-Bianchet et al., 2011). Caribou inhabiting the boreal forest used burned areas less frequently for decades after fire occurs, due to the slow regeneration of lichen (Thomas et al., 1996; Joly et al., 2003).

Increases in winter temperature are associated with more freezing and thawing snowpack cycles (Gunn et al., 2009), and more snow in some areas (Brotton & Wall, 1997; Maxwell, 1992). Average temperature increases of 3º to 6ºC have been observed on the Bluenose-east, Bluenose-west and Bathurst winter ranges since the mid 1980's (Gunn et al., 2009). Ice and rain can also have negative impacts on the body condition of caribou. When temperature warms, causing ice to melt or rainfall, and is quickly followed by a drop in temperature, an icy crust forms on the top of the snow. Much more energy is expended trying to break through the crust and access food (Adamczewski et al., 1988; Russell et al., 1993), which could lead to a reduction in body fat in the spring, and lower calf survival rates (Cameron et al., 1993; Cameron & VerHoef, 1994). Caribou also become more vulnerable to predation because it is more difficult to escape in icy conditions (Brotton & Wall, 1997; Bergerud et al., 2008). Years with large amounts of snow have been linked with lower calf birth weights (Adams, 2005), lower calf and adult survival (Kumpula & Colpaert, 2003), reduced growth rate in calves, fewer pregnancies in the fall, weak body condition for calves in the winter months, and late parturition the next spring (Adams & Dale, 1998; Adams et al., 2006). The amounts of snow can also affect the date of vegetation onset, which can result in nutritional deficiencies and a lower reproductive success (Adams et al., 2006).

Local climate conditions largely control the quantity and quality of forage vegetation in the calving and summer seasons, which are essential for caribou growth and survival (Chapin et al., 1995; Joly & Klein, 2011). When pregnant cows begin their migration toward the calving grounds their food source switches from lichen to moss and evergreen shrubs until new emergent vegetation becomes available (Gunn et al., 2009). This typically occurs during, or within a week of calving, when their nutritional requirements are highest. The timing and rate of vegetation greening-up is therefore a key factor in determining the survival of calves (Gunn et al., 2009). Increases in temperature are likely to lead to an earlier snowmelt and start of the growing season, which may contribute to lower caribou survival. For example cotton grass forage is most nutritious and digestible when it first emerges, and then declines significantly after a few days. If caribou are not able to shift their migration to match the earlier snowmelt, there may be a lot less high quality vegetation available (Eastland & White, 1990).

It is unclear how temperature changes during the summer months will affect caribou populations. On one hand, increases in summer temperature and precipitation result in increases in vegetation biomass, which enables caribou to build body mass for the winter (Gunn et al., 1990). However, increases in temperature along with full sunlight and low precipitation (Shaver et al., 1986; Chapin et al., 1995) can cause vegetation quality to decline (Gunn et al., 1990). Increases in temperature may cause an increase in the ratio of carbon to nitrogen, in turn lowering the quality of some vegetation species for part of the growing season (Walsh et al., 1997).

Increases in summer temperatures will also lead to an increase in insect harassment (Gunn et al., 1990). Caribou summer ranges are also inhabited by ectoparasitic mosquitoes (Culicidae), black flies (Simuliidae), and oestrid flies (Oestridae) (Toupin, Huot & Manseau,

1996; Hagemoen & Reimers, 2002). Insect harassment can cause caribou to alter their habitat selection and seek shelter in windy, elevated areas (White et al., 1975; Downes et al., 1986; Ion & Kershaw, 1989; Anderson & Nilssen, 1996; Hagemoen & Reimers, 2002). Caribou may also experience a decrease in body condition due to blood loss from parasitic infections, such as gastrointestinal nematodes (Hagemoen & Reimers, 2002; Hughes et al., 2009), and an energy deficit because caribou spend more time and energy escaping insects than feeding on vegetation (Pollard et al., 1996; Russell et al., 1993). Even small increases in summer temperature and the growing season are predicted to result in an increase in the amount and distribution of insects, parasites and diseases (Joly & Klein, 2011).

Hunting can have serious impacts on population sizes, especially when the population is in a declining phase. Modern advances in hunting, snowmobile technology, and increased road access have made it much easier to track and kill caribou, even when population numbers are low (Powell, 2004; Nesbitt & Adamczewski, 2009). Currently, the allowable harvest does not change based on the size of the caribou population, and hunter harvest for many herds has not been consistently documented (Nesbitt & Adamczewski, 2009; Festa-Bianchet et al., 2011). For example when the Bathurst population was high in 1996, the hunter harvest would have been about 2% (Nesbitt & Adamczewski, 2009). The same number of caribou harvested in 2009 would have been approximately 22% of the caribou population (Nesbitt & Adamczewski, 2009). Biologists feared that the Bathurst was heading for the same drastic decline as the Beverly herd, so the NWT Government introduced a hunting ban on the winter range of the Bathurst herd beginning January 1st 2010 (Nesbitt & Adamczewski, 2009; WRRB, 2010).

If caribou populations are large, over-grazing and trampling of vegetation may also be contributing to the long-term decline of caribou populations. When caribou populations

are large, the quantity of available forage can be reduced if the amount of grazing caribou exceeds the regeneration rate of vegetation. After a few decades of over-grazing, caribou also compete for lower quality vegetation (Klein, 1968; Leader-Williams, 1988). This can then result in nutritional loss, and reduced body condition (Joly & Klein, 2011). In addition, when caribou are migrating in large herds the high volume of tramping can quickly destroy lichen. When both trampling and overgrazing occur simultaneously, lichen may disappear entirely in a very short period of time (Morneau & Payette, 1998). In dry conditions, fruticose lichens, which are preferred by barren-ground caribou, especially those in the *Cladina* genus (Klein, 1991; Heggberget, Gaare & Ball, 2002) are very susceptible to trampling (Haapasaari, 1988; Biermann & Daniels, 1997). Vegetation damage from trampling may take a long time to recover because the most common species of lichen, including *Cladina* species, have slow growth rates (Pegau, 1968; Ouzilleau & Payette, 1975).

Distribution Modeling

Accurate predictions of how species' distributions change in response to shifting environmental conditions will inform management activities that may improve conservation prospects (Kerr et al., 2007). Habitat modeling has been used to investigate the movement of invasive species (Thuiller et al., 2005), responses to climate change (Thomas et al., 2004), and spatial relationships of species diversity (Graham et al., 2006). Traditional habitat models required both species presence and absence data (Zarnetske et al., 2007; Baldwin, 2009). However, because it is difficult to obtain and verify absence data there has been a greater effort in the last decade to create models based only on presence data, for example, Genetic Algorithm for Rule Set Production (GARP), Bioclimatic Modeling (BIOCLIM), and Maxent (Baldwin, 2009). There have been many comparative studies that have shown

models built using software (called Maxent) using the maximum entropy principle (Maxent) perform well relative to other species distribution modeling methods (Elith et al., 2006; Hernandez et al., 2006; Phillips et al., 2006). It is vital to note that Box's rule for models applies also to species distribution models: all models are wrong, but some are useful (Box, 1979). Predictions of species' range limits relative to environmental conditions prevailing on those ranges represent testable hypotheses.

Maxent approximates the largest spread (maximum entropy) of a species' presence across a geographic landscape using incomplete data (Phillips et al., 2006; Phillips & Dud'ik, 2008). Sampling points over the known habitat of the species and information about environmental constraints within the habitat are compared to background locations (Dud'ik et al., 2007). Some advantages of Maxent are that it can use both continuous and categorical variables (Phillips & Dud'ik, 2008), that it has a regularization component to help prevent over-fitting (Phillips & Dud'ik, 2008), that it does not require as many presence locations compared to other modeling approaches (Elith et al., 2006; Hernandez et al., 2006; Phillips et al., 2006), and that it is relatively robust to bias that could arise from moderate errors in the accuracy of spatial location of the presence data (Graham et al., 2008).

Maxent has been used to predict suitable habitat and species distributions for many different types of wildlife including Grey Crowned-cranes (*Balearica regulorumgib bericeps*) (Stabach et al., 2009), Geckos (*Uroplatus spp*.) (Pearson et al., 2007), and Mexican Herpetofauna (Urbina-Cardona & Flores-Villela, 2010). A recent study by Environment Canada (2008) used Maxent models as evidence to support the identification of critical habitat for Woodland caribou by using the environmental niche analysis to interpret the pattern of occupancy in the present extent of occurrence. Maxent has been used to assist in making conservation management decisions; however, the results of the models are rarely

tested temporally. Despite being widely used for projections of conservation (Urbina-Cardona & Flores-Villela, 2010; Carroll, 2010; Torres et al., 2010; Razgour et al., 2011), Maxent and other species distribution model methods have rarely been evaluated for their capacity to predict through time.

Remote Sensing

Satellite remote sensing has been used by ecologists over the past few decades as a monitoring tool over large and small spatial extents to help make informed management decisions. A general definition of remote sensing is acquiring information about the earth's surface by recording and analyzing reflected or emitted energy. Satellite remote sensing has been used to map species spatial habitat and characteristics and to monitor natural and anthropogenic habitat disturbances (i.e. change detection) (Kerr & Ostrovsky, 2003). Some advantages of satellite remote sensing are: (1) it is a relatively inexpensive way to rapidly acquire up-to-date information over large geographical areas, (2) it can monitor areas that are inaccessible from the ground, and (3) the information can be combined with other spatially referenced datasets in a GIS, to get an overall picture of the landscape (Poompavai & Ramalingam, 2009). These characteristics make remote sensing data sources particularly valuable for measurements of environmental conditions in remote areas, such as those prevailing across the calving and overwintering territories of barren ground caribou.

There are many different types of remote sensing satellites, each with strengths and weaknesses. The Advanced Very High Resolution Radiometer (AVHRR) is a coarse resolution (1 km) optical satellite (Reed et al., 1994). Some advantages of AVHRR include daily global coverage, which is useful for mapping and monitoring vegetation, forest fires and sea surface temperatures (Kerr & Ostrovsky, 2003). AVHRR has multiple bands, each

covering a different portion of the electromagnetic spectrum; therefore it is referred to as multispectral and monitoring indices can be derived (Reed et al., 1994). For example the Normalized Difference Vegetation Index (NDVI) is calculated using the red and near infrared (NIR) bands based on the following equation: NDVI = (NIR - RED)/(NIR + RED). NDVI is useful because it has been shown to be a surrogate for the area of green leaves, and aboveground net primary productivity (Reed et al., 1994; Pettorelli et al., 2005). Integrated NDVI (INDVI) is calculated as the sum of all NDVI measurements taken over the entire growing season, and provides a proxy for overall annual productivity and growing biomass (Yang et al., 1998; Wentz & Schabel, 2000; Chen & Pan, 2002; Pettorelli et al., 2005). Incorporating satellite remote sensing with other caribou monitoring techniques and research may improve predictions of caribou herds' population fluctuations.

Introduction to Thesis Topic

Many past studies have attempted to determine the influence of various environmental factors on fluctuations in barren-ground caribou (*Rangifer tarandus groenlandicus*) herd populations. However, it is still unclear why some herds are at critically low numbers, while others are increasing or are stable. The majority of previous caribou research has focused on a short period of time and/or on a single caribou herd. Environmental stressors may not have the same effect on all caribou herds at the same time because climate changes are not consistent over the Canadian Arctic (Rigour et al., 2000; Gunn et al., 2009). Thus different management strategies may be needed for each caribou herd. If periods of barren-ground caribou population decline are related to the positive phase of the Arctic Oscillation, or lower amounts of vegetation quantity, quality, or amount of suitable habitat are observed on the habitat ranges of barren-ground caribou with a declining

population status compared to herds with an increasing or stable population, managers will have improved capacity to understand caribou population fluctuations in the study region that could also prove useful in predicting their future trajectory. If predictions are incorrect, managers will nevertheless gain a practical benefit because their focus can shift to other (such as density-dependent) factors that could affect caribou population dynamics.

It is unclear how large-scale and local climate have affected barren-ground caribou population abundance and habitat over the past two decades. I address this issue in Chapter 1 of this thesis. I examined several density-independent climate and plant phenology trends from 1985-2006 to determine if there was an association with periods of population decline or the habitat location of the Barren-ground caribou herds in the Northwest Territories/Nunavut region.

Decreases in habitat area due to climate and landscape change may reduce caribou populations. Chapter 2 examines changes in suitable habitat using local climate and landscape variables together with known caribou presence locations. These are used as input into Maxent to build habitat models and project them forward through time. Maxent was used as a tool to determine if the amount of suitable habitat on the calving or summer caribou ranges were predictable through time and to evaluate whether Maxent is a reasonable tool for management of caribou.

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Table 2.1: Acronyms and abbreviations for Chapter 2

Acronym/Abbreviation	Definition
AO	Arctic Oscillation
AVHRR	Advanced Very High Resolution Radiometer
Bath	Bathurst
Bev	Beverly
BNE	Bluenose East
BNW	Bluenose West
Cape B	Cape Bathurst
DEC	Decrease
Df	Degrees of Freedom
INC	Increase
INDVI	Integrated Normalized Vegetation Index
NAO	North Atlantic Oscillation
NDVI	Normalized Difference Vegetation Index
NWT	Northwest Territories
pers. Comm	Personal Communication
PDO	Pacific Decadal Oscillation
Qam	Qamanirjuaq
STB	Stable
Tuk P	Tuktoyaktuk Peninsula
UNK	Unknown
VI	Vegetation Index

Chapter 2 – Relationship between Barren-ground Caribou populations and trends in climate and phenology

(1) Abstract

Changes in climate and vegetation may be influencing Barren-ground caribou (*Rangifer tarandus groenlandicus*) populations in the Northwest Territories (NWT)/Nunavut region (Zalatan, 2006; Gunn et al., 2009; Gunn et al., 2011; Chen et al., in press). If that is so, differences is global climate should predict periods of population fluctuation and local climate differences should results in lower amounts of vegetation quantity or quality on the habitat ranges of caribou with a declining population status. To test this prediction, I examined the phase of the Arctic Oscillation (AO; refers to changes in sea level pressure over the Arctic (Thompson & Wallace, 2001) during periods of population increase and periods of population decrease. The average of the AO phase for all years in between population estimations, and the average of the AO phase the year prior to a population estimate were compared to periods of population increase and decrease. I also tested whether the habitat of caribou with an increasing, stable or declining population status was related to biomass quantity and timing of vegetation growth derived from satellite observations across northern Canada from 1985 to 2006, focusing on significant ($p<0.05$) temporal changes in greenness and phenology (start, end, length of growing season, integrated greenness, and the rate of increase in greenness) as measures of vegetation quantity and quality. The mean and slope in vegetation quantity and quality were compared between groups of caribou with an increasing, decreasing and stable population status. The positive phase of the AO, which causes greater snowfall, increased insect harassment, and reduced vegetation growth (Zalatan, 2006), had no association with periods of barren-ground caribou population

declines. The habitat ranges of caribou with a declining population status did not have a larger area with a significant increase in NDVI from 1985-2006, or lower amounts of vegetation quality or quantity. Population data for many barren ground herds are sparse, or have large error bars for some of the herds which may have affected periods of population increase or decrease, so results should be interpreted with caution. Nevertheless, large population fluctuations in NWT/Nunavut barren-ground caribou do not appear to relate to the Arctic Oscillation, and lower amounts of vegetation quantity or quality do not appear to be occurring on the habitat ranges of caribou which are declining in abundance. Downward trends in populations may reflect natural population cycles and density-dependent effects, such as locale-specific over-grazing, intra-specific competition, trampling and disease whose negative impacts on local population sizes may be amplified by hunter harvest. This is the first multi-herd, long- term test of density-independent effects, including herd-specific, satellite-based measurements of climate-driven phenological shifts, on population cycles of caribou in this region.

(2) Introduction

Determining the factors controlling population abundance of caribou in the Canadian Arctic may help prevent endangered herds from becoming extinct. Some caribou herds are increasing; however, most Northwest Territories (NWT)/Nunavut Barren-ground populations are decreasing (Gunn et al., 2011). Several factors could be contributing to their decline including habitat loss, vegetation quality and quantity, insect harassment, disease, hunting, and intra-specific competition (White, 1983; Russell et al., 1993; Boertje et al., 1996). Broad-scale climate patterns often predict population dynamics among Arctic mammals, including caribou (Post & Forchhammer, 2002; Aanes et al., 2002; Zalatan, 2008). For example a link was observed between the body mass of caribou calves in north-eastern Canada and the North Atlantic Oscillation (NAO) (Couturier et al., 2009). In addition, the Arctic Oscillation (AO) has been shown to influence caribou population fluctuations in the Canadian Northwest Territories (Zalatan, 2008), while the Pacific Decadal Oscillation (PDO) had an effect on caribou calf recruitment in the Canadian Yukon and interior Alaska (Hegel et al., 2010). These oscillations are important because they can predict the intensity of broad-scale climate patterns (Joly & Klein, 2011) and help explain differences in precipitation and temperature patterns over sizeable regions (Hurrell, 1995).

The NAO, AO and PDO are all able to influence changes in oceanic temperature and sea-level pressure (Hurrell, 1995). The difference in the normalized monthly mean sea-level pressure between Stykkisholmur (Iceland), and Lisbon (Portugal) is used to calculate the NAO. In contrast, mean monthly sea-level pressure over the northern hemisphere north of 20°N is used to calculate the AO (Thompson & Wallace, 2000). The

PDO is calculated from sea surface temperatures in the Pacific that are poleward of 20°N (Mantua et al., 1997). Because these large-scale climate patterns are calculated from values in different geographic areas, they do not affect all locations to the same degree. Greater than fifty percent of the temperature trends occurring in the eastern Arctic, and fewer than fifty percent in the western Arctic can be attributed to the AO. Therefore, the AO is a better measure than the NAO or PDO for examining the relationship between large-scale climate patterns and caribou population in the Northwest Territories/Nunavut region (Zalatan, 2006).

The AO is cyclical (Hartmann & Wendler, 2005), as are caribou population cycles (Gunn et al., 2011). AO varies seasonally and regionally (Post & Stenseth, 1999; Hartmann & Wendler, 2005). The cycle has a positive and a negative phase, and can remain in one phase for years or decades (Mantua et al., 1997; Hartmann & Wendler, 2005). The positive phase leads to wetter, warmer conditions in the north, and results from low sea-level pressure, while the negative phase leads to colder, drier conditions (Hartmann & Wendler, 2005). The warmer, wetter conditions in the winter would result in a larger amount of snowfall and freeze-thaw days, in turn making caribou more vulnerable to predators, and they would have a harder time digging through the snow to access vegetation (Pettorelli et al., 2005a; Tyler, 2010). The reverse winter conditions associated with the negative phase should be beneficial for caribou populations. The positive phase of the AO is linked to cloudy, cold and wet summers (Zalatan, 2006). This is detrimental to caribou populations because it can increase the number of biting insects, causing caribou to expend more energy trying to escape the insects (Noel et al., 1998) and reduce optimal growing conditions for vegetation (Zalatan, 2006). The model

below (Figure 2.1) describes the relationship between the phase of the AO and caribou population dynamics.

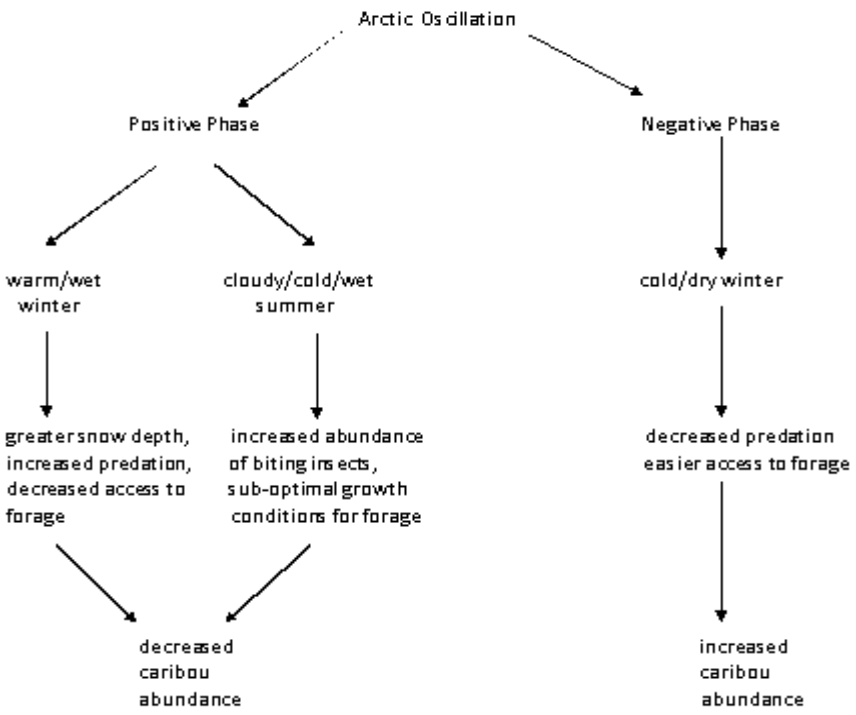

Figure 2.1: Model to illustrate how the phase of the AO affects caribou populations during the winter and summer months (Based on Zalatan, 2006).

Local climate conditions have also negatively impacted caribou populations (Chapin et al., 1995; Gunn et al., 2011). For example, local climate can alter vegetation phenology, quality, and quantity. Phenology is the timing (beginning, end and length) of seasonal vegetation (Walther et al., 2002). Forage in the arctic varies seasonally (Pettorelli et al., 2005c), and is critical to the health of caribou because it provides energy, improves body condition (Chan-McLeod et al., 1994), and increases juvenile survival (Inouye et al., 2000, Visser et al., 2004). Caribou can be affected by the timing of the growing season (Pettorelli et al., 2005c). Climate change is causing snow to melt earlier in the Arctic (Stone et al., 2002), and in turn is altering the timing of the start of the growing season (Myneni et al., 1997). Caribou are migratory and have synched their spring migration to coincide with the beginning of the growing season, so that their offspring will have access to vegetation during the entire growing season (Rutberg, 1987). It is not clear whether caribou will be able to change the timing of their migration to match the shift in timing of the growing season. The body condition of female caribou also relates to forage quality and quantity, which then affect reproduction and calf survival (Reimers, 1983; Skogland, 1986). It is important to note that not all types of plants provide the same nutrients for caribou. For example, some types of lichen have higher amounts of protein and are easier to digest (Griffith et al., 2002), so increased availability of that resource should have a positive impact on individual caribou health and overall caribou population sizes.

It is uncertain whether recent climate changes have altered forage quantity or quality across large enough areas to account for observed population fluctuations among

Barren ground caribou. However, vegetation phenology is affected by climate change (Gunn et al., 2011). Timing of snowmelt triggers the start of spring vegetation growth, which in turn affects the survival rates of alpine ungulates (Rutberg, 1987; Kudo, 1991). The mean start of the growing season in Europe from 1989 to 1998 began eight days earlier (Chmielewski & Rotzer, 2002), and 5-6 days earlier in North America from 1959 to 1993 (Schwartz & Reiter, 2000). This shift in the growing season may not affect all caribou herds in the same way. An increase in spring temperature has been observed on the Porcupine herd range for the past three decades (Griffith et al., 2002). As a result there has been a higher quantity of food available after calving, and thus a higher rate of calf survival (Griffith et al., 2002). However, there were also twice as many freeze-thaw days during spring migration when the Porcupine herd population was in a declining phase (1989-2001), compared to the previous increasing population phase (1975-1988) (Griffith et al., 2002). An increase in the number of freeze-thaw days will increase the amount of energy caribou expend while migrating, accessing vegetation, and escaping predators (Griffith et al., 2002). A shift in the start of the growing season may result in more vegetation at the beginning of the growing season for some herds, but will also mean that end of the growing season is earlier, and will signal caribou to begin migrating from their summer habitat sooner (Griffith, pers. comm.). Juvenile offspring may not be able to forage for the entire growing season (Rutberg, 1987), which could reduce access to vegetation quantity and quality, and cause a decline in growth and survival rates (Visser et al., 2004; Pettorelli et al., 2005c). If caribou do not have enough protein and fat reserves for the winter, this would likely cause a decline in pregnancies and an increase in death rates (Gerhart et al., 1996; Gerhart et al., 1997). Continued phenological

shifts could indirectly cause caribou populations to decline in areas where the timing of the growing season negatively affected vegetation quantity.

Forage quality affects caribou survival. Plant phenology strongly affects forage quality (Laycock & Price, 1970), so phenology is among the most important determinants of habitat use by vertebrate herbivores (Fryxell, 1991; Albon & Langvatn, 1992). Remotely sensed information can be used to help monitor vegetation over large areas. For example the normalized difference vegetation index (NDVI) derived from remote sensing sources is often used because it is a proxy for aboveground net primary productivity (Pettorelli et al., 2005b). NDVI is measured by calculating the normalized difference between the red and near-infrared reflectance of vegetation (Tucker, 1979). NDVI increased during caribou peak-lactation from 1985-1999 for the Porcupine, Western Arctic, and Bathurst herds, suggesting earlier vegetation green-up. This trend was not observed on the Central Arctic, and Teshekpuk Lake calving ranges, which are located on wet coastal areas (Figure 2.2) (Russell et al., 2002). Caribou require particularly nutritious and digestible vegetation during their peak lactation period, which occurs while on their calving range. It is during this period that female cows experience energy deficits (Russell et al., 1993). Plants have the highest amount of protein and are most digestible in early growth stages and protein content decreases as the vegetation matures. Highest forage quality occurs at the beginning of the growing season (Crawley, 1983). Start of the growing season is usually calculated as the Julian day (the number of days since the start of the calendar year) when mean temperatures rise above 5°C for 5 consecutive days in the spring (Zhang et al., 2008) or from remote sensing when NDVI values get consistently larger than an NDVI threshold representing the start of the

growing season (Li pers. comm.). If the start of growing season advances this could have a negative impact on the survival and growth of many juvenile species including caribou because they may not migrate in time to access the highest vegetation quality during peak lactation (Inouye et al., 2000; Visser et al., 2004).

Few studies have looked at the effects of long-term global climate patterns (Griffith et al., 2002; Zalatan, 2008; Joly & Klein, 2011) and local phenology trends (Griffith et al., 2002) for Barren-ground caribou in the Canadian Arctic. To determine if global climate trends and vegetation quantity and quality may be playing a role in the population trends of Barren-ground caribou in the Canadian Arctic I will examine data from 1985-2006. Does the Arctic Oscillation explain barren ground population trends among observed herds in the Northwest Territories and Nunavut? I expect that the positive phase of the AO will be associated with caribou population decline. This phase leads to warm, wet winters, and cold, cloudy summers, which may reduce vegetation accessibility and quality during the winter and spring because of an increase in snowfall, and an increase in insect harassment and poor vegetation growth during the summer because of the weather conditions.

Can trends in vegetation quantity and phenological timing explain trends in caribou population numbers? To address this question, I measured long term trends in vegetation greenness (specifically using the Normalized Vegetation Difference Index, NDVI) using satellite data collected between 1985-2006 (Latifovic et al., 2005). Forage quality declines when spring vegetation green-up accelerates (Pettorelli, 2007; Griffith et al., 2002) and may lead to seasonal mismatches between caribou peak lactation and maximum vegetation quality, so I expected caribou populations to decline in areas where

such phenological shifts were observed. I also expected caribou populations to be positively related to growing season length, as vegetation quantity available for grazing is higher in areas where growing seasons are longer (Tape et al., 2011). The study region covers more than one million km^2, so remotely sensed observations of greenness provide the only practical means of synoptic phenological measurements relevant to the 8 herds in this region. No previous caribou research has incorporated detailed, satellite-based measurements of phenological trends or vegetation quantity over such as broad area of northern Canada.

(3) Methods

(3 a) Study Area:

The summer and calving ranges of barren-ground caribou are located in Nunavut and the Northwest Territories. The calving ranges are located within the Southern Arctic ecozone. The Qamanirjuaq herd is also partially located on the Boreal shield and Hudson Plains ecozone. The summer ranges span the Southern Arctic Ecozone and the Taiga Shield ecozone (Gunn et al., 2011). Within the Taiga Shield, there is the Taiga forest and the Canadian Shield (Traynor, 2001). The general climate is short, cool summers and long cold winters. The mean average amount of precipitation per year is 200-300mm (Traynor, 2001). The landscape is rolling, with both uplands and lowlands. In addition there are bedrock outcrops, and hummocky and ridged morainal deposits (Ecological Stratification Working group, 1995). Permafrost is usually continuous. There are many lakes, wetlands, meadows and open forests. In the northern portion of the ecozone there is patchy lichen woodlands and open Arcitc tundra (Traynor, 2011). The Southern Arctic

ecozone is generally low arctic tundra (Ecological Stratification Working Group, 1995). This area has comparable amounts of rainfall to the Taiga Shield, has continuous permafrost and is semi-arid (Traynor, 2001). The landscape has slightly rolling uplands, lowlands and plateaus. The uplands consist mostly of unvegetated rock outcrops from the Canadian Shield. The lowlands are predominantly made up of sedge wetlands mixed with fends and bogs. The dominant vegetation cover is heath and shrub species. In the Southern portion of the ecozone close to the treeline, there are sparse stands of black and white spruce (Traynor, 2001).

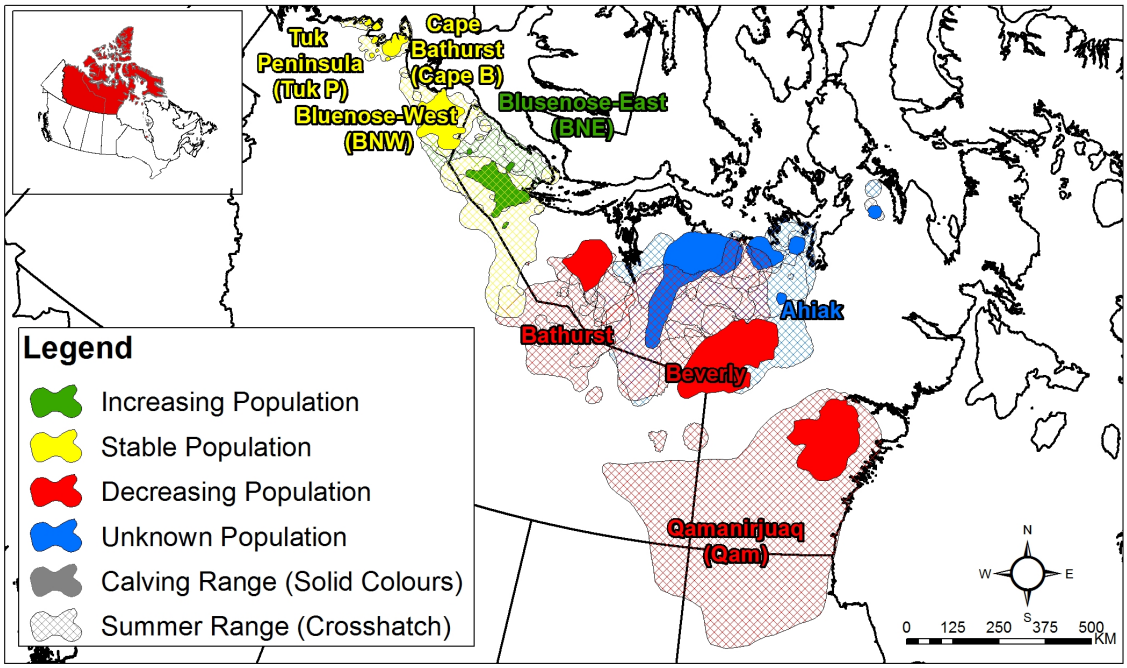

Figure 2.2: Map showing the calving and summer range for all the caribou herds included in this study and their current population status.
Population estimates, calf:cow ratios, systematic transects, and expert opinion were used to determine the current population status of the Barren-ground caribou herds.

(*3 b) Caribou Population Observations*

The majority of population estimates were derived from aerial surveys by caribou biologists (Gunn et al., 2011). Radio-collar locations were used to estimate early population sizes for the Bluenose East, Bluenose West and Cape Bathurst herds (Gunn et al., 2011). Refer to Appendix A for population estimates and confidence intervals for each caribou herd. The caribou herd population sizes were not estimated consistently each year due to the high cost of conducting aerial surveys from helicopters, and frequent adverse weather conditions. This made comparing climate and phenology with population impossible on a yearly basis. Thus, I compared the mean and slope of climate and phenology trends (1985-2006) on caribou calving and summer ranges. The logistic regression trends in population from 1985-2006 represent the long-term population status and the logistic regression trend in more recent years (2006-2011) represent the current population status. The status of long-term and current caribou populations were determined by (1) plotting all available population estimates and adding a linear regression trend line in S-Plus and (2) using previously published population status results when available (Gunn et al., 2000; Gunn et al., 2011; Department of Environment and Natural Resources, unpublished data). Caribou herds were then grouped first based on their current population status (increasing, decreasing or stable), and second on their long-term population status (increasing or decreasing), to increase sample size. Herds whose long-term or current population status was unknown were not included in the analysis. I also calculated the rate of change in population, for each time period between population surveys using the following equation: rate of change = ((T2-T1/T1)*100%). T1 and T2 vary between herds because the population estimates are from different years.

T1 always represents the population estimate from the earlier year and T2 the later population estimate (Refer to Appendix B to see the rates of change in caribou populations).

(3 c) Arctic Oscillation Data

I used AO values from the National Oceanic and Atmospheric Administration (NOAA) (http://www.arctic.noaa.gov/detect/climate-ao.shtml). I first calculated the phase intensity average for each month, and then used the monthly averages to calculate a summer, winter and yearly phase average (Joly & Klein, 2011). Arctic Oscillation phases vary from positive (+3, lower then normal pressure over the polar region) to negative (-3, higher then normal pressure over the polar region, www.arctic.noaa.gov). The summer phase average was calculated using mean monthly AO phase values from June-August. The winter phase was calculated from mean monthly AO phase values during the December-February time period. The yearly average included the mean monthly AO values for all twelve months. The average of the AO phase the year prior to a caribou population estimate, as well as the average AO phase for all years in between population estimates was compared to periods where caribou population abundance increased and periods where caribou population abundance decreased. The use of a time-lagged variable follows other studies analyzing ungulate population data (Post & Stenseth, 1998; Loison et al., 1999; Coulson et al., 2004). I used the AO phase the year before a caribou population estimate to test for a one-year lag effect, which has been demonstrated in past ungulate research (Aanes et al., 2002; Post & Forchhammer, 2002). To determine if there was a significant relationship between the phase of the AO and change in caribou population the Chi-square statistic was used. The data from all herds was pooled

together. The temporal pattern of the AO from 1985-2006 was not included in the analysis because the average summer, winter and yearly phase trend only slightly decreased during this time period. There was only one example where the sign of the AO phase switched from positive to negative (indicating a rapid transition from lower then normal pressure, to higher then normal pressure) from year to year. This occurred when the average of the AO was calculated during the winter months from 1995 to 2002. However, the intensity of the phases during these years was not strong.

(3 d) Use of Satellite–based NDVI

I tested whether phenological and biomass changes can explain observed caribou population trends in two ways. First, in section 3 d i, I used long-term satellite trends in NDVI to identify areas which have experienced significant positive increases in NDVI as a proxy for climate-related productivity changes. Second in section 3 d ii, climate and satellite data were used to measure vegetation characteristics (phenology and biomass) annually (1985-2006) to determine long-term trends (direction of slope) and the mean value. Then in section 3 d iii, I compared the means and slopes of biomass and phenology (1985-2006) by caribou grouping caribou based on population status. Detailed descriptions of each group of measurements are provided below.

(3 d i) Long-term trends in Satellite NDVI

Advanced Very High Resolution Radiometer (AVHRR) satellite data with 1 km resolution were used to determine growing-season vegetation NDVI trends across Canada from 1985-2006 (Pouliot et al., 2009). Trends in peak growing season condition were measured using the three 10-day periods each year with highest NDVI. The Mann-

Kendall test is used to monitor for monotonic (consistently increasing or decreasing) trends in time series, and is used when datasets are nonparametric. The Mann-Kendall test was used to determine if the increase in NDVI (1985-2006) was significant (Figure 2.3, Pouliot et al., 2009). Refer to Pouliot et al., 2009 for more detailed methods used to calculate the trend in NDVI annual peak. I overlaid the caribou herd's ranges on the map identifying areas of significant increase in NDVI to measure the percent of each caribou herd's calving and summer range that underwent positive changes in NDVI over the 1985-2006 time period. I quantitatively compared the percent of significant increase in NDVI from 1985-2006 between herds to determine whether the amount differed among herds' with a declining, increasing or stable population.

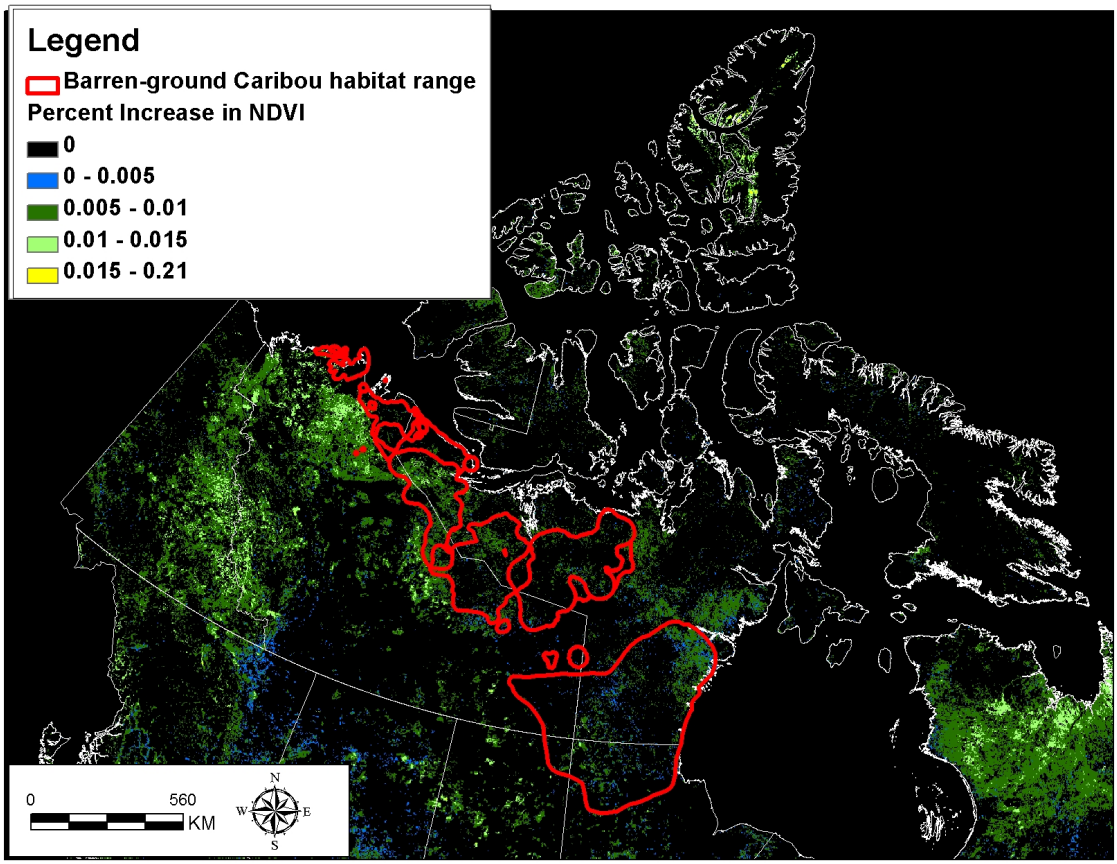

Figure 2.3: Areas across Canada that had a significant ($p<0.05$) positive linear trend in vegetation NDVI from 1985-2006 (Pouliot et al., 2009). Red polygons represent the barren-ground caribou calving and summer habitat ranges.

(3 d ii) Growing Season Annual Measurements (1985-2006): Climate data and Satellite NDVI

Climate Data

Gridded climate data assembled by the Canadian Forest Service (McKenney et al., 2006) were used as a preliminary measure of the timing and duration of growing season. These phenology measurements were available from the Canadian Forest Service (McKenney et al., 2006). Refer to McKenney et al. (2006) for more information on how the start, end and length of the growing season were calculated. The phenology grids were clipped to the calving and summer ranges for each herd. The weighted average (by number of pixels) for each variable was then calculated.

Satellite Based NDVI

Ten-day, composite AVHRR 1km data created specifically for climate change studies in Canada (Latifovic et al., 2005) for the 1985-2006 period were used as input for the satellite-based arctic-subarctic tundra phenology analysis system (SATPAS) (Li et al., pers. comm.). This provided a second means of calculating the start, end and length of the growing season, along with integrated NDVI (INDVI), which is the sum of composited NDVI values observed over the course of the calculated growing season. AVHRR data are observed daily and are susceptible to atmospheric haze and cloud cover, variability due to topography, and observations must also be corrected for variability in the sun-target-sensor viewing geometry across the 2399 km swath over which the sensor collects data. Effective processing techniques exist to control these sources of error. AVHRR data were processed using cloud screening (Khlopenkov & Trishchenko, 2007), a sun-target-sensor viewing geometry correction (Latifovic et al., 2003), orthorectified,

atmospheric corrected and composited so that only haze- and cloud-free pixels were included in datasets for further analysis (Latifovic et al., 2005). The phenological measures calculated using SATPAS were validated using snow-depth derived leaf onset data, which revealed that SATPAS provides accurate estimates of growing season length (Li et al., pers. comm.). Measures similar to NDVI have been used in other studies as an approximation of vegetation primary productivity or accumulation within a growing season (Prince & Tucker, 1986; Box et al., 1989; Diallo et al., 1991; Price, 1991; Petttorelli et al., 2007).

SATPAS was selected as a method to calculate variables related to growing season length and timing for the following reasons: (1) it was developed specifically for the Arctic and sub-arctic tundra environment, (2) has the ability to be calibrated using biomass measurements, and (3) assigns pixel values for the Julian date associated with each pixel (Li et al., pers comm.). The key steps in the SATPAS workflow are (1) reducing noise in NDVI (2) interpreting the 10-day composite NDVI to create a daily NDVI, and (3) calculating the phenology variables. For computing beginning and end of growing season, a threshold of 30% maximum NDVI observed over the year at that locale yielded the most accurate results for Wapusk National Park, where ground-based tests of growing season estimates have been completed (Li et al., pers comm.). The land cover within Wapusk National Park is a combination of coniferous and deciduous forest, wetlands, lichen, shrubs and graminoids (Chen et al., in press). Other research found a threshold of 50% of the maximum NDVI observed over the year was most suitable for calculating the most rapid increase and decrease in vegetation greenness on broadleaf forest and grassland sites (White et al., 1997). It is unclear whether a threshold of 30 %

or 50% would be suitable for Arctic landscapes. The start, end and length of the growing season were calculated by creating smoothed NDVI profiles and using the dates when the profile becomes larger or smaller than the threshold value (Lloyd, 1990; White et al., 1997). Very low values of NDVI can be confused with soil reflectance, thus compromising the accuracy of phenology variables (Huete et al., 2002). Therefore, I decided to run SATPAS once using a threshold of 30% and a second time with 50% of maximum NDVI from the partially smoothed NDVI profile in SATPAS to calculate two sets of phenology variables. Previously collected field-based foliage biomass measurements on the Bathurst range (Chen et al., in press) were also used as input into SATPAS to calculate growing season variables. The start of the growing season calculated as the date where the foliage biomass is ≥ 0 g m^{-2} based on the smoothed NDVI profile. Similarly, the end of the growing season is the date when the foliage biomass appears to be ≤ 0 g m^{-2}.

(3 d iv) Comparing Population Trends with Phenology and Biomass

The start of the growing season, end of the growing season, length of the growing season and INDVI were used as indicators of vegetation quantity. I first analyzed the phenology trends by comparing the values of the start, end and length of the growing season the same year there was a population estimate and the year before to account for a possible one-year lag affect. There was no relationship between the timing of the growing season and herd population estimates, regardless of whether growing season timing was measured in the year of the population observation or in the previous year, so this approach was abandoned. This result may reflect the small number of caribou

population observations available. Therefore, I tested for relationships between the average of long-term (1985-2006) phenology variables and caribou long-term(1985-2006) or current (2006-2011) population status using the one-way ANOVA and Tukey's HSD multiple comparison tests. I also measured the slope for the growing season start, end and length (all as Julian day), and the seasonally-integrated NDVI (INDVI, no units) over the 1985-2006 study period. These measurements were related to current and long-term caribou population trends by visually comparing the slopes.

The daily rate of NDVI increase (NDVI-rate) between the start of the calving season (June 1st) to peak lactation (June 15th) was calculated to provide a measure of the rate of green-up and forage quality. NDVI_rate measures the quality of vegetation by indexing the build-up of new plant tissue daily (Cameron & Whitten, 1980; Griffith et al., 2002), which is easily digested by caribou. The start of the calving season and peak lactation can vary from year to year and from herd to herd. However, specific dates for the start of the calving season and peak lactation for each year from 1985-2006 were not available for any of the herds. Therefore, I decided to use June 1st and June 15th to represent the start of the growing season and peak lactation for all herds, based on the opinion of a caribou expert (Jan Adamczewski, pers. comm.). NDVI measurements were taken on June 1st and June 11th for each year. I used NDVI values as close to these dates as possible (+/- 5 days). I determined the number of days between the first date and the second date for each pixel to calculate the daily rate of green-up. Therefore, this measures the average daily increase in NDVI, because NDVI does not increase at a constant rate through the growing season. To determine if there was a relationship

between the average daily rate of green-up and caribou long-term and current population status, the one-way ANOVA statistic was used.

(3 e) Land Cover Data

A circa 2000 Landsat-based land cover classification at 30 m resolution (Olthof et al., 2008) was used to determine if the start, end, and length of the growing season, and INDVI trends within Barren-ground caribou habitat were consistent among land cover types, and if vegetation trends in one land cover type had a stronger correlation with population status. I selected pixels from the graminoid, shrub and sparse-vegetation/barren land cover classes and aggregated them to the 1 km AVHRR resolution. I then selected pixels that were composed of at least 80% graminoid, shrub, or sparse-vegetation/barren at 1 km and calculated the phenology variables using the CFS climate grids, and 10-day AVHRR composites for all herds, on calving and summer ranges.

(4) Results

(4a) Population Status

Long-term Population Status

The long-term (1985-2006) and current population status for each of the barren-ground caribou herds was determined from available population estimates and plotting a linear regression line (Figure 2.4, Figure 2.5). The linear regression trend line was not reliable to determine the long-term population status of the Beverly, Qamanirjuaq and Ahiak herds or the current population stats of the Beverly and Qamanirjuaq herds

because there were few or no recent population estimates. For herds where there are not a sufficient number of recent population estimates or there were high error bars associated with a population estimate, calf:cow ratios, systematic transect survey results, expert opinion and traditional knowledge (Nesbitt & Jan Adamczewski, 2009; CARMA, 2009; BQCMB, 2010; Gunn et al., 2011) were used to determine population status. For detailed information refer to Appendix A.

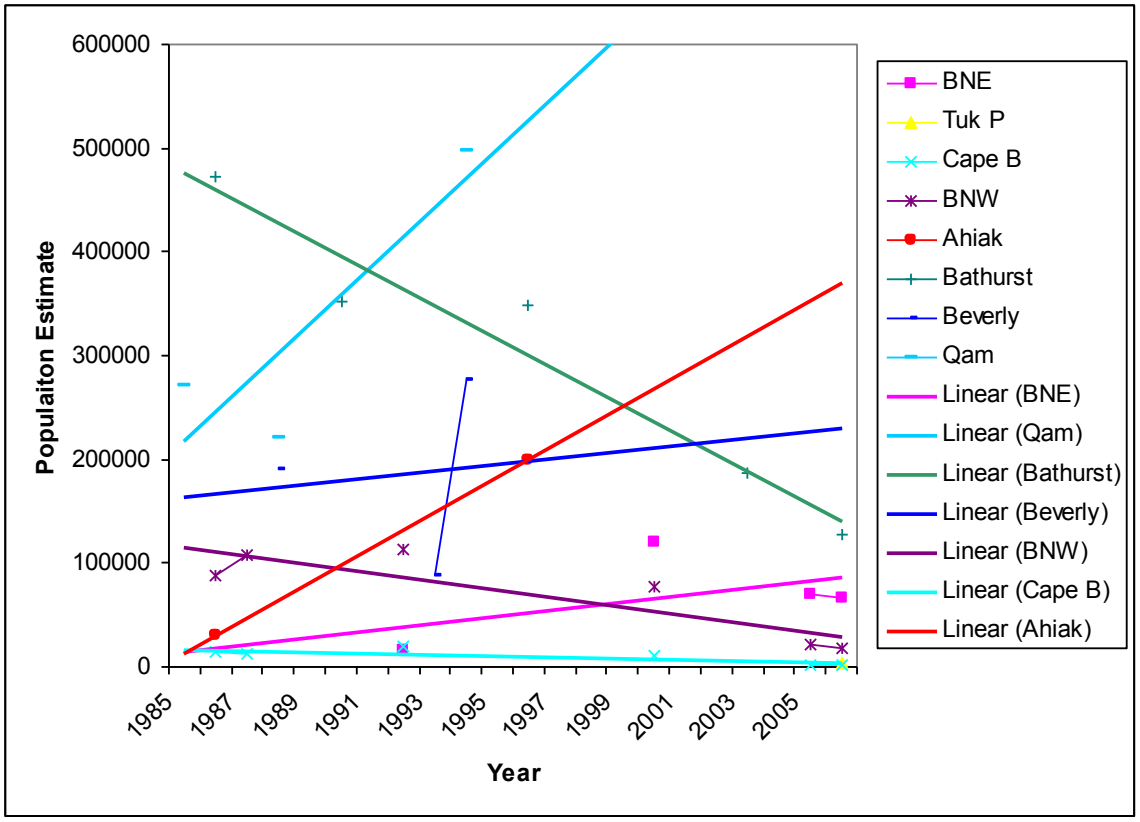

Figure 2.4: Population estimates from 1985 to 2006 for each Barren-ground caribou herd included in this thesis. A linear trend line was used to determine that the long-term population status of the Bluenose-east (BNE) herd was increasing, and the Bluenose-west (BNW), and Bathurst Cape Bathurst (Cape B) were declining. Population estimates for the Qamanirjuaq (Qam), Beverly and Ahiak were not recent enough to use a linear regression trend line. The long-term population status of the Tuktoyaktuk herd is unknown.

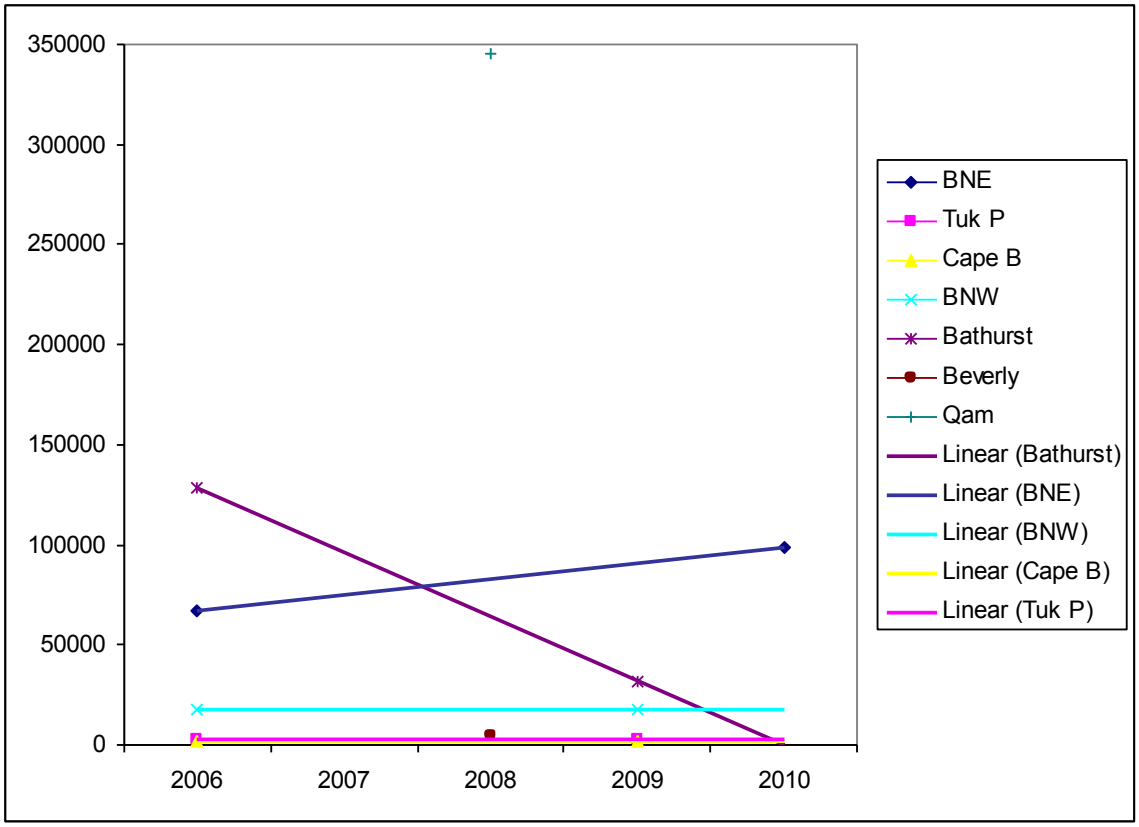

Figure 2.5: Population estimates from 2006 to 2011 for each Barren-ground caribou herd included in this thesis. A linear trend line was used to determine that the current population status of the Bluenose-east (BNE) herd was increasing, the Bluenose-west (BNW), Cape Bathurst (Cape B), Tuktoyaktuk (Tuk P), were stable and the Bathurst was declining. Population estimates for the Qamanirjuaq (Qam) and Beverly were not recent enough to use a linear regression trend line. The long-term population status of the Ahiak herd is unknown.

(4 b) Arctic Oscillation

There was no relationship between the positive phase of the AO (warm, wet winters, and cloudy, cold wet summers) and periods of population decrease (Table 2.2). The positive phase of the AO was observed more often from 1985 to 2000, when many of the Barren-ground caribou populations were increasing or table (Figure 2.6). The negative phase of the Arctic was observed more often from 2000 to 2010 when most of the barren-ground caribou populations were in decline (Figure 2.6). Based on the results of the chi-square test ($p > 0.05$, 1 df), a positive AO phase was not observed significantly more often than the negative phase the year prior to a population estimate, when there had been a decline in the rate of population (Table 2.2, refer to Appendix C for the AO values during periods of population increase and decrease for each individual barren-ground caribou herd). Likewise, the chi-square test ($p > 0.05$, 1 df), showed a positive AO did not occur more frequently than the negative phase, when the average of the AO was calculated in between caribou population estimates, and there was a decline in population (Table 2.2). Therefore, I reject the hypothesis that the positive phase of the AO would be associated with barren-ground caribou declines.

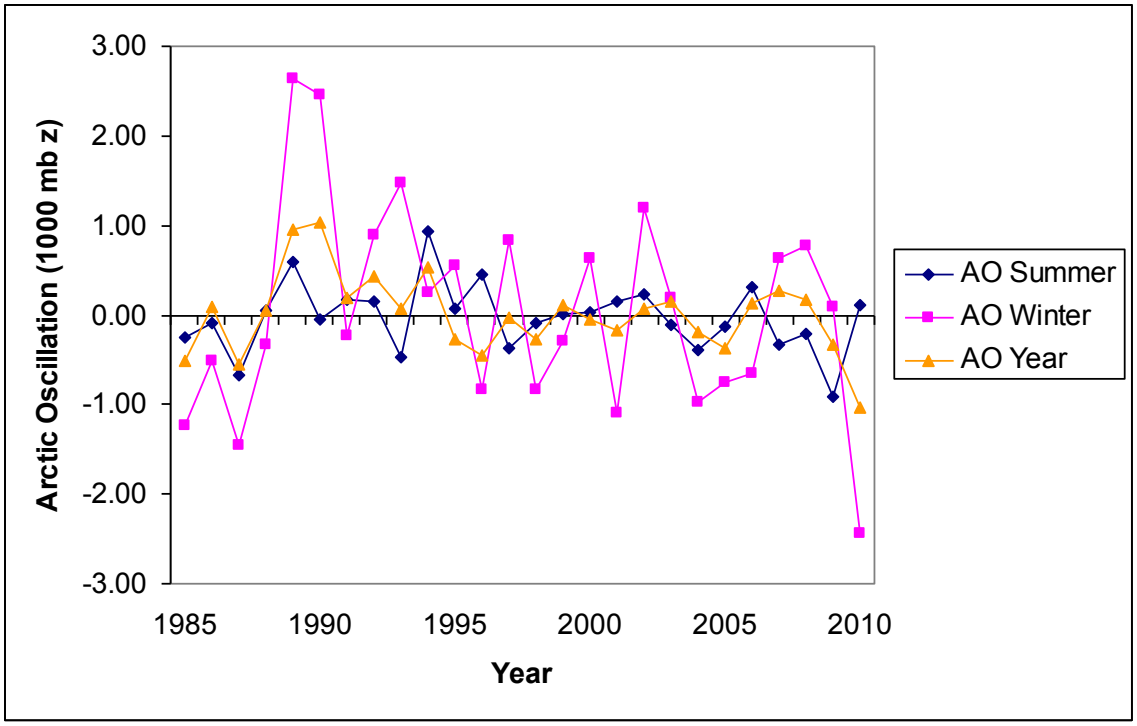

Figure 2.6: The Arctic Oscillation (AO) mean value for each year from 1985 to 2010. The summer AO was calculated using mean monthly values from June to August, the winter AO used mean monthly values from December to February, and the AO year used all mean monthly values throughout the year.

Table 2.2: Observed and expected values from the Chi-square statistic. The Chi-square test was used determine if the positive phase of the AO occurred significantly more during periods of population decline, or if the negative phase of the AO occurred significantly more during periods of population increase. There was 1 degree of freedom. All chi square p-values were > 0.05. The results were based on pooling the data from all caribou.

	Summer		Winter		Yearly	
Average of Arctic Oscillation Phase For Years in Between Population Estimates						
Observed Values						
Chi Square	Increase in Population	Decrease in Population	Increase in Population	Decrease in Population	Increase in Population	Decrease in Population
+ve AO	8	10	10	10	8	7
-ve AO	5	10	3	10	6	12
Expected Values						
	Increase in Population	Decrease in Population	Increase in Population	Decrease in Population	Increase in Population	Decrease in Population
+ve AO	7.09	10.91	7.88	12.12	6.36	8.64
-ve AO	5.91	9.09	5.12	7.88	7.64	10.36
Arctic Oscillation Phase the Year Prior to a Population Estimate						
Observed Values						
Chi Square	Increase in Population	Decrease in Population	Increase in Population	Decrease in Population	Increase in Population	Decrease in Population
+ve AO	6	9	7	8	8	11
-ve AO	7	11	6	12	3	11
Expected Values						
+ve AO	5.91	9.09	5.91	9.09	6.33	12.67
-ve AO	7.09	10.91	7.09	10.91	4.67	9.33

(4 c) Significant NDVI Changes

Caribou herds with a current or long-term decline in population status did not have a higher increase in NDVI annual peak from 1985-2006. NDVI increased within the calving range for all caribou herds. There was no correlation with current or long-term declining caribou populations and the percent of significant NDVI increase, based on the Mann-Kendal test at the 95% confidence interval, from 1985 to 2006 (Figure 2.7 and Figure 2.8). For example, the BNE herd is currently increasing in population and had the highest increase in NDVI and the Bathurst and the Qamanirjuaq herds are both currently declining and had the second and third largest proportional NDVI increase on calving grounds (Figure 2.7). NDVI increased substantially across caribou summer ranges also. Similar increases in NDVI through time were observed for the BNE and BNW herds, which have opposite current population trends (Figure 2.8).

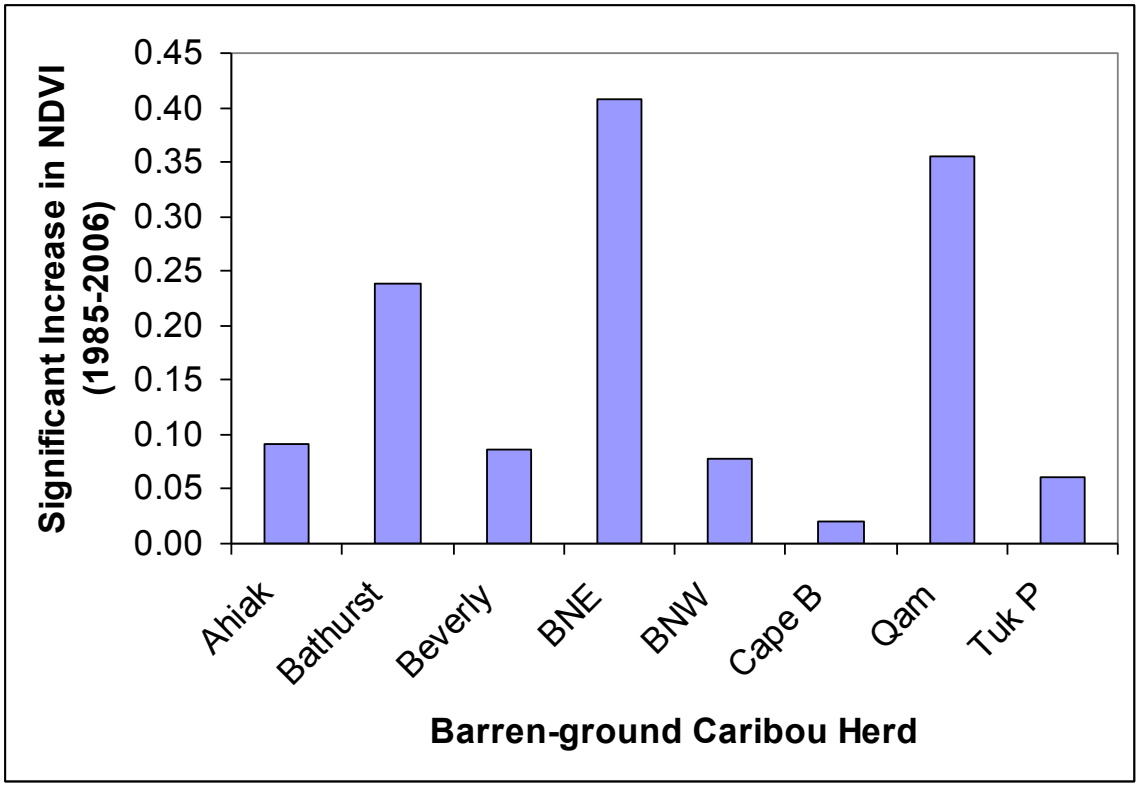

Figure 2.7: A graph representing the percent of each Barren-ground caribou herd's caving range that had a significant increase in NDVI from 1985-2006. BNE refers to the Bluenose east herd, BNW the Bluenose west herd, Cape B the Cape Bathurst herd, Qam the Qamanirjuaq herd, and Tuk P the Tuktoyaktuk Peninsula herd.

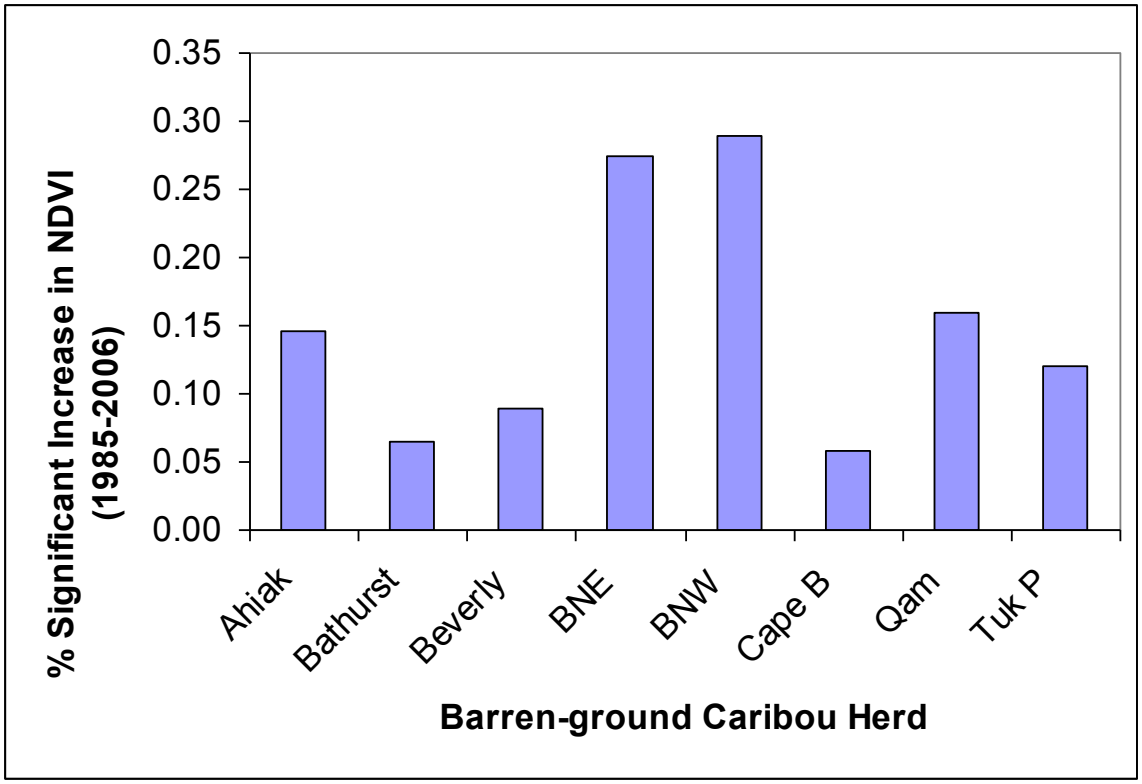

Figure 2.8: A graph representing the percent of each Barren-ground caribou herd's summer range that had a significant increase in NDVI from 1985-2006. BNE refers to the Bluenose east herd, BNW the Bluenose west herd, Cape B the Cape Bathurst herd, Qam the Qamanirjuaq herd, and Tuk P the Tuktoyaktuk Peninsula herd.

(4 d) Measures of Vegetation Quantity

Timing of green-up, end of the growing season, length of the growing season and INDVI representing lower amounts of vegetation quantity and quality were not observed on the habitat ranges of caribou with a declining population status. Although the mean start, end and length of the growing season and INDVI were statistically different most of the time ($p < 0.05$, 2 df, Table 2.3) between herds with increasing, decreasing and stable populations, it was not often that declining herds had the earliest, latest and longest growing season, or highest values in INDVI (Tukey's Test Appendix D). For example the ANOVA and Tukey's HSD test showed that the mean length of the growing season on the caribou summer habitat range was only significantly different between increasing and stable herds (Figure 2.9). Increasing herds had the shortest length in growing season, and the length of the growing season was unchanged for herds with a stable and declining population status (Figure 2.9).

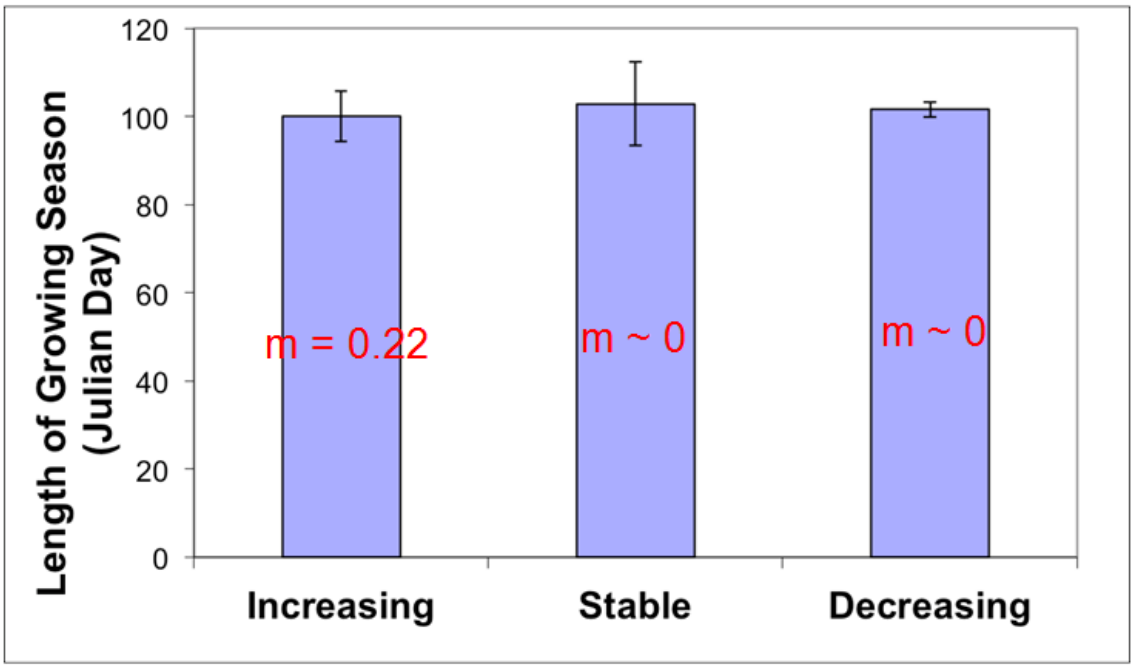

Figure 2.9: The mean length and slope of the growing season on the summer habitat range of barren-ground caribou herds with an increasing, stable and declining population status. The slope is represented by m. The ANOVA statistical test indicated that the mean length of the growing season was only statistically significantly different between herds with an increasing and stable population status. The slope (m) of the length of the growing season was approximately zero for herds who were declining or stable in population.

Table 2.3: ANOVA was used to determine if declining caribou populations, compared to herds with an increasing or stable population, had statistically earlier and shorter growing seasons (GS), or lower INDVI values when calculated with foliage biomass, a threshold of 30 or 50, and climate data. The analysis was done within the calving range (CR), the summer range (SR), and by land cover class. First caribou herds were grouped based on their current population status (CPS), and second by their Long-term Population Status (OPS). P-values greater than 0.05 indicate the means were not statistically different. Foliage Biomass, threshold 30 and 50 were calculated using AVHRR 1 km satellite data and SATPAS. The climate values were calculated by the Canadian Forestry Service using climate records. There were 2 degrees of freedom between groups, and 63 degrees of freedom within groups. NA refers to no data, and gram refers to graminoid.

Phenology Variable	SATPAS P-values						Climate Grids P-values	
	Foliage Biomass (Linear Regression)		Threshold 30		Threshold 50			
	CPS	OPS	CPS	OPS	CPS	OPS	CPS	OPS
Start GS CR	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	0.003
Start GS CR(Gram)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	0.040
Start GS CR(Shrub)	$<10^{-3}$	0.105	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.004	0.413
Start GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Start GS SR	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$
Start GS SR (Gram)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	0.001	0.001
Start GS SR (Shrub)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	0.001	0.574
Start GS SR (Bare)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	0.071	0.747
End GS CR	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$
End GS CR (Gram)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$<10^{-3}$	0.012
End GS CR (Shrub)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$<10^{-3}$	0.004
End GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
End GS SR	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	0.006	$<10^{-3}$
End GS SR (Gram)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	0.094	0.015
End GS SR (Shrub)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	0.626	0.024
End GS SR (Bare)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	0.949	0.001
Length GS CR	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.004	0.302
Length GS CR (Gram)	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.761	$< 10^{-3}$	0.002	0.403
Length GS CR (Shrub)	$< 10^{-3}$	0.546	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.583	0.179
Length GS CR (Bare)	N/A	N/A	< N/A	N/A	N/A	N/A	N/A	N/A
Length GS SR	$< 10^{-3}$	0.001	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.002
Length GS SR (Gram)	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.737
Length GS SR (Shrub)	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.015	0.730
Length GS SR (Bare)	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.009	0.305	0.751
INDVI CR	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	N/A	N/A
INDVI CR (Gram)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	N/A	N/A
INDVI CR (Shrub)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	N/A	N/A
INDVI CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
INDVI SR	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	N/A	N/A
INDVI SR (Gram)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	N/A	N/A
INDVI SR (Shrub)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	N/A	N/A
INDVI SR (Bare)	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	$< 10^{-3}$	$<10^{-3}$	N/A	N/A

There were a few notable exceptions, for example an average earlier end to the growing season on the calving range was sometimes observed for caribou with a long-term decline in population (Table 2.4) , or on the summer range for caribou currently declining in population (Table 2.5). This trend was only consistently observed when the SATPAS program was applied with a threshold of 30 or 50, and separated by land cover class. In spite of this, the slope for the start or end of the growing season from 1985-2006 indicated for the above examples, was not steeper (1985-2006) for long-term or current declining caribou populations. Even though the end of the growing season may have been earlier in some cases for caribou with a declining population, the growing season was increasing at a faster rate for caribou with an increase or stable population (Table 2.6 and Table 2.7). Therefore, there is not enough evidence to accept the hypothesis that the start, end or length of the growing season or INDVI has contributed significantly to the long-term or current decline of barren-ground caribou. Much stronger evidence would be needed to conclude that there is a relationship between timing of the growing season and caribou populations.

Table 2.4: Mean start, end, length and INDVI from 1985 to 2006 on the calving (CR) and summer ranges (SR). The mean of the pheonology variables were also calculated by land cover class. The mean of the phenology variables were measured from the ANOVA statistic and were calculated by grouping all herds based on their long-term population status, increasing (Inc), stable (Stb) or decreasing (Dec). AVHRR data and the SATPAS program were first used to calculate the phenology variables, and second climate grids. N/A refers to no data, and gram refers to graminoid.

Phenology Variable	SATPAS									Climate Grids		
	Foliage Biomass (Linear Regression)			Threshold 30			Threshold 50					
	Inc	Stb	Dec	Inc	Stb	Dec	Inc	Stb	Dec	Inc	Stb	Dec
Start GS CR	139	142	143	127	121	130	128	125	135	168	172	171
Start GS CR(Gram)	126	147	148	139	121	130	122	121	132	169	173	171
Start GS CR(Shrub)	147	147	147	120	120	126	121	121	126	168	169	171
Start GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Start GS SR	145	142	144	137	140	129	150	140	132	168	157	168
Start GS SR (Gram)	145	142	143	135	136	132	136	136	132	170	172	170
Start GS SR (Shrub)	148	148	146	135	136	131	135	136	131	169	171	169
Start GS SR (Bare)	137	145	147	127	122	133	128	123	132	172	172	171
End GS CR	252	247	247	265	271	262	264	269	261	252	267	261
End GS CR (Gram)	243	243	244	273	269	260	273	269	259	263	261	263
End GS CR (Shrub)	243	244	244	270	270	265	270	270	265	264	267	261
End GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
End GS SR	245	273	245	255	251	260	277	251	260	261	274	262
End GS SR (Gram)	243	244	244	255	255	259	255	255	259	262	267	262
End GS SR (Shrub)	243	244	245	256	255	260	256	255	261	263	267	263
End GS SR (Bare)	254	246	245	264	269	259	263	270	261	260	267	261
Length GS CR	100	103	102	118	115	131	127	137	128	93	104	94
Length GS CR (Gram)	99	98	96	131	149	135	147	147	128	94	91	90
Length GS CR (Shrub)	95	95	91	151	151	139	149	149	139	95	95	91
Length GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length GS SR	100	103	102	118	115	131	127	137	128	93	104	94
Length GS SR (Gram)	98	101	100	120	120	127	120	119	126	92	90	92
Length GS SR (Shrub)	94	96	99	121	120	129	121	118	130	94	92	94
Length GS SR (Bare)	118	109	98	138	142	126	135	140	129	88	89	91
INDVI CR	55	59	58	53	57	57	53	57	57	N/A	N/A	N/A
INDVI CR (Gram)	40	38	55	41	37	56	40	40	56	N/A	N/A	N/A
INDVI CR (Shrub)	60	59	60	59	59	59	59	59	58	N/A	N/A	N/A
INDVI CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
INDVI SR	55	60	59	54	59	58	31	59	58	N/A	N/A	N/A
INDVI SR (Gram)	60	59	60	59	59	59	59	59	58	N/A	N/A	N/A
INDVI SR (Shrub)	60	59	59	60	58	58	60	58	58	N/A	N/A	N/A
INDVI SR (Bare)	40	40	62	35	37	62	35	26	61	N/A	N/A	N/A

Table 2.5: Mean start, end, length and INDVI from 1985 to 2006 on the calving (CR) and summer ranges (SR). The mean of the pheonology variables were also calculated by land cover class. The mean of the phenology variables were measured from the ANOVA statistic and were calculated by grouping all herds based on their current population status, increasing (Inc), stable (Stb) or decreasing (Dec). AVHRR data and the SATPAS program were first used to calculate the phenology variables, and second climate grids. N/A refers to no data, and gram refers to graminoid.

Phenology Variable	SATPAS									Climate Grids		
	Foliage Biomass (Linear Regression)			Threshold 30			Threshold 50					
Current Pop	Inc	Stb	Dec	Inc	Stb	Dec	Inc	Stb	Dec	Inc	Stb	Dec
Start GS CR	145	140	144	130	125	128	123	149	137	167	170	171
Start GS CR(Gram)	148	148	147	127	122	131	139	128	131	167	170	171
Start GS CR(Shrub)	147	146	148	120	119	125	121	119	125	169	170	170
Start GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Start GS SR	147	140	144	128	122	137	148	123	137	166	167	164
Start GS SR (Gram)	147	140	144	125	126	125	125	126	136	167	169	169
Start GS SR (Shrub)	148	143	146	135	136	136	135	136	136	166	168	169
Start GS SR (Bare)	136	144	148	127	126	133	129	127	131	168	168	172
End GS CR	246	250	247	269	267	265	268	266	264	263	260	264
End GS CR (Gram)	243	243	244	273	269	260	273	269	259	263	261	263
End GS CR (Shrub)	244	245	243	271	273	266	270	272	265	263	261	264
End GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
End GS SR	244	247	254	264	269	254	278	269	254	262	262	266
End GS SR (Gram)	242	244	244	266	265	255	265	265	255	263	261	264
End GS SR (Shrub)	243	249	243	256	269	254	256	268	256	263	263	264
End GS SR (Bare)	254	248	243	264	267	258	263	266	260	260	261	261
Length GS CR	102	109	103	139	142	137	145	117	127	95	90	93
Length GS CR (Gram)	96	95	97	146	148	129	123	141	128	95	90	89
Length GS CR (Shrub)	97	99	94	150	154	141	143	142	140	94	91	94
Length GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length GS SR	97	107	110	136	146	117	130	145	117	95	94	102
Length GS SR (Gram)	96	104	100	140	139	119	140	139	119	96	93	85
Length GS SR (Shrub)	96	106	96	97	146	119	121	145	121	93	94	96
Length GS SR (Bare)	96	104	96	99	140	124	99	142	127	88	93	93
INDVI CR	60	56	59	59	55	58	59	56	58	N/A	N/A	N/A
INDVI CR (Gram)	52	48	52	53	52	52	52	51	53	N/A	N/A	N/A
INDVI CR (Shrub)	40	52	55	37	53	54	36	53	53	N/A	N/A	N/A
INDVI CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
INDVI SR	60	58	59	59	57	59	46	57	59	N/A	N/A	N/A
INDVI SR (Gram)	43	60	59	43	60	59	43	57	59	N/A	N/A	N/A
INDVI SR (Shrub)	60	58	59	60	57	59	60	57	58	N/A	N/A	N/A
INDVI SR (Bare)	44	55	51	35	50	50	35	49	48	N/A	N/A	N/A

Table 2.6: Slope of the start, end, length and INDVI from 1985 to 2006 on the calving (CR) and summer ranges (SR). The slope of the pheonology variables were also calculated by land cover class. The mean of the phenology variables were measured from the ANOVA statistic and were calculated by grouping all herds based on their long-term population status, increasing (Inc), stable (Stb) or decreasing (Dec). AVHRR data and the SATPAS program were first used to calculate the phenology variables, and second climate grids. N/A refers to no data, and gram refers to graminoid.

Phenology Variable	SATPAS									Climate Grids		
	Foliage Biomass (Linear Regression)			Threshold 30			Threshold 50					
	Inc	Stb	Dec	Inc	Stb	Dec	Inc	Stb	Dec	Inc	Stb	Dec
Start GS CR	-0.03	0.01	-0.04	0.01	0.00	-0.01	0.03	-0.03	0.00	-0.16	-0.37	-0.19
Start GS CR(Gram)	0.02	-0.05	0.01	-0.79	0.05	-0.03	-0.26	-0.01	-0.02	-0.38	-0.52	-0.41
Start GS CR(Shrub)	-0.01	0.00	0.00	0.02	0.02	0.01	0.00	0.00	-0.01	-0.59	-0.24	-0.41
Start GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Start GS SR	0.04	-0.02	-0.01	0.03	0.02	0.02	0.06	0.02	0.00	-0.38	-0.14	-0.23
Start GS SR (Gram)	0.04	-0.06	-0.01	-0.07	0.03	0.04	-0.08	0.02	0.04	-0.61	-0.32	-0.40
Start GS SR (Shrub)	0.02	0.01	-0.01	0.08	0.07	0.05	0.08	0.08	0.06	-0.58	-0.31	-0.39
Start GS SR (Bare)	-0.94	-0.07	-0.16	1.09	0.29	0.26	1.21	0.29	0.24	-0.47	-0.32	-0.22
End GS CR	0.07	-0.10	-0.01	-0.05	0.09	0.05	-0.04	0.05	0.05	0.21	0.28	0.16
End GS CR (Gram)	-0.04	-0.02	0.03	0.03	0.05	-0.01	0.04	0.10	-0.02	0.21	0.27	0.14
End GS CR (Shrub)	0.01	0.00	0.03	0.00	0.01	0.01	-0.01	-0.01	0.03	0.21	0.28	0.14
End GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
End GS SR	-0.07	0.09	-0.02	0.00	-0.01	0.06	0.10	0.00	0.07	0.42	0.40	0.15
End GS SR (Gram)	-0.05	-0.04	0.02	0.06	-0.02	-0.04	0.06	-0.02	-0.04	0.17	0.23	0.17
End GS SR (Shrub)	-0.04	0.02	0.02	-0.09	-0.05	-0.01	-0.09	-0.05	-0.03	0.12	0.18	0.08
End GS SR (Bare)	0..95	0.08	0.22	-1.03	-0.26	-0.20	-1.11	0.11	0.00	0.14	0.26	0.18
Length GS CR	0.14	0.13	0.01	-0.13	0.01	0.05	-0.09	-0.05	0.09	0.65	0.45	0.41
Length GS CR (Gram)	-0.07	-0.09	0.07	1.55	0.08	-0.03	0.04	0.13	-0.03	0.82	0.50	0.59
Length GS CR (Shrub)	0.02	0.01	0.04	-0.02	-0.02	0.00	-0.01	-0.01	0.04	0.80	0.45	0.55
Length GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length GS SR	-0.12	-0.02	-0.01	-0.04	-0.02	0.01	0.04	0.09	0.03	0.83	0.57	0.40
Length GS SR (Gram)	-0.08	0.02	0.03	0.13	0.02	-0.09	0.14	0.04	-0.09	0.08	0.51	0.60
Length GS SR (Shrub)	0.79	0.51	0.55	-0.18	-0.17	-0.06	-0.17	-0.16	-0.08	-0.06	0.01	0.04
Length GS SR (Bare)	1.88	1.02	0.38	-2.12	-1.32	-0.46	-2.32	-1.40	-0.24	0.61	0.46	0.39
INDVI CR	-0.09	-0.03	-0.02	-0.10	0.00	-0.04	-0.12	0.02	-0.02	N/A	N/A	N/A
INDVI CR (Gram)	0.02	-0.13	-0.05	0.00	-0.13	-0.11	-0.01	-0.13	-0.12	N/A	N/A	N/A
INDVI CR (Shrub)	0.05	-0.11	-0.05	0.07	-0.15	-0.08	0.07	-0.11	0.07	N/A	N/A	N/A
INDVI CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
INDVI SR	0.11	-0.02	-0.01	0.12	0.03	0.00	0.57	0.06	-0.04	N/A	N/A	N/A
INDVI SR (Gram)	0.02	-0.13	-0.05	0.00	-0.13	-0.11	-0.01	-0.13	-0.12	N/A	N/A	N/A
INDVI SR (Shrub)	0.79	0.51	0.55	-0.18	-0.17	-0.06	-0.17	-0.16	-0.08	N/A	N/A	N/A
INDVI SR (Bare)	0.50	0.50	0.01	-1.22	-1.18	0.02	-1.25	-1.21	0.01	N/A	N/A	N/A

Table 2.7: Slope of the start, end, length and INDVI from 1985 to 2006 on the calving (CR) and summer ranges (SR). The slope of the pheonology variables were also calculated by land cover class. The mean of the phenology variables were measured from the ANOVA statistic and were calculated by grouping all herds based on their current-term population status, increasing (Inc), stable (Stb) or decreasing (Dec). AVHRR data and the SATPAS program were first used to calculate the phenology variables, and second climate grids. N/A refers to no data, and gram refers to graminoid.

Phenology Variable	SATPAS									Climate Grids		
	Foliage Biomass (Linear Regression)			Threshold 30			Threshold 50					
Current Pop	Inc	Stb	Dec	Inc	Stb	Dec	Inc	Stb	Dec	Inc	Stb	Dec
Start GS CR	-0.03	0.01	-0.04	0.01	0.00	-0.01	0.03	-0.03	0.00	-0.16	-0.37	-0.19
Start GS CR(Gram)	0.02	-0.05	0.01	-0.79	0.05	-0.03	-0.26	-0.01	-0.02	-0.38	-0.52	-0.41
Start GS CR(Shrub)	-0.01	0.01	0.00	0.02	0.02	-0.01	0.00	0.02	-0.02	-0.41	-0.45	-0.36
Start GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Start GS SR	0.01	0.01	-0.04	0.02	-0.03	0.05	0.05	-0.06	0.05	-0.22	-0.28	-0.20
Start GS SR (Gram)	0.01	0.01	-0.04	-0.03	0.12	0.01	-0.04	0.12	0.01	-0.35	-0.51	-0.35
Start GS SR (Shrub)	0.01	0.01	-0.04	-0.03	0.12	0.01	-0.04	0.12	0.01	-0.35	-0.51	-0.35
Start GS SR (Bare)	-0.87	-0.39	-0.03	1.02	0.58	0.05	1.13	0.58	0.09	-0.32	-0.32	-0.25
End GS CR	0.05	-0.05	0.03	-0.02	0.10	0.05	-0.01	0.11	0.05	0.29	0.18	0.19
End GS CR (Gram)	-0.02	0.06	0.01	0.05	-0.06	0.05	0.06	-0.07	0.06	0.22	0.14	0.22
End GS CR (Shrub)	0.01	0.05	0.00	-0.02	0.00	0.02	-0.01	0.00	0.02	0.23	0.19	0.24
End GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
End GS SR	-0.03	-0.02	0.03	-0.01	0.09	-0.02	0.06	0.10	-0.02	0.35	0.23	0.29
End GS SR (Gram)	-0.01	0.05	-0.02	0.04	-0.15	-0.02	0.05	-0.16	-0.02	0.22	0.30	0.23
End GS SR (Shrub)	-0.04	0.08	0.00	-0.09	-0.06	0.00	-0.09	-0.07	-0.02	0.21	0.18	0.17
End GS SR (Bare)	-0.01	0.05	-0.02	0.04	-0.15	-0.02	0.05	-0.16	-0.02	0.22	0.30	0.23
Length GS CR	0.07	-0.06	0.06	-0.04	0.08	0.05	-0.05	0.11	0.04	0.42	0.55	0.37
Length GS CR (Gram)	-0.04	0.08	0.00	0.79	-0.10	0.07	0.40	-0.05	0.07	0.57	0.65	0.55
Length GS CR (Shrub)	0.02	0.05	0.01	-0.02	-0.02	0.04	0.21	0.11	0.03	0.61	0.58	0.55
Length GS CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Length GS SR	-0.05	-0.05	0.07	-0.02	0.30	-0.08	0.00	0.17	-0.07	0.53	0.46	0.44
Length GS SR (Gram)	-0.04	0.08	0.00	0.79	-0.10	0.07	0.40	-0.05	0.07	0.57	0.65	0.55
Length GS SR (Shrub)	0.00	0.12	-0.02	-0.32	-0.18	-0.02	-0.17	-0.18	-0.09	0.79	0.64	0.50
Length GS SR (Bare)	-0.11	0.87	0.05	-0.76	-1.09	-0.10	-0.74	-0.53	-0.11	0.74	0.56	0.62
INDVI CR	-0.05	0.01	-0.04	-0.06	0.01	-0.05	-0.07	0.03	-0.02	N/A	N/A	N/A
INDVI CR (Gram)	0.05	-0.31	0.10	0.05	0.00	-0.03	0.07	-0.03	-0.11	N/A	N/A	N/A
INDVI CR (Shrub)	0.61	-0.13	0.20	-0.89	0.03	-0.30	-0.97	0.02	-0.31	N/A	N/A	N/A
INDVI CR (Bare)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
INDVI SR	0.06	-0.02	-0.02	0.06	-0.06	-0.05	0.27	-0.06	-0.04	N/A	N/A	N/A
INDVI SR (Gram)	0.03	-0.07	-0.05	-0.07	-0.12	-0.10	-0.13	-0.14	-0.09	N/A	N/A	N/A
INDVI SR (Shrub)	0.05	-0.11	-0.03	0.07	-0.12	-0.07	0.07	-0.11	-0.08	N/A	N/A	N/A
INDVI SR (Bare)	-0.14	-0.03	-0.20	-1.15	-0.64	-0.37	-1.18	-0.70	-0.38	N/A	N/A	N/A

(4 d) Daily Rate of Green-up

Caribou herds that have a current or long-term decreasing population status did not have a higher daily rate of green-up (NDVI), compared to herds that were increasing in population or were stable. Based on the ANOVA statistic the mean daily rates of NDVI increase from 1985-2006 were statistically different between herds with declining, increasing and stable populations ($p < 0.05$, 2df, Appendix E). However, the caribou herds with either a current or long-term declining population had the lowest average daily rate of green-up (Appendix E). In addition the long-term status of the daily rate of green-up was often stable or decreasing, but the Bathurst herd continued to decline during the same time period. Caribou herds with current increasing and decreasing populations had the same slope value, and a very similar rate of increase in NDVI was calculated for caribou with long-term increasing and decreasing populations. This suggests vegetation quality increased at the same rate in recent years, despite having different directions for current and Long-term Population Status.

(5) Discussion

If caribou population size is controlled by the phase of the AO, the positive phase, which generally results in a reduction in access to forage (Turner et al., 1994; Malcolm, 1996; Griffith et al., 2002) and more snowfall (Zalatan, 2006), should be linked with declines in population. I found no evidence to support this expectation for any herd in this analysis, contrary to analyses conducted over somewhat longer timescales or in different regions. For example, a one-year lagged decline in population growth rates was associated with the average annual intensity of the positive AO phase for the Porcupine

and Central Arctic herds (Joly & Klein, 2011) over 1970-2008, as did fecundity for the Central Arctic herd for the same time period (Joly & Klein, 2011). Similarly, Svalbard caribou experienced reduced population growth rates (one-year lag) during the AO positive phase over 1978-1999 (Aanes et al., 2002). It is possible that the dataset used in this analysis did not go far back enough in time, there were not enough population estimates available to detect a trend, or that high error bars for some population estimates caused periods of population increase and decrease to be measured incorrectly. It is also conceivable that the relationship with the Arctic Oscillation is indirect and possibly not causal, reflecting instead negative impacts of warmer winters, which increase icing events (Putkonen & Roe, 2003) that make foraging more energy-intensive because forage is more difficult to access (Joly & Klein, 2011) and thus reduce population (Griffith et al., 2002; Gunn, pers. comm.). This change may be because of a combination of environmental trends including increases in temperature on winter ranges, reduction in the amount of lichen due to forest fires, and a higher number of freeze-thaw days (Gunn et al., 2009). Alternatively, the AO is known to have distinct seasonal and regional differences (Post & Stenseth, 1999; Hartmann & Wendler, 2005). The AO has strong effects in the Arctic, but are more pronounced in north-eastern Canada compared to north-western Canada (Thompson & Wallace, 1998; Rigor et al., 2000). Therefore, because the strength of the AO varies by location it may not be a good predictor over large areas.

Although the Arctic is warming and vegetation biomass shows widespread increases, caribou populations do not respond consistently to those trends. For example,

the BNE and Qamanirjuaq herds have opposing population trends, but share similar increases in NDVI on their calving ranges throughout the monitoring period (1985-2006). I also observed significant increases in NDVI measurements across all summer ranges (1985-2006) for caribou (Table 2.2), yet caribou population trends were unrelated to these broad-scale trends. Although increases in NDVI undoubtedly reflect northern warming trends that are widely acknowledged (Olthof & Latifovic, 2007; Olthof et al., 2008; Pouliot et al., 2009), it is possible that even the relatively detailed remote sensing measurements are too coarse to capture some biologically-relevant processes, such as insect harassment, local or microclimatically-driven freeze-thaw events, or the effects on grazing of snowfall and drifting snow. Nevertheless, these data provide the basis for the most powerful test to date of whether pronounced broad-scale trends in productivity and seasonal timing could provide a common explanation for caribou population status.

If caribou population declines were dependent on vegetation quantity, I would have expected an earlier, shorter growing season and lower INDVI values, which are known to decrease the availability of vegetation, to be observed on the habitat ranges of caribou with a declining population status. Caribou population trends have been very pronounced, with documented declines of 45% in the Bathurst population from 2003 to 2006, while the largest observed shift in growing season length in the study region was an increase of 1 day when calculated with satellite data and the SATPAS program. Although lengthening growing seasons are associated with greater primary production and lead to increasing INDVI, phenological shifts observed to date may simply be too small to exert biologically meaningful effects on caribou herds. Alternatively, if caribou populations naturally cycle between large and small population sizes through time (Gunn et al.,

2011), it is at least plausible that rapid environmental changes underway in the Arctic may exert small negative effects on caribou populations. If those effects are experienced during a herd's natural downward swing in population size, they would present risks to herd persistence. Because of the vast areas needed for monitoring, existing caribou population data for Canadian Arctic regions are insufficient to provide strong tests of this idea. Longer-term monitoring data with consistent population estimation methods are needed.

Although vegetation quality is important for caribou survival, if vegetation quality were a dominant factor controlling large caribou populations, I would have expected higher rates of green-up to be observed on the ranges of caribou whose population was declining. My results showed the opposite trend for some herds. For example there were years with consistently low percentages of daily increases in NDVI compared to other years for the Bathurst herd, yet the population continued to decline. My findings contradict some previous research. One study concluded that the growth of female and male lambs and kids of mountain ungulates were negatively associated with rapid changes in plant productivity during green-up. This was likely due to a decrease in the time-period of access to high forage quality (Pettorelli et al., 2007). The precision of the data included in this study may have prevented the detection of a relationship between vegetation quality and the status of caribou populations. The same dates for the start of the calving season and peak lactation were used to calculate the rate of change in NDVI every year for all herds. It is likely that these dates varied between years and among herds. Using imprecise dates to calculate rate of change in NDVI each year for all caribou herds, may have resulted in missing the highest daily rate of increase in NDVI,

and thus identifying a relationship between high rates of daily increase in NDVI and declining caribou populations. It is also important to note that using 10-day composite 1 km satellite data to calculate NDVI rate of change limited the precision of this variable, therefore small changes may not have been detected.

Density-independent factors are known to influence caribou population size, however the density-independent variables tested here, representing greater climate change, and lower vegetation quantity and quality, were not observed on the habitat ranges of Barren-ground caribou with a declining population. It is possible that caribou populations are currently more affected by density-independent variables not included in this study. One such factor is hunter harvest, which may have been responsible for the rapid and continued decline in the Bathurst, BNW and Cape Bathurst herds from 2000 to 2006. When a population is declining naturally and hunter harvest levels remain the same, or short-term icing events occur it can be detrimental to caribou survival (Miller & Barry, 2009; Nesbitt & Adamczewski, 2009; Vors & Boyce, 2009). It is also possible that density-dependent factors, such as grazing, trampling of forage vegetation, diseases and intraspecific competition, which are associated with caribou population cycles (Joly & Klein, 2011) are having the greatest impact on barren-ground populations. When their population size gets quite large, they may decrease the amount of vegetation available because they exceed carrying capacity (Joly & Klein, 2011). Population dynamics among Peary caribou are influenced by both density-independent and density-dependent factors. Density-dependent factors exert strong effects in winters with unusual conditions (e.g. extremely high or low snowfall or intense icing conditions, Tews et al., 2007).

Similarly, the Riviere George herd reached very high population densities and fragmented and reduced the extent of their food sources within their summer range (e.g. dwarf birch was reduced to very low levels, Manseau et al., 1996). It is clear that barren-ground caribou also do not respond in any simple way to the broad-scale environmental changes currently underway. Relationships with density-dependent and density-independent factors are likely complex and herd specific, and therefore are going to be challenging to measure and predict how they will change in the future.

(6) Conclusion

There was no evidence to indicate that the positive phase of the Arctic Oscillation was related to periods of population decline, or higher amounts of climate change, and lower amounts of vegetation quantity or quality had occurred on the habitat ranges of barren-ground caribou with a declining population. The relationship between both density-dependent and density-independent variables and barren-ground caribou population cycles are not easily understood or monitored. The approach of the thesis highlights the advantage remote sensing provides in analyzing large areas covering broad landscapes. These results are the first to examine these density-independent variables over a long time period for multiple herds using satellite-based data.

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(8) Appendix

Appendix A – Barren-ground Caribou Population Estimates

Bluenose-East Herd

Year	Population Estimate	Range (95% CI)	Reference
1992	15544	not available	Russell, pers comm.
2000	119584	84410-126100	Department of Environment and Natural Resources, No Date (Bluenose-East)
2005	66600	62200-70970	Department of Environment and Natural Resources, No Date (Bluenose-East)
2006	66186	62625-69747	Department of Environment and Natural Resources, No Date (Bluenose-East)
2010	98600	±7100	Adamczewski, pers comm.
Long-term Population Status: Increasing			
Current Population Status: Increasing (Gunn et al., 2011)			

The Bluenose-East population started to increase consistently in the mid 1980's Department of Environment and Natural Resources, No Date (Bluenose-East). From 2000-2006 the herd experienced a 10% decline, and then increased again in 2010 (Gunn et al., 2011).

Tuktoyaktuk Peninsula Herd

Year	Population Estimate	Range (95% CI)	Reference
2006	3078	not available	Department of Environment and Natural Resources, No Date (Tuktoyaktuk Peninsula).
2009	2752	±276	Department of Environment and Natural Resources, No Date (Tuktoyaktuk Peninsula).
Long-term Population Status: Unknown			
Current Population Status (Gunn et al., 2011)			

There have been few surveys for the Tuktoyaktuk Peninsula herd, therefore the long-term population trend is unknown. The two population estimates from 2006 and 2009 together with high calf:cow ratios from 2008 to 2011(Davison & Branigan, 2011) suggest the population is currently stable (Gunn et al., 2011).

Cape Bathurst Herd

Year	Population Estimate	Range (95% CI)	Reference
1986	13476 - Based on locations of radio-collars during post-calving surveys of the bluenose herd (Gunn et al., 2011)	not available	Russell, pers. comm.
1987	12512 - Based on locations of radio-collars during post-calving surveys of the bluenose herd (Gunn et al., 2011)	9,012 – 16020	Department of Environment and Natural Resources, No Date (Cape Bathurst)
1992	19278 - Based on locations of radio-collars during post-calving surveys of the bluenose herd (Gunn et al., 2011)	13881 – 24675	Department of Environment and Natural Resources, No Date (Cape Bathurst)
2000	11089	9333 – 12845	Department of Environment and Natural Resources, No Date (Cape Bathurst)
2005	2434	2178 – 2691	Department of Environment and Natural Resources, No Date (Cape Bathurst)
2006	1821	1672 – 1971	Department of Environment and Natural Resources, No Date (Cape Bathurst)
2009	1934	1585 – 2283	Department of Environment and Natural Resources, No Date (Cape Bathurst)
Long-term Population Status: Decreasing (Gunn et al ., 2011)			
Current Population Status: Stable at low populations (Gunn et al., 2011)			

Bluenose-west Herd

Year	Population Estimate	Range (95% CI)	Reference
1986	88369 - Based on locations of radio-collars during post-calving surveys of the bluenose herd (Gunn et al., 2011)	not available	Russell, pers comm.
1987	106887- Based on locations of radio-collars during post-calving surveys of the bluenose herd (Gunn et al., 2011)	102233 - 111542	Department of Environment and Natural Resources, No Date (Bluenose-West)
1992	112360- Based on locations of radio-collars during post-calving surveys of the bluenose herd (Gunn et al., 2011)	86794 – 137926	Department of Environment and Natural Resources, No Date (Bluenose-East)
2000	76376	62029 – 90723	Department of Environment and Natural Resources, No Date (Bluenose-West)
2005	20800	18760 – 22840	Department of Environment and Natural Resources, No Date (Bluenose-West)
2006	18050	17523 – 18578	Department of Environment and Natural Resources, No Date (Bluenose-West)
2009	17897	16587 – 19207	Department of Environment and Natural Resources, No Date (Bluenose-West)
Long-term Population Status: Decreasing (Gunn et al., 2011)			
Current Population Status: Stable (Gunn et al., 2011)			

The Bluenose-West herd reached a population peak in 1992, and then started to decline based on the 2000 and 2005 population estimates (Gunn et al., 2011). The population currently appears to be stable (Davison, 2009 pers. Comm. from Gunn et al., 2011)

Ahiak Herd

Year	Population Estimate	Standard Error (+/-)	Reference
1986	30000	4300	Gunn et al., 2000
1997	200000	12746	Gunn et al., 2000
Long-term Population Status: decreasing (but based on preliminary data) (Gunn et al., 2011)			
Current Population Status: Unknown (Gunn et al., 2011)			

Bathurst Herd

Year	Population Estimate	Standard Error (+/-)	Reference
1986	472000	72900	Department of Environment and Natural Resources, No Date (Bathurst)
1990	352000	77800	Department of Environment and Natural Resources, No Date (Bathurst)
1996	349000	94900	Department of Environment and Natural Resources, No Date (Bathurst)
2003	186000	40000	Department of Environment and Natural Resources, No Date (Bathurst)
2006	128000	27300	Department of Environment and Natural Resources, No Date (Bathurst)
2009	32000	5300	Department of Environment and Natural Resources, No Date (Bathurst)
Long-term Population Status: Decreasing (Gunn et al., 2011)			
Current Population Status: Decreasing (Gunn et al., 2011)			

The Bathurst herd began to decline at a rate of 5% per year in 1986 and continued until 2006 (Gunn et al., 2011). Based on the 2009 population survey it appears the herd experienced a 70% decline after 2006 (Gunn et al., 2011).

Beverly Herd

Year	Population Estimate	Standard Error (+/-)	Reference
1988	190000	71000	Government of the Northwest Territories http://www.enr.gov.nt.ca/_live/pages/wpPages/Beverly_herd.aspx
1993	87000	17900	Government of the Northwest Territories http://www.enr.gov.nt.ca/_live/pages/wpPages/Beverly_herd.aspx
1994	276000	106600	Government of the Northwest Territories http://www.enr.gov.nt.ca/_live/pages/wpPages/Beverly_herd.aspx
2008	5000		Russsell, D (pers comm.)
Long-term Population Status: in 1980's, peak in mid 1990's, then declined (Gunn et al., 2011). Will count as declining because in most years from 1988-2008 the herd was declining.			
Current Population Status: Decreasing (Adamczewski, 2009)			

During the 1980's the Beverly herd population was increasing (Gunn et al., 2011). A calving ground survey in 2002 suggested that there was a decrease in densities compared to 1994 (Johnson & Mulders, 2009), and that the population probably peaked in the early to mid 1990's (Gunn et al., 2011). The 2008 population estimated the herd at 5000 (Russell, pers. Comm.), and the low cow:calf ratios from 2007-2008 show that the herd has experienced a serious decline (BQCMB, 2010).

Qamanirjuaq

Year	Population Estimate	Standard Error (+/-)	Reference
1985	272,000	142,000	Heard and Jackson, 1990; Thomas, 1998; Williams, 1995
1988	221,000	72,000	Heard and Jackson, 1990; Thomas, 1998; Williams, 1995
1994	495,665	105,426	Thomas, 1996
2008	349000	44900	Campbell et al., 2010
Long-term Population Status: Increasing from 1980's to 1994, then declining (Gunn et al., 2011)			
Current Population Status: Decreasing, but trend is not statistically significant. The herd is under active study to test for population trends (Gunn et al., 2011)			

The Qamanirjuaq herd increases in size from the 1980's to 1994 (Gunn, et al., 2011). Based on the 2008 population survey, it is estimated that the herd declined by 30% since 1994. However, the decrease was not statistically significant (Gunn et al., 2011). Further evidence to support the population decline is decreasing cow:calf ratio's from 1992- 2008 (Campell et al., 2010).

Appendix B – Rate of Change in Caribou Populations

Table B Rate of change in caribou populations between population surveys, and the overall rate of change in population from 1985-2006. (Yrs refers to years).

Ahiak		Bathurst		Beverly		Bluenose-east		Bluenose-west		Cape Bathurst		Qamanirjuaq		Tuktoyaktuk Peninula	
Yrs	Rate of Change	Yrs	Rate of Change	Yrs	Rate of Change	Yrs	Rate of Change	Yrs	Rate of Change	Yrs	Rate of Change	Yrs	Rate of Change	Yrs	Rate of Change
86 - 96	566.67%	86 - 90	-25.49%	88 - 93	-53.72%	92 - 00	699.33%	86 - 87	20.96%	86 - 87	-7.12%	85 - 88	-18.76%	06 - 09	-10.59%
		90 - 96	-0.76%	93 - 94	214.6%	00 - 05	-41.40%	87 - 92	5.12%	87 - 92	54.01%	88 - 94	124.44%		
		96 - 03	-46.71%	94 - 08	-98.19%	05 - 06	-4.74%	92 - 00	-32.03%	92 - 00	-42.48%	94 - 08	-30.44%		
		03 - 06	-31.16%	84-08	-97..36%	06 - 10	47.71%	00 - 05	-72.77%	00 - 05	-78.05%	85 - 08	26.82%		
		06 - 09	-75.08%			92 - 10	534.33%	05 - 06	-13.22%	05 - 06	-25.18%				
		86 - 09	-93.24%					06 - 09	-0.85%	06 - 09	6.205%				
								86 - 09	-79.75%	86 - 09	-85.65%				

Appendix C – Average AO Phase

Table C Count of the average AO phase value during periods when of population increase, and over periods of population decrease. The count is based on all herds combined. The probability values were calculated using the chi square statistic to determine if the positive AO occurred more often during periods of population decline or if the negative AO occurred more often during periods of population increase. P-values greater than 0.05 indicate that the sign of the AO phase was not significantly different during periods of population increase or decrease. (Pop refers to population, +AO to the positive arctic oscillation phase, –AO to the negative Arctic Oscillaiton phase, BNE the Bluenose-east herd, BNW the Bluenose-west herd, Cape B the Cape Bathurst herd, Qam the Qamanirjuaq herd, and Tuk Pen the Tuktoyaktuk Peninsula herd)

Herd	Summer		Winter		Yearly	
Average of Arctic Oscillation Phase For Years in Between Population Estimates						
	Period of population increase	Period of population decrease	Period of population increase	Period of population decrease	Period of population increase	Period of population decrease
Ahiak						
+ AO	1	0	1	0	1	0
-AO	0	0	0	0	0	0
Bathurst						
+ AO	0	2	0	3	0	3
-AO	0	3	0	2	0	2
Beverly						
+ AO	1	1	1	2	1	1
-AO	0	1	0	0	0	1
BNE						
+ AO	1	2	2	0	0	1
-AO	1	0	0	2	2	1
BNW						
+ AO	1	2	1	2	1	1
-AO	1	2	1	2	1	3
Cape B						
+ AO	1	2	1	1	2	1
-AO	1	2	1	3	0	3
Qam						
+ AO	1	0	1	1	1	0
-AO	0	2	0	1	1	1
Tuk Pen						
+ AO	2	2	3	1	2	0
-AO	1	0	1	0	2	1
Total						
+ AO	8	11	10	10	8	7
-AO	4	10	3	10	6	12
P-Value	0.888		0.122		0.247	
Arctic Oscillation Phase the Year Prior to a Population Estimate						
Ahiak						
+ AO	0	0	1	0	0	0
-AO	1	0	0	0	1	0
Bathurst						
+ AO	0	3	0	3	0	3
-AO	0	2	0	2	0	2
Beverly						
+ AO	1	2	1	2	1	2
-AO	0	0	0	0	0	0
BNE						
+ AO	0	0	1	0	0	0
-AO	2	2	1	2	2	2
BNW						

+ AO	2	2	0	1	2	2
-AO	0	2	2	3	0	2
Cape B						
+ AO	1	1	1	0	2	2
-AO	1	3	1	4	0	2
Qam						
+ AO	0	0	1	1	1	1
-AO	1	2	0	1	0	1
Tuk Pen						
+ AO	2	1	2	1	2	1
-AO	2	0	2	0	0	2
Total						
+ AO	6	9	7	8	8	11
-AO	7	11	6	12	3	11
P-value	0.948		0.435		0.213	

Appendix D – Tukey's HSD Multiple Comparison Test

Table D Tukey's HSD multiple comparison test was used to determine if phenology variable means were statistically different. P-values calculated by Tukey's HSD test, < 0.01 are significantly different at the 99% confidence interval, and p-values <0.05 are significant at the 95% confidence interval. N/S indicates the means were not significantly different. DP refers to decreasing population, SP stable population, Pop population, LR linear regression, thr threshold, and clim climate.

Start of the Growing Season Calving Range								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	n/s	n/s
Decreasing Pop		n/s		<0.01		<0.01		n/s
Start of the Growing Season Calving Range – Graminod Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.01	<0.01	<0.01	n/s	<0.01	n/s	n/s
Decreasing Pop		<0.01		<0.01		<0.01		n/s
Start of the Growing Season Calving Range –Shrub Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	n/s	n/s	n/s	<0.01	n/s	<0.01	n/s	n/s
Decreasing Pop		n/s		<0.01		<0.01		n/s
Start of the Growing Season Summer Range								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	n/s	<0.01	<0.01	n/s	<0.01	<0.01	n/s
Decreasing Pop		n/s		<0.01		<0.01		<0.01
Start of the Growing Season Calving Range – Graminod Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	n/s	<0.01	n/s	<0.01	n/s	<0.01	n/s	n/s
Decreasing Pop		<0.01		<0.01		<0.01		n/s
Start of the Growing Season Summer Range –Shrub Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	n/s	<0.01	<0.01	n/s	<0.01	n/s	n/s
Decreasing Pop		n/s		<0.01		<0.01		n/s
End of the Growing Season Calving Range								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	n/s	n/s
Decreasing Pop		n/s		<0.01		<0.01		<0.01
End of the Growing Season Calving Range – Graminod Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.01	n/s	<0.01	n/s	<0.01	n/s	n/s
Decreasing Pop		n/s		<0.01		<0.01		<0.01
End of the Growing Season Calving Range –Shrub Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	n/s	<0.01	n/s	<0.01	n/s	<0.01	<0.05	n/s
Decreasing Pop		<0.01		<0.01		<0.01		n/s
End of the Growing Season Summer Range								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	n/s	<0.01	<0.01	<0.01	<0.01	<0.01	n/s
Decreasing Pop		<0.01		<0.01		<0.01		<0.01
End of the Growing Season Summer Range – Graminod Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.01	n/s	<0.01	n/s	<0.01	<0.05	n/s

Decreasing Pop		n/s		<0.01		<0.01		<0.05
End of the Growing Season Summer Range –Shrub Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.01	n/s	<0.01	n/s	<0.01	<0.05	n/s
Decreasing Pop		<0.01		<0.01		<0.01		<0.05
Length of the Growing Calving Range								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.05	<0.01	<0.05	<0.01	n/s	<0.01	n/s	n/s
Decreasing Pop		<0.01		<0.01		<0.01		n/s
Length of the Growing Calving Range – Graminod Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	n/s	<0.01	<0.01	n/s	n/s	<0.01	n/s	n/s
Decreasing Pop		<0.01		<0.01		<0.01		n/s
Length of the Growing Calving Range –Shrub Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	n/s	n/s	n/s	<0.01	n/s	<0.01	n/s	n/s
Decreasing Pop		n/s		<0.01		<0.01		n/s
Length of the Growing Summer Range								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.05	<0.01	<0.01	<0.01	n/s	<0.01	n/s
Decreasing Pop		n/s		<0.01		<0.01		<0.01
Length of the Growing Summer Range – Graminod Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.01		<0.01	<0.05	<0.01	n/s	n/s
Decreasing Pop		<0.01		<0.01		<0.01		n/s
Length of the Growing Summer Range –Shrub Land Cover								
	LR		Thr 30		Thr 50		Clim	
	DP	SP	DP	SP	DP	SP	DP	SP
Increasing Pop	<0.01	<0.01	n/s	<0.01	<0.05	<0.01	n/s	n/s
Decreasing Pop		n/s		<0.01		<0.01		n/s
INDVI Calving Range								
	LR		Thr 30		Thr 50			
Increasing Pop	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		
Decreasing Pop		<0.05		n/s		n/s		
INDVI Calving Range – Graminod Land Cover								
	LR		Thr 30		Thr 50			
	DP	SP	DP	SP	DP	SP		
Increasing Pop	n/s	<0.01	<0.01	<0.01	n/s	<0.01		
Decreasing Pop		<0.01		<0.01		<0.01		
INDVI Calving Range –Shrub Land Cover								
	LR		Thr 30		Thr 50			
	DP	SP	DP	SP	DP	SP		
Increasing Pop	n/s	n/s	n/s	n/s	n/s	n/s		
Decreasing Pop		n/s		n/s		n/s		
INDVI Summer Range								
	LR		Thr 30		Thr 50			
	DP	SP	DP	SP	DP	SP		
Increasing Pop	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		
Decreasing Pop		<0.05		n/s		n/s		
INDVI Summer Range – Graminod Land Cover								
	LR		Thr 30		Thr 50			
	DP	SP	DP	SP	DP	SP		
Increasing Pop	n/s	n/s	n/s	n/s	n/s	n/s		
Decreasing Pop		n/s		n/s		n/s		
INDVI Summer Range – Shrub Land Cover								
	LR		Thr 30		Thr 50			
	DP	SP	DP	SP	DP	SP		
Increasing Pop	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01		
Decreasing Pop		n/s		n/s		n/s		

Appendix E – Mean, Standard Deviation, and Slope for the Daily Rate of Increase in NDVI (1985-2006)

Table E Daily percent increase in NDVI (daily rate of green-up) from June 1st to June 11th (± 5 days) was calculated for 1985-2006. Ten day composite, AVHRR 1km satellite imagery was used. The mean represents the average vegetation quality, and the slope represents the rate which vegetation quality increased or decreased. BNE refers to Bluenose-east, BNW Bluenose-west, Qam Qamanirjuaq, and Tuk Peninsula Tuktoyaktuk Peninsula.

Value	Tuk Peninsula (%)	BNE (%)	BNW (%)	Cape Bathurst (%)	Beverly (%)	Bathurst (%)	Qam (%)	Ahiak (%)
Mean Number	2.18	1.86	1.59	1.64	1.91	1.73	2.00	1.91
Standard Deviation	0.853	0.774	0.666	0.953	0.811	0.883	1.07	0.684
Slope	0.09	0.02	0.04	0.06	0.02	-0.01	-0.01	0.00

Table 3.1: Acronyms and abbreviations for Chapter 3

Acronym	Definition
AUC	Area under the curve
Bath	Bathurst herd
Bev	Beverly herd
BNE	Bluenose-east herd
BNW	Bluenose-west herd
CDED	Canadian Digital Elevation Data
Cape B	Cape Bathurst herd
% CP	Percent of correctly projected presence points
GDD	Growing Degree Days
NDVI	Normalized Difference Vegetation Index
PCA	Principle component analysis
Qam	Qamanirjuaq herd
ROC	Receiver operating characteristic
% SH	Percent of suitable habitat
Temp	Temperature.
Tuk P	Tuktoyaktuk Peninsula herd

Chapter 3 – Monitoring Changes in Caribou Habitat using Maxent Distribution Models

(1) Abstract

Widespread declines among barren ground (*Ranifer tarandus groenlandicus)* caribou populations, which are divided among regional herds, across Arctic regions of Canada have been observed (CARMA, 2009; Festa-Bianchet, 2011; Gunn et al., 2011). The causes of these declines are hotly debated. Extensive evidence indicates that herds are vulnerable in their spring calving and in subsequent summer grazing lands (Van der Wal et al., 2000; Russell et al., 2002; Skarin et al., 2008; Couturier, 2009). Recent climate changes have been noted from regions where caribou declines are underway (Comiso, 2012; Overland & Serreze, 2012), raising the question of whether climate may play some role in recent downswings in herd sizes. I used regional climate and landscape measurements together with the largest barren-ground caribou presence dataset yet collected to construct herd-by-herd distribution models. The modelling method used was Maxent, which is widely employed to project how individual species distributions will change through time as a function of climate change (Thomas et al., 2004; Baldwin, 2009; Environment Canada, 2008), although it is very rarely tested for its capacity to make temporal predictions. Herd data were available over several years, enabling testing of Maxent results. These models were intended to test whether herd sizes tracked changes in projected suitability through time, which would have indicated the possibility that simple, directional, environmental changes could have contributed to declining caribou herd sizes. However, Maxent models were only accurate as spatial tools to predict known herd distributions. Although there is environmental variability among calving and summer territories used by each herd, spatial and temporal climatic, productivity, and

land cover changes on calving and summering grounds do not directly account for lower amounts of suitable habitat for barren-ground caribou. I cannot exclude the possibility that more other environmental changes on calving/summer grounds are reducing the effective area of these lands or degrading their quality and consequently contributing to caribou population trends. If so, however, those changes are subtle and not detectable using remote sensing observations or the existing meteorological monitoring capacity present in Canada's Arctic landscapes.

(2) Introduction

Biologists are increasingly concerned about the effects that climate, anthropogenic development and natural disturbances are having on caribou habitat. A species' geographic distribution is a result of its ecology and evolutionary history, which is influenced by a variety of factors working at different spatial scales, like climate (Case & Taper 2000; Soberon, 2007). The majority of barren-ground caribou have specific winter, calving and summer habitat ranges, and return to these same areas each year. The calving ground is defined as the area within the calving range where pregnant cows are concentrated. The extent of calving grounds area can vary through time but usually overlaps somewhat with previous years (Fleck & Gunn, 1982; BQCMB, 2004). Caribou shift their grazing locales in response to differences in the rate of vegetation emergence, or "green-up" (Skoog, 1968; Kelsall, 1968; Skogland, 1984, Russell et al., 1993; Cook, 2002), taking advantage of the highest quality vegetation, because the nutritional requirements for female caribou are greatest in late gestation and when they are lactating (Clutton-Brock et al., 1989; Robbins, 1993). Thus the location of the calving grounds should reflect the availability of emergent vegetation. Female ungulates that have access to large amounts of high-quality vegetation will be able to better care for their young, maximize calf survival, and will have higher fat content, giving them a better chance to conceive the following autumn (Festa-Bianchet, 1998; Gaillard et al., 2003).

Climate models predict that recently observed changes in temperature and precipitation will continue for the foreseeable future in the Arctic (IPCC, 1997; Ford et al., 2008; Melles et al., 2012). Accompanying widespread Arctic climate changes is the likelihood that forage will be covered by snow or ice because of transitory warming that

make snow more likely and that may cause brief melting of snowy surfaces that ice over shortly afterward. Caribou must then expend greater effort to dig through snow or break icy surfaces to reach grazing vegetation below (Joly et al., 2009; Tyler, 2010), but caribou may also be more susceptible to predation under these circumstances (Brotton & Wall, 1997; Joly et al., 2009). Such changes increase calf mortality (Cameron et al., 1992; Kumpula & Colpaert, 2003; Adams, 2005). In addition, an increase in temperature could shift the peak availability of highly nutritious and digestible vegetation and reduce caribou survival rates if caribou migration is consequently disrupted or vegetation is sparse in areas where caribou migrate (Russell et al., 1993; Visser et al., 2004; Pettorelli et al., 2005; Gunn et al., 2011).

The extent and location of caribou summer habitat may also be important to their survival, and is vulnerable to the effects of climate change. Caribou summer habitat selection is thought to reflect a balance between the best foraging opportunities and lowest insect harassment (Russell et al., 1993), and thus can vary from year to year. Specific vegetation is preferred by caribou in summer (forbs, shrubs and cottongrass) because they have high nitrogen concentrations, are easy to digest, and experience their nitrogen peak when the growing season begins (Johnstone et al., 2002). When available, fructicose lichen is the preferred food source because it contains high amounts of digestible energy (Parker et al., 2009). Climate (cloudy, cold, and wet summers) can reduce the amount and location of the summer habitat year to year by causing less than optimal forage growing conditions and an increase in certain biting insects (Zalatan, 2006), causing caribou to seek refuge in areas of high elevation and low amounts of vegetation (Russell et al. 1993, Skarin et al. 2004).

In the absence of comprehensive, range-wide monitoring of populations' statuses, species distribution models provide a means of projecting the impacts of habitat changes on species distributions, either over broader extents than permitted by existing models or through time (Guisan & Zimmermann, 2000; Peterson, 2006; Phillips et al., 2006). The reliability of these models through time (specifically, in terms of their capacity to accurately predict the changing distribution of species with respect to environmental changes) varies (Kharouba et al., 2009). Although species distribution models are used routinely to forecast global change impacts on species distributions (e.g. Thuiller et al. 2011) and even extinction rates (e.g. Thomas et al. 2004), availability of long-term species observation datasets has limited tests of their reliability (Dobrowski et al. 2010). When long-term data are available for both presence records and environmental variables that biological observation demonstrate could limit the species distribution, it is possible to test the accuracy of the model through a period of observed environmental change (Phillips et al., 2006; Kharouba et al., 2009). Species distribution models rely most commonly on presence-only datasets (Phillips, 2006; Soberon, 2007; Phillips & Dudík, 2008).

A recent study by Environment Canada (2008) used species distribution models as evidence to support the identification of critical habitat for woodland caribou (*Rangifer tarandus caribou)* by using the environmental species distribution models to interpret the pattern of occupancy in the present extent of occurrence. Because barren-ground caribou and woodland caribou share so many biological characteristics, a similar modeling approach for barren ground caribou might provide insight into whether there is an

environmental basis for population declines that appeared widespread among barren-ground caribou. Species distribution models (using Maxent) were constructed using past observations of barren-ground caribou presence using broad-scale satellite observations to represent environmental variables know to be important for barren-ground caribou presence. These models were used to explore three questions that provide the impetus for this research on barren grounds caribou and that I have adapted for this research:
Can Maxent correctly specify environmental limitations on the spatial and temporal distributions of barren ground caribou? Are declines in calving and summer range habitat that is projected to be suitable for barren ground caribou greater for caribou with a declining population status, compared to herds with an increase or stable population status? Do these environmental limitations vary among herds?

(3) Methods

3 a) Study Area

3 a i) Landscape

The calving and summer ranges for most Barren-ground caribou are located in one Canadian ecozone, and their winter range is located in one or two different ecozones (Gunn et al., 2011). All calving ranges are located in the Southern Arctic ecozone, with the exception of the Qamanirjuaq herd (Figure 3.1). The southern portion of the Qamanirjuaq calving range falls partially in the Boreal Shield and the Hudson Plains ecozones (Gunn et al., 2011). All herds except the Tuktoyaktuk Peninusla and Cape Bathurst have a portion of their summer range in the taiga shield ecozone (Figure 3.1).

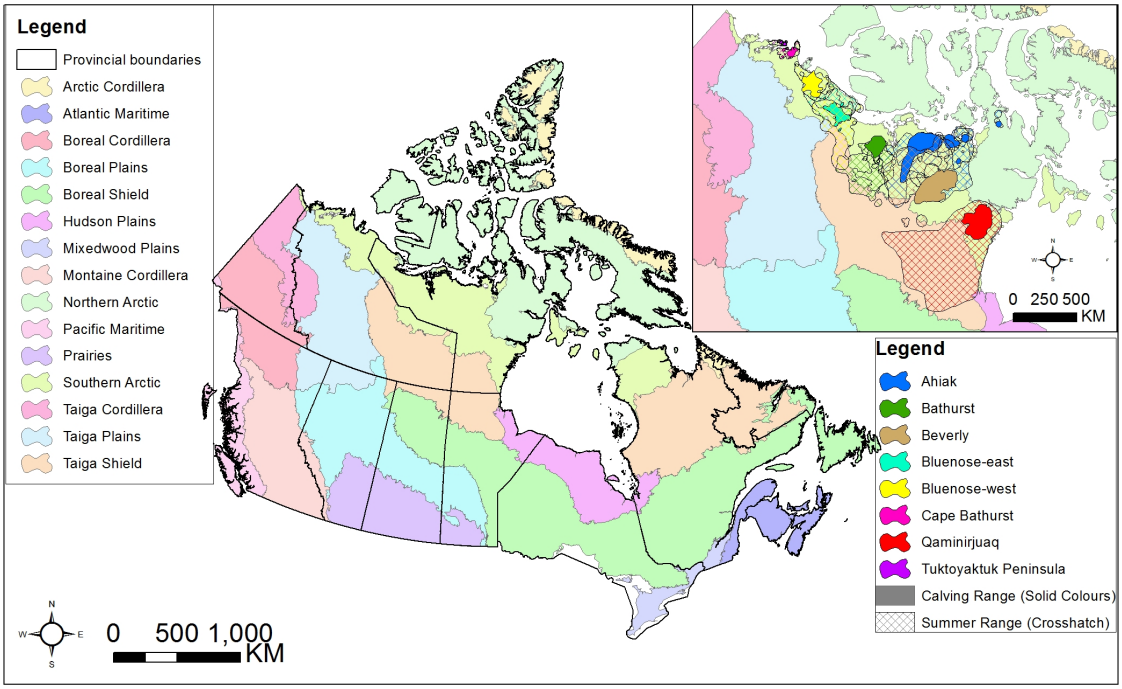

Figure 3.1: The main map shows the Canadian ecozones. The map in the top right corner shows the ecozones, which fall within the barren-ground caribou calving and summer ranges.

3 a ii) Southern Arctic Ecozone

Topography in the Southern Arctic ecozone consists of rolling uplands and lowlands, mixed with lakes, ponds and wetlands (Environment Canada, 2008). The winters are long and cold, and summers short and cool. The average temperature in July only reaches 10ºC. There is a large fluctuation in winter temperatures, but the average is about -30ºC (NWT Environmental Audit Status of the Environment Report, 2005). The mean precipitation from north to south is between 200 mm and 400 mm (NWT Environmental Audit Status of the Environment Report, 2005). There are several types of shrubs including, dwarf birth, willows and heath species. Many types of herbs and lichens also exist (NWT Environmental Audit Status of the Environment Report, 2005). Fire is rare in this landscape and only about 0.03% of this region annually (Stocks et al., 2002).

3 a iii) Taiga Shield Ecozone

The landscape in the Taiga Shield ecozone is a combination of eskers, bedrock erratic and morainal deposits. In addition there are several lakes, open forests, peatlands, and some shrubland and meadows (Environment Canada, 2008). The average temperature in January is between -17.5ºC to -27.5ºC, and in July 7.5ºC - 17.5ºC. There is considerably less precipitation, (175 mm-200 mm), when compared with the Southern Arctic ecozone (NWT Environmental Audit Status of the Environment Report, 2005). In the northern portion of the ecozone, there are open forest stands, lichen woodlands and of open tundra. Less productive and often stunted coniferous and deciduous stands, such as black spruce, white spruce, balsam fir, willows and alders, are characteristic of the centre portion of the taiga shield (NWT Environmental Audit Status of the Environment Report,

2005). Upland locations are susceptible to forest fires because they are well drained (Environment Canada, 2008).

3 b) Data

3 b i) Calving and Summer Habitat Ranges

Caribou biologists from the Northwest Territories Government created GIS shapefiles representing the calving and summer ranges of barren-ground caribou. Range estimates were constructed using the Animal Movement Program (Hooge & Eichenlaub, 2000) with GPS or radio collar location data for female breeding caribou. The parameters that were used in the Animal Movement program were the batch Kernel Home Range processing option (all ranges from 50% to 95% were calculated) to calculate the home range, automated data smoothing method to remove outliers, and default cell size (20 km).

3 b ii) Maxent Models

Georeferenced presence points were collected from GPS and satellite radio collars. In an effort to reduce spatial and temporal autocorrelation, only one randomly selected presence location for each caribou was used for input into the habitat models. Twenty-five randomly selected presence points were used as the input to train the calving habitat models, and fifty for the summer habitat models. Herds and years with fewer than twenty-five (on calving rage), or fifty (on summer range) presence points were excluded from the analysis. The calving and summer ranges were buffered by a minimum of 500 km, and 10,000 background points were created to represent areas where the caribou were not present. These points were also included to help train the

Maxent model by identifying environmental combinations where caribou appear to be consistently absent.

Based on past research (Johnstone et al., 1999; Parker et al., 2009; Cook, 2002; Zalatan, 2006; Environment Canada 2008; Joly et al., 2009; Gunn et al., 2011), I selected environmental variables known to be important for caribou survival to be potentially included in the Maxent models. I randomly selected 1000 grid cells from the Northwest Territories and Nunavut region and calculated Pearson's correlation coefficients among measurements of elevation, terrain ruggedness, slope, aspect, snow cover, land cover and the 35 bioclimatic variables created by The Canadian Forestry Service (McKenney et al., 2006). This was done to measure collinearity among variables included in the Maxent models. No two variables that had a correlation coefficient higher than 0.7 were included in the models (Parra et al., 2004; Environment Canada, 2008). In cases where two or more variables were highly correlated, only one was chosen to be included in the final Maxent model. The variable was selected based on (1) biological relevance from past research and (2) running Maxent with all variables and using the jackknife approach. This method eliminates one variable at a time form the model, so that the user can determine the degree to which each variable was able to explain the species distribution and the amount of unique information each variable provided (Baldwin & Bender, 2008; Phillips, http://www.cs.princeton.edu/~schapire/maxent/).

Tables 3.2 and 3.3 describe the final set environmental variables selected used to train the Maxent calving range and Maxent summer range models and their hypothesized relationship to caribou habitat.

Table 3.2: Environmental variables selected for the final caribou calving range Maxent models. All variables that were highly correlated with other variables in the final model or had little ability to explain species distribution are not included. The rationale for variables included in the models is summarized in the table below, but are described in full in the text. Variables in the calving range model were slightly different then those included in the summer range model because of the time of year which caribou are located on the ranges. Precipitation and growing degree days from the first six week of the growing season were included only in the calving range model because this is the time of year barren-ground caribou migrate to the calving ranges.

Variable	Rationale
Digital Elevation Model (DEM)	Ranges with more topographic relief will have more suitable habitat (Bergerud et al., 1984; Ion & Kershaw, 1989; Nellemann & Cameron 1996)
Total precipitation for first 6 weeks of growing season	Warmer temperatures in spring cause more freeze/thaw days, thus preventing caribou from reaching optimal calving range (Griffith & Russell, 2001)
Growing degree days (gdd) above base temperature for the first 6 weeks of growing season	Warmer temperatures in spring cause more freeze/thaw days, thus preventing caribou from reaching optimal calving range (Griffith & Russell, 2001)
PCA of Temperature Seasonality (C of V) & Precipitation Seasonality (C of V)	Reduced climatic variability throughout the season may result in fewer climate fluctuations during the spring migration, which would also result in fewer freeze/thaw days (Griffith & Russell, 2001)
Average NDVI for approximately the first 6 weeks for the growing season from 10 day composite 1 km AVHRR	Years with higher NDVI values will result in more forage availability, and thus more suitable habitat (Skogland, 1984; Russell et al., 1993)
Snow Cover	Years with more snow cover result in more freeze/thaw days and therefore less suitable habitat (Griffith & Russell, 2001; Kohler & Aanes, 2004)
12 class 1 km AVHRR Land Cover (Lativovic & Pouliot, 2005)	Ranges with more graminoid land cover will have more suitable habitat (Russell et al., 1993; Pouliot, et al., 2009)

Table 3.3: Environmental variables selected for the final caribou summer range Maxent models. All variables that were highly correlated with other variables in the final model or had little ability to explain species distribution are not included. Precipitation and temperature closest to the date range which barren-ground caribou are located on their summer ranges were included. There is no snow cover when barren-ground caribou are present on their summer ranges.

Variable	Rationale
Digital Elevation Model	Ranges with more topographic relief will have more suitable habitat (Bergerud et al., 1984; Ion & Kershaw, 1989; Nellemann & Cameron 1996)
Total Precipitation for the growing season	Drier summers earlier peak biomass, plants harden earlier, increased oestrid harassment, and thus less suitable habitat (Griffith & Russell, 2001)
Mean temperature for the growing season	Warmer summers earlier peak biomass, plants harden earlier, increased oestrid harassment, and thus less suitable habitat (Griffith & Russell, 2001)
PCA of Temperature Seasonality (C of V) & Precipitation Seasonality(C of V)	Reduced climatic variability throughout the season may result in an increase in insect harassment and poor growing conditions for vegetation (Griffith & Russell, 2001)
Average NDVI for approximately the growing season from 10 day composite 1 Km AVHRR NDVI	Years with higher NDVI values will result in more forage availability, and thus more suitable habitat (Skogland, 1984; Russell et al., 1993)
12 class 1 km AVHRR Land Cover (Lativovic & Pouliot, 2005)	Ranges with more graminoid land cover will have more suitable habitat (Russell et al., 1993; Pouliot, et al., 2009)

A digital elevation model was created from Canadian Digital Elevation Data (CDED) with a resolution of 250 m, and was resampled to 10 km using ArcMap. Previous research has shown that topography may play a role in caribou habitat selection when they are calving (Bergerud et al., 1984; Nellemann & Cameron 1996). Variations in topography increase the variety of vegetation available early in the growing season (Nellemann & Thomsen 1994; Nellemann & Cameron 1996). In addition topographically variable terrain may provide caribou with more protection from predators because they are more difficult to spot (Bergerud et al., 1984) and refuge from insect harassment because there is more wind (Ion & Kershaw, 1989).

Caribou require large amounts of energy-rich food, especially during peak lactation (Russell et al., 1993), and land cover was included in the Maxent models because it can approximate quantity of vegetation and quality of forage. It is widely known that climate change has caused land cover disturbances in the North, such as forest fires or storms that are detrimental to caribou. Disturbances over such extensive areas could alter land cover and associated composition or density of vegetation to reduce caribou populations (Pouliot et al., 2009).

NDVI was used as input to the models because NDVI represents gross photosynthesis and quantity of vegetation at large spatial scales (Kerr & Ostrovsky, 2003; Goetz et al., 2005; Petorrelli, 2005). Caribou have the ability to track vegetation green-up, and therefore select habitat with large amount of green-up (Skogland, 1984; Russell et al., 1993). NDVI is calculated as

NDVI = (NIR-RED)/(NIR+RED), where NIR is near infrared reflectance and RED is red reflectance. NDVI has no units.

Precipitation and temperature (see Tables 3.1 and 3.2) were included because climate can affect caribou habitat suitability, both positively and negatively. Temperature and precipitation greatly influence vegetation quantity and quality, the number of freeze-thaw days in the spring, the timing of snow melt, and insect harassment (Griffith & Russell, 2001). Precipitation and temperature from the calving and summer time frame, as well as seasonal values were used in the habitat models. Both the precipitation and temperature data came from climate grids created by the Canadian Forest Service. The climatic variables were created using monthly temperature and precipitation values (McKenny et al., 2006).

Digital elevation, land cover, snow cover, and NDVI data were all resampled to approximately 10 km resolution in ArcMap, because that was the finest resolution in the climate data set that could be interpreted (McKenney et al., 2006).

3 c) Habitat Model Methodology

3 c i) Habitat Models

In this thesis Maxent was used to (1) determine if it is a reasonable tool for caribou management, (2) evaluate whether the effects of resource availability and climatic constraints of projected suitable habitat extent, and (3) investigate which environmental variables were most important for calving and summer habitat. I did not attempt to prove that any given model was true but to measure whether models usefulness could be defended by testing them using independent spatiotemporal caribou observations to assess whether these models might be useful. In this respect, my use of models follows Box (1979), theory that "all models are wrong, but some are useful".

For many species, it is very challenging to collect true absence data. Where only presence data are available, many conventional statistical methods, such as logistic regression, are unsuitable. In recent years, species distribution modelling techniques, such as Maxent, have been developed that require only presence data. The details explaining the modeling technique can be found elsewhere (Phillips et al., 2006) and Maxent is now commonly used for species distribution modelling purposes. Presence points were randomly selected to avoid spatial autocorrelation (25 on the calving range, 50 on the summer range) for the earliest year available and the environmental variables for the same year were used to build a habitat model (year 1) for each caribou herd for both the calving and summer habitat. The presence points were randomly selected to ensure I was getting points evenly distributed within the habitat ranges. The same model was then projected forward through time, and applied to the environmental conditions in subsequent years. Thus the models were not just a spatial snapshot in time, but were also used to test how the habitat variables predicted caribou presence through time. Each model was run ten times using the same presence points and then averaged. The fit of each model was refined using tenfold cross-validation, in which models are fit to 90% of data and tested on the remaining 10% of observations ten times, so all observations are used both for fitting and testing in the model construction phase (Phillips, 2006). The tenfold cross-validation was calculated by the Maxent software, and is an option which can be selected by the user.

A model was also created using all presence points from 1999-2006 and all environmental variables from 1999-2006 to build the habitat model on the Bathurst calving range. This was done to test whether models built using presence points and

environmental variables from all years was better able to predict caribou presence spatially and temporally.

3 c ii) Accuracy Assessment

Accuracy assessment was determined for the habitat models in two ways. Maxent produces a receiver operating characteristic (ROC) curve. The area under the curve (AUC), which ranges from 1 to 0, is a measure of overall accuracy (Fielding & Bell, 1997). A value of 0.5 implies the model is no more accurate than a random model, and a value of 1 implies the model had complete discrimination (Fielding & Bell, 1997).

To determine how accurately Maxent modelled suitable and unsuitable habitat for the projected models, the percentage of presence points located on suitable habitat (that is, in areas that Maxent predicts to be suitable) was calculated. To convert a probability of habitat suitability into areas of suitable and unsuitable habitat a threshold must be defined (Liu et al., 2005). All data above the threshold is deemed to be suitable habitat, and everything below the threshold is unsuitable habitat. There are several methods for determining a threshold. For this thesis the presence point used in the training set of each model with the lowest predicted suitability was used as the threshold (Pearson et al., 2007). This method is slightly biased, because there would be no false presences on the year the model was built. However, this threshold method was been widely used in other Maxent models (Pyron et al., 2008; Kharouba et al., 2009; Kumar & Stohlgren, 2009; Rodda, et al., 2011).

The amount of suitable habitat for each caribou herd, calculated using Maxent, was first grouped together based on their long-term, then second based on their current population trends to increase sample size. The mean amounts of suitable habitat and the

slope of the amount of suitable habitat through time were compared to determine if caribou with a long-term or current decline in population status had a lower mean amount of suitable habitat or declined at a faster rate, compared to herds with an increasing or stable population status. The amount of suitable habitat was not normally distributed, therefore the Mann-Whitney (compared caribou herds with increasing and decreasing long-term populations) and Kruskal-Wallis (compared caribou herds with current increasing, decreasing and stable populations) tests were used to compare the mean amount of suitable habitat.

Maxent estimates the relative contribution of each of the environmental variables to predict species presence. I compared how Maxent ranked each environmental variable. If the same environmental variables were having the strongest influence of barren-ground caribou, then they may respond in a similar manner to climate or landscape changes.

(4) Results

The Maxent calving and summer habitat models were able to accurately model caribou presence spatially, but likely underestimated the amount of suitable habitat when trained using environmental variables from only one year. Maxent failed to accurately model barren-ground caribou presence temporally when models were run through time. The very high minimum area under the curve (AUC) values (≥0.934, Table 3.4), which indicates that models were "excellent", were misleading. The AUC values were produced by Maxent, and were based on the training model (Appendix A). All models had a very high accuracy rate of predicting suitable habitat for year 1, the year the model was trained on (Table 3.4). However, all models had a very low accuracy of predicting

suitable habitat when the trained models were projected through time for most years. This suggests that species observations from a single year lead to very overfit models that specify environmental constraints so tightly that in any other year, even slight deviations from exactly what the model was trained on cause the model to project 0% suitability. Climate conditions varied widely from year to year, suggesting that barren-ground caribou are able to adapt to a range of climate conditions. For example the total amount of precipitation for the first six weeks of the growing season was temperature was 63.10 mm in 1999, and 28.8 mm in 2000, within the Bathurst calving range. The number of days above base temperature also varied from 96.27 in 1999 to 279.77 in 2000 (refer to Appendix B for all climatic variable averages included in the Maxent models).

Table 3.4: Results from Maxent models. Year (yr) 1 is the model on which Maxent was trained. The remaining years are the years in which Maxent was projected forward through time. AUC values are a measure of how accurate the Maxent year 1 model was. A value greater than 0.90 indicate the model was excellent. Percent of suitable habitat (% SH) was determined by applying the value on the minimum training presence data as a threshold. Areas above this threshold were deemed suitable for habitat. Percent of correctly projected presence points (% CP) was determined by overlaying the presence points on the resulting Maxent model after the minimum training presence threshold had been applied.

Year	Ahiak			Bathurst			Bluenose-east			Bluenose-west			Cape Bathurst		
	AUC	% SH	% CP	AUC	% SH	% CP	AUC	% SH	% CP	AUC	% SH	% CP	AUC	% SH	% CP
Calving															
1996															
1987															
1998							0.98 (yr 1)	63	99	0.94 (yr 1)	83	100	0.98 (yr 1)	100	100
1999				0.97 (yr 1)	99	100		24	90		41	68		32	23
2000					31	71		0	0		0	0		0	0
2001					1	0		19	0		3	0		0	0
2002					0	0		18	0		18	13		0	0
2003					0	0		1	0		0	0		0	0
2004					3	0		19	0		1	0		0	0
2005					16	0		33	75		44	100		0	0
2006					0	0		25	9		12	0		100	83
Summer															
1996				0.96 (yr 1)	93	100	0.97 (yr 1)	65	100	0.99 (yr 1)	35	98	0.99 (yr 1)	91	99
1997					60	100		51	100		51	0		1	0
1998					34	0		11	6		11	0		0	0
1999					51	86		24	30		24	0		0	0
2000					48	100		9	0		10	0		1	0
2001					43	98		49	67		49	0		1	8
2002	0.97 (yr 1)	42	82		42	90		58	88		58	62		1	16
2003		38	100		33	84		56	0		6	0		0	0
2004		48	96		57	100		42	100		42	0		1	4
2005		47	100		57	100		44	86		45	0		0	0
2006		17	0		40	98		30	100		30	0		1	2

When all presence points and environmental variables from all available years except one were used to train the Maxent model, the results from the year 1 model appear to be more accurate at predicting caribou presence spatially and temporally. There was more suitable habitat modelled when the Maxent model was trained using environmental variables from 1999 to 2006 (except 2005) on the Bathurst calving range (Figure 3.4) compared to only the environmental variables from 1999 (Figure 3.2). None of the presence points were correctly modeled as suitable when the model was built using only 1999 environmental variables, and projected forward onto the 2005 environmental variables (Figure 3.3). When all years from 1999 to 2006, excluding 2005, were used to build the Bathurst calving range model, and then projected onto the 2005 environmental variables, 81% of the presence points were correctly predicted as suitable habitat (Figure 3.5). Similar results were observed when each year between 2000 and 2006 were excluded from training the Maxent model, and the model was projected onto the same year which was excluded in training (Appendix C). The second modelling approach used a much wider range of climatic, land cover and elevation values to train the Maxent model, therefore was better able to model caribou presence through time under changing environmental conditions.

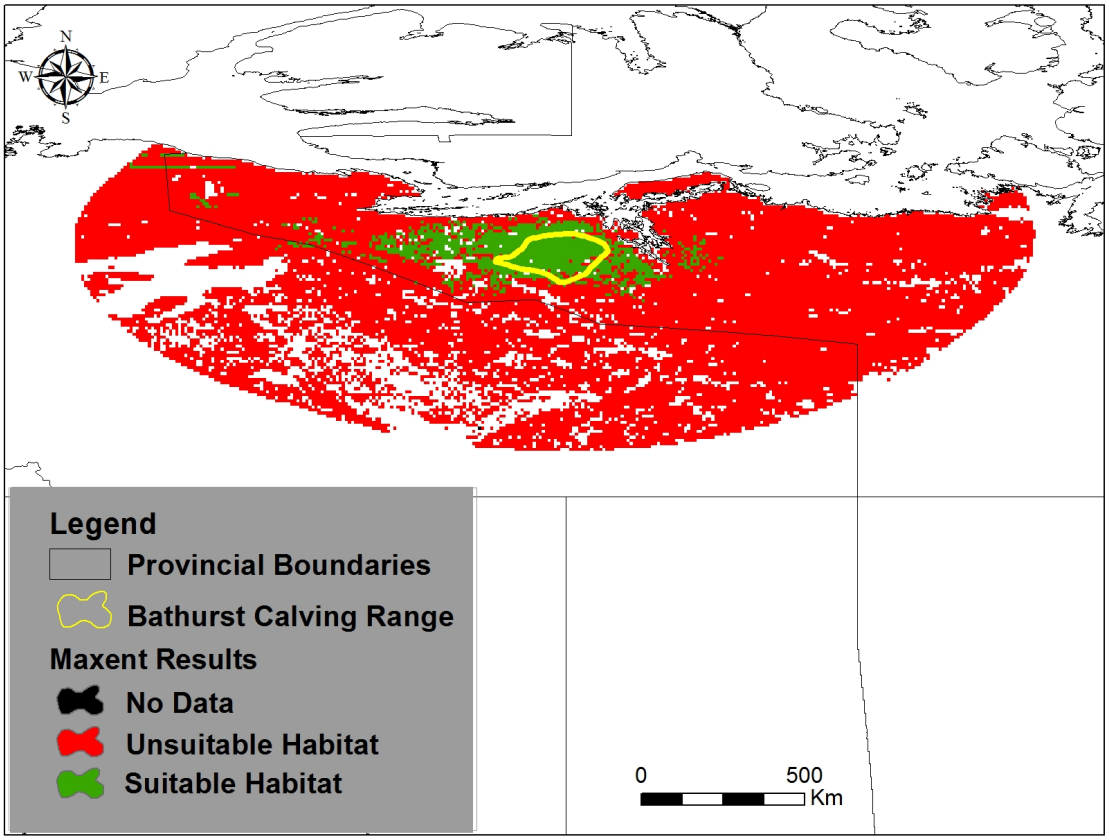

Figure 3.2: The image is the result from the Maxent Bathurst calving range model built using single year data. The presence points and environmental variables were both from 1999.

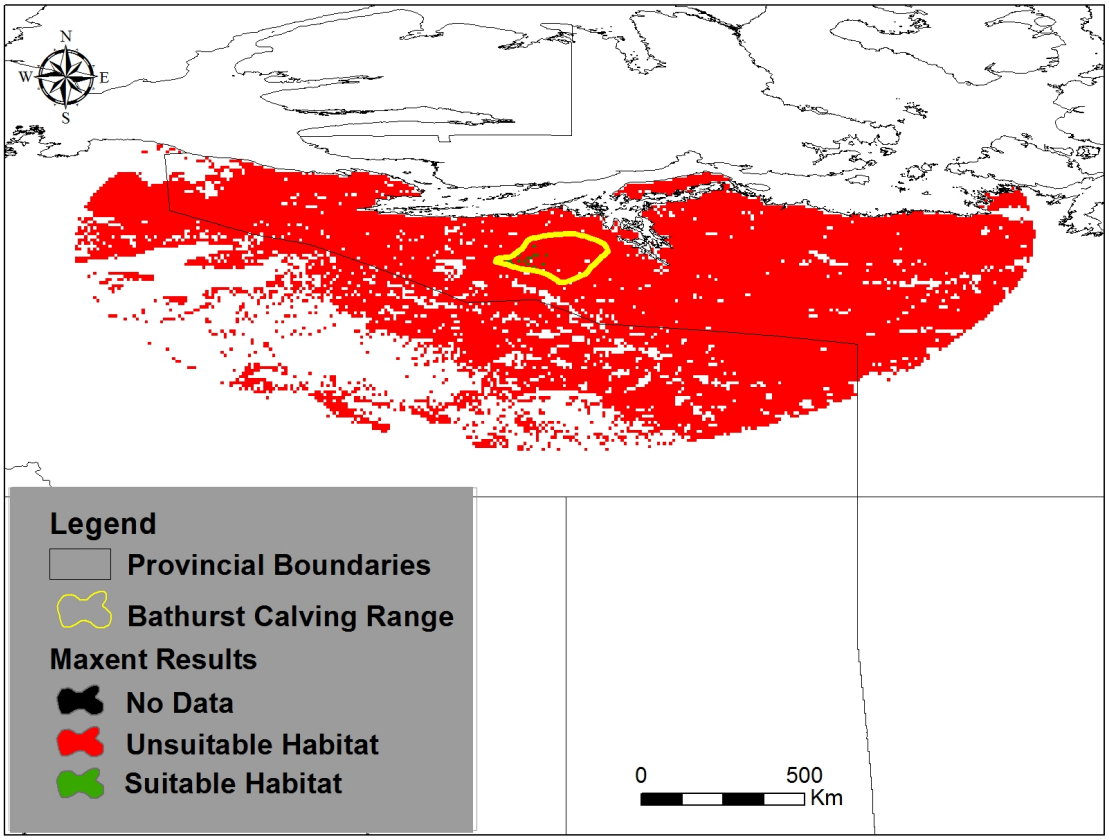

Figure 3.3: The image is the result when the Maxent Bathurst calving range model built using the 1999 single year data was projected onto the 2005 environmental variables.

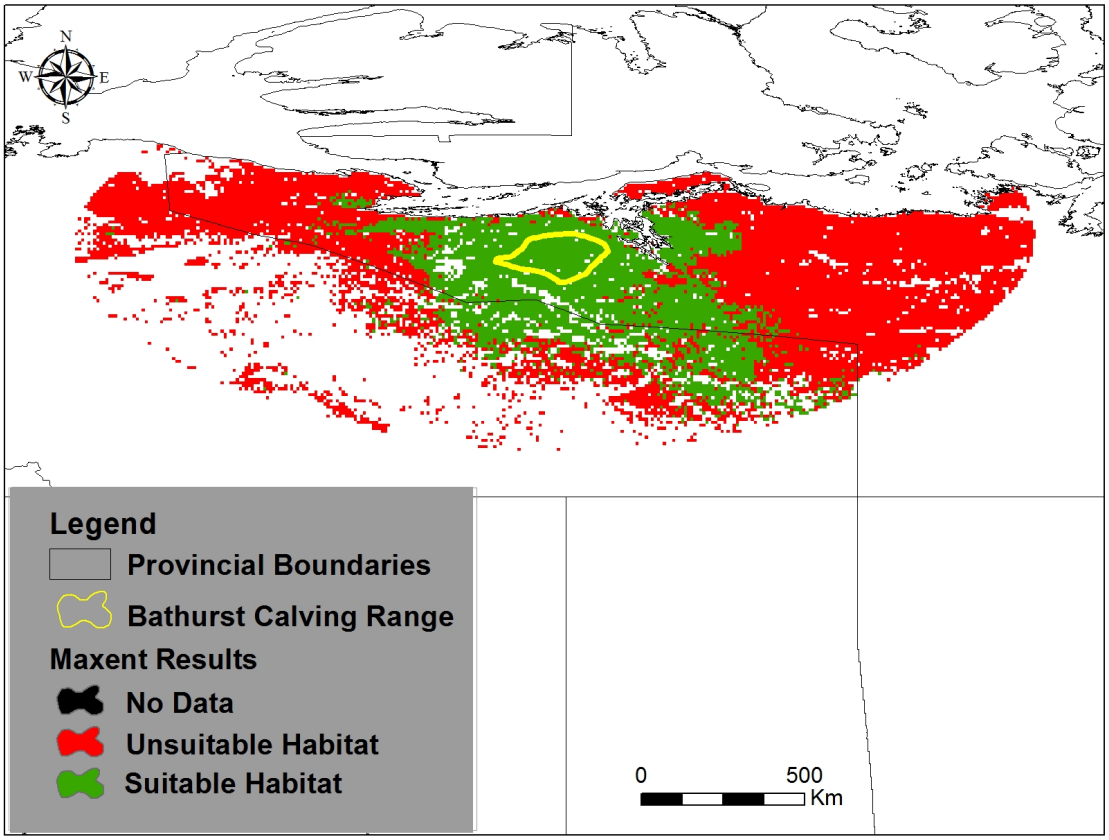

Figure 3.4: The image is the result from the Maxent Bathurst calving range model built using multi year data. The presence points and environmental variables were from all years from 1999 to 2006, except for 2005.

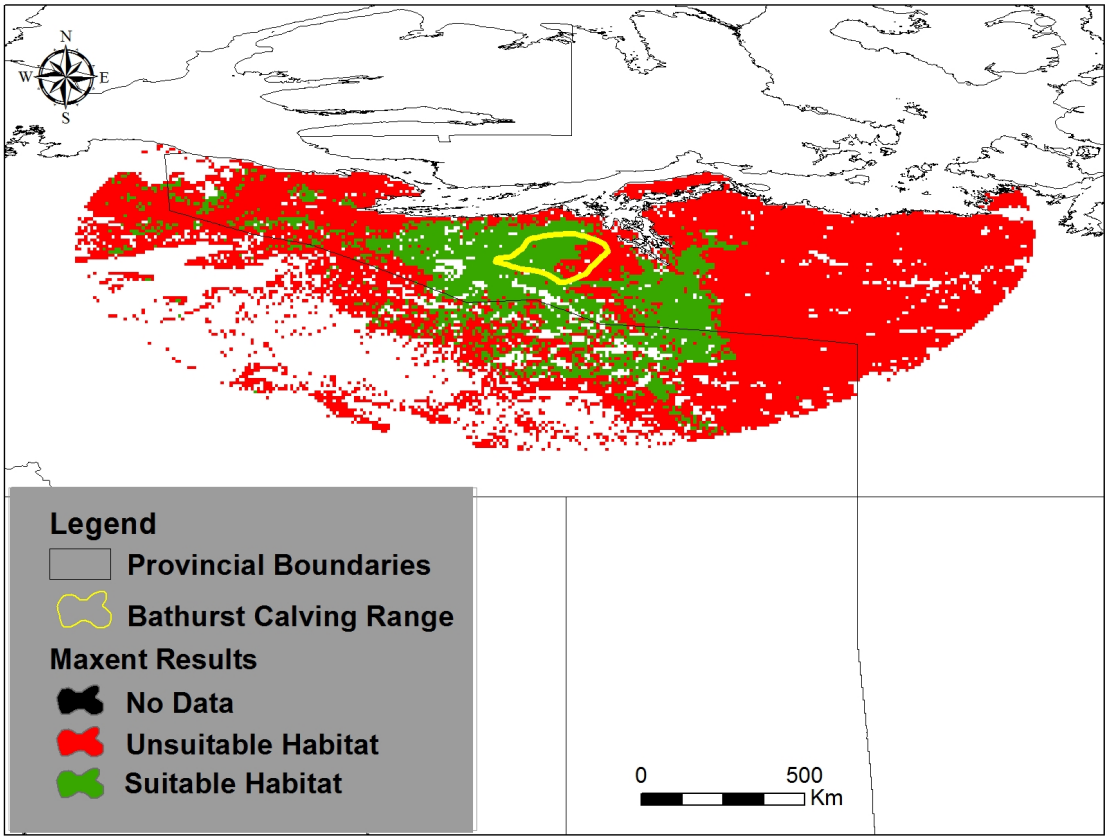

Figure 3.5: The image is the result when the Maxent Bathurst calving range model built using all environmental variables from 1999 to 2006 (except for 2005) was projected onto the 2005 environmental variables.

Table 3.5: Percent of correctly predicted Bathurst presence points on the Bathurst calving range. Each Maxent model was trained using all presence points and environmental variables from 1999-2006, excluding one year. The Maxent models were then projected onto the environmental variables of the year that was excluded.

Years used to train the Maxent model	Year the Maxent model was projected onto	Percent of Presence Points Correctly Predicted
1999, 2001-2006	2000	100%
1999-2000, 2002-2006	2001	100%
1999-2001, 2003-2006	2002	94%
1999-2002, 2004-2006	2003	86%
1999-2003, 2005-2006	2004	71%
1999-2004, 2006	2005	100%
1999-2005	2006	81%
2000-2006	1999	61%

Caribou with a current or long-term declining population status did not consistently have a lower mean amount of suitable habitat or steeper decline (slope) in suitable habitat (Table 3.6), compared to herds with an increasing or stable population. The Kruskal-Wallis test (comparing increasing, decreasing and stable populations) and the Mann-Whitney test (comparing increasing and decreasing populations) revealed that the mean amount of suitable habitat was significantly different ($p < 0.050$) between herds with different population trends, however, herds with increasing or stable populations had the lowest amount of suitable habitat. The exception was caribou with a long-term population status were compared on the calving range, the mean amount of suitable habitat was not significantly different between herds with increasing (group 1) and decreasing populations (group 2),($p > 0.5$, 2 df, Kruskal-Wallis test).

Table 3.6: Mean and slope of the amount of suitable habitat over time on caribou calving and summer habitat ranges. Values were used to determine if caribou with a current or long-term population decline had a lower mean amount of suitable habitat, or whether the amount of suitable habitat had a steeper slope over time.

Population Time Frame	Population Trend	Mean	Slope
	Calving Range		
Current	Increasing	15.4	2.45
	Stable	21.2	0.80
	Decreasing	8.33	-2.82
Long-term	Increasing	15.4	2.45
	Decreasing	26.4	1.27
	Summer Range		
Current	Increasing	35.1	2.52
	Stable	15.9	0.84
	Decreasing	51.5	4.05
Long-term	Increasing	35.1	2.52
	Decreasing	90.9	8.08

Climate variables were ranked by Maxent to have the most influence on barren-ground caribou presence on both the calving range and summer range (Table 3.7). The exception was the Cape Bathurst calving range model and Bathurst summer model. Elevation was determined to be very important in determining presence on the Cape Bathurst calving range and the Bathurst summer range.

Table 3.7: Estimate of the relative contribution that each variable had in predicting barren-ground caribou presence locations. These statistics are only based on the first year of data. Variables that were given a higher percent contribution, were better predictors of caribou presence locations. GDD is an abbreviation for growing degree days, PCA principle component analysis, & temp temperature.

Variable	Ahiak	Bathurst	Bluenose-east	Bluenose-west	Cape Bathurst
Calving Range					
gdd above base temp for 1st 6 weeks of growing season	no data	0.2%	0.0%	42.1%	16.3%
PCA Seasonal Climate	no data	69.7%	0.0%	0.0%	0.5%
Snow Cover	no data	0.6%	15.2%	55.9%	0.0%
Total precipitation for 1st 6 weeks of growing season	no data	0.0%	79.5%	0.0%	3.9%
Digital Elevation Model	no data	19.7%	3.3%	0.8%	49.5%
NDVI	no data	2.3%	0.1%	0.0%	11.5%
Land Cover	no data	7.5%	2.0%	1.2%	0.1%
Summer Range					
mean temp for 1st 6 weeks of growing season	0.4%	4.6%	0.7%	0.0%	0.3%
PCA Seasonal Climate	3.8%	15.2%	39.7%	0.2%	15.5%
Total precipitation for the growing season	47.5%	29.8%	59.4%	90.3%	84.1%
Digital Elevation Model	13.2%	41.7%	0.0%	9.3%	0.0%
NDVI	2.2%	0.2%	0.0%	0.1%	0.1%
Land Cover	28.3%	6.4%	0.2%	0.0%	0.0%

(5) Discussion

Maxent was not able to successfully model the range of climate conditions present on barren-ground caribou calving and summer ranges. The models failed both spatially and temporally. Although Maxent models that were trained using species observations from one year (year 1) appeared reliable (high AUC, and rate of correctly predicted presence points), they were not able to predict caribou presence when projected forward through time. This suggests the year 1 models were overfit, which causes under prediction when a model is projected onto new geographic areas or environmental conditions (Rodda et al., 2011). Overfitting in a Maxent model occurs when the input regularization parameters (choice of feature types and settings) is too closely matched with the input data, causing a negative effect on predictive performance (Hastie et al., 2001). Because the Maxent models failed to correctly project presence points through time, a relationship between declines in caribou herd sizes and declines in calving and summer range habitat is inconclusive. The model failures also suggest that Maxent built in this manner are not a useful tool to monitor caribou habitat change over time.

Model results did show that climate greatly influences the location and amount of suitable habitat for caribou. Climate conditions from a single year (year one) had the most influence when training the Maxent models for most herds, thus even slight changes in climate from year to year caused poor results when projecting the models forward through time. Adverse or favourable climate conditions often cause barren-ground caribou to use only a portion of their fundamental climate habitat, in order to take advantage of the most optimal habitat conditions, thus improving the chances of survival for themselves and their offspring. For example in 2000 and 2001 there was

exceptionally late snow melt on the calving range for the Porcupine herd, which resulted in unique calving distributions (Griffith et al., 2002). The other variables (DEM, land cover) would not have changed at all or very little during the years the models were projected forward, and were ranked by Maxent for most herds to be much less important compared to climate for predicting caribou presence locations.

The range of climate conditions present on caribou habitat ranges were not captured in the training models. The risk in building models this way is that they are more narrowly defined, and the "realized climate habitat" is modelled rather than the "fundamental climate habitat" (Soberon & Peterson, 2005; Soberon & Nakamura, 2009; Rodda et al., 2011), and has often been noted as a problem when using Maxent to model realized climate habitat (Randin et al., 2006; Heikkinen et al., 2006; Jeschke & Strayer, 2008). The fundamental climate habitat is climate conditions that could be inhabited by a species if climate were the only restrictive factor. The realized climate habitat is the variety of climate conditions that the species actually inhabits (Rodda et al., 2011). Other studies which have attempted to create models based on the realized climate niche and then project them to other geographic locations to try and determine whether they could accurately model the fundamental climate space, which has already occurred, had inconsistent results (Duncan et al., 2009; Beaumont, et al., 2009).

Some caution must be taken when creating Maxent models, because like every modelling technique flaws exist. As previously mentioned, one flaw is not being able to accurately model a species realized niche. To address this, including ranges that characterize the realized climate niche may improve the realized model results (Broennimann & Guisan, 2008; Beaumont et al., 2009). An additional concern is how

Maxent determines a fundamental climate niche. Maxent assumes that the central tendency (middle value) for the realized niche presence points does not create a bias when used to model the realized climate niche (Rodda et al., 2011). It has been suggested that a better approach may be to model niches by determining the central tendency and include all values within a distance from a threshold value (Rodda et al. 2011). A Maxent model was built over the Bathurst calving range using all environmental variables from 1999-2006 to address the first concern, and all presence locations from 1999-2006 to address the second concern, to determine if Maxent was able to more accurately project species presence through time. Much higher rates of modeling caribou presence through time suggest that several years worth of data are needed to train barren-ground caribou Maxent models to capture the range of climate conditions present on their habitat. In addition these results demonstrate that caribou are able to adapt to wide range of environmental conditions. Thus, it is possible that caribou may be able to adapt to subtle changes in climate.

Another limitation was that there was no data included to represent predators or top-down interactions, which are also known to influence the distribution of caribou. For example, hunter harvest contributed to the population declines in several barren-ground caribou in the last few years (Nesbitt & Adamczewski, 2009). In order to accurately model a species realized or fundamental niche variables that represent dispersal barriers or intraspecific or interspecific competition, which can prevent species from getting to their optimal location, should be included in Maxent models.

(6) Conclusion

Maxent was not able to accurately predict suitable barren-ground caribou habitat through time when built using single year data. Climate variables had a strong influence on predicting caribou presence, and even slight changes in climate from year to year caused the Maxent models to predict little or no suitable habitat. Barren-ground caribou are able to adapt to a range of climate conditions within their calving and summer ranges. This range must be accurate captured to model barren-ground caribou habitat spatially and temporally. This thesis is the first to use Maxent as a tool to estimate suitable habitat as a measure of available resources through time for multiple herds.

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(8) Appendix

Appendix A- Results of the ten replicate Maxent models for each herds used in 10 fold cross-validation

All of the Maxent models were replicated ten times. The average of the ten models was used as the final model results. Replicating the model ten times allowed for cross-validation of the models. Cross-validation is when some of the presence data is randomly selected and split into groups of equal size. The models are then run leaving out each group once to validate the results. The tables in Appendix A are the results from the ten replicates. The training AUC, test AUC and minimum training threshold presence value are included.

Results of the ten replicates for the Ahiak herd summer range Maxent model

Year	Species	Iterations	Training AUC	Test AUC	Minimum training presence logistic threshold
2002	Ahiak_0	500	0.9705	0.9572	0.185
2002	Ahiak_1	500	0.9675	0.9365	0.1639
2002	Ahiak_2	360	0.9686	0.9662	0.1812
2002	Ahiak_3	500	0.9677	0.9709	0.1877
2002	Ahiak_4	500	0.9664	0.9802	0.1693
2002	Ahiak_5	500	0.9671	0.989	0.1856
2002	Ahiak_6	420	0.9687	0.8684	0.1655
2002	Ahiak_7	500	0.9665	0.9909	0.1897
2002	Ahiak_8	440	0.9721	0.9235	0.3657
2002	Ahiak_9	500	0.9696	0.9515	0.1764
2002	Ahiak (average)	472	0.9685	0.9534	0.197
2003	Ahiak_0	500	0.9705	0.9572	0.185
2003	Ahiak_1	500	0.9675	0.9365	0.1639
2003	Ahiak_2	360	0.9686	0.9662	0.1812
2003	Ahiak_3	500	0.9677	0.9709	0.1877
2003	Ahiak_4	500	0.9664	0.9802	0.1693
2003	Ahiak_5	500	0.9671	0.989	0.1856
2003	Ahiak_6	420	0.9687	0.8684	0.1655
2003	Ahiak_7	500	0.9665	0.9909	0.1897
2003	Ahiak_8	440	0.9721	0.9235	0.3657
2003	Ahiak_9	500	0.9696	0.9515	0.1764
2003	Ahiak (average)	472	0.9685	0.9534	0.197
2004	Ahiak_0	500	0.9705	0.9572	0.185
2004	Ahiak_1	500	0.9675	0.9365	0.1639
2004	Ahiak_2	360	0.9686	0.9662	0.1812
2004	Ahiak_3	500	0.9677	0.9709	0.1877

2004	Ahiak_4	500	0.9664	0.9802	0.1693
2004	Ahiak_5	500	0.9671	0.989	0.1856
2004	Ahiak_6	420	0.9687	0.8684	0.1655
2004	Ahiak_7	500	0.9665	0.9909	0.1897
2004	Ahiak_8	440	0.9721	0.9235	0.3657
2004	Ahiak_9	500	0.9696	0.9515	0.1764
2004	Ahiak (average)	472	0.9685	0.9534	0.197
2005	Ahiak_0	500	0.9705	0.9572	0.185
2005	Ahiak_1	500	0.9675	0.9365	0.1639
2005	Ahiak_2	360	0.9686	0.9662	0.1812
2005	Ahiak_3	500	0.9677	0.9709	0.1877
2005	Ahiak_4	500	0.9664	0.9802	0.1693
2005	Ahiak_5	500	0.9671	0.989	0.1856
2005	Ahiak_6	420	0.9687	0.8684	0.1655
2005	Ahiak_7	500	0.9665	0.9909	0.1897
2005	Ahiak_8	440	0.9721	0.9235	0.3657
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Results of the ten replicates for the Bathurst herd calving range Maxent model

Year	Species	Iterations	Training AUC	Test AUC	Minimum training presence logistic threshold
1999	Bathurst_0	460	0.9853	0.9847	0.0549
1999	Bathurst_1	480	0.9851	0.9843	0.0515
1999	Bathurst_2	500	0.9851	0.9874	0.0512
1999	Bathurst_3	500	0.9844	0.9865	0.0428
1999	Bathurst_4	480	0.9854	0.993	0.0571
1999	Bathurst_5	460	0.9828	0.9457	0.0063
1999	Bathurst_6	360	0.9827	0.9502	0.0058
1999	Bathurst_7	500	0.9849	0.9872	0.0538
1999	Bathurst_8	480	0.985	0.9851	0.0526
1999	Bathurst_9	480	0.9848	0.9868	0.0511
1999	Bathurst (average)	470	0.9845	0.9791	0.0427
2000	Bathurst_0	460	0.9853	0.9847	0.0549
2000	Bathurst_1	480	0.9851	0.9843	0.0515
2000	Bathurst_2	500	0.9851	0.9874	0.0512
2000	Bathurst_3	500	0.9844	0.9865	0.0428
2000	Bathurst_4	480	0.9854	0.993	0.0571
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Results of the ten replicates for the Bathurst herd summer range Maxent model

Year	Species	Iterations	Training AUC	Test AUC	Minimum training presence logistic threshold
1996	Bathurst_0	500	0.9734	0.976	0.1264
1996	Bathurst_1	360	0.9734	0.9717	0.0896
1996	Bathurst_2	420	0.9734	0.9697	0.0899
1996	Bathurst_3	360	0.9734	0.9724	0.0915
1996	Bathurst_4	380	0.9734	0.9779	0.0875
1996	Bathurst_5	420	0.9734	0.9712	0.0895
1996	Bathurst_6	420	0.9734	0.9651	0.1096
1996	Bathurst_7	440	0.9734	0.9785	0.1162
1996	Bathurst_8	420	0.9732	0.9728	0.0935
1996	Bathurst_9	400	0.9732	0.9739	0.0879
1996	Bathurst (average)	412	0.9734	0.9729	0.0982
1997	Bathurst_0	500	0.9734	0.976	0.1264
1997	Bathurst_1	360	0.9734	0.9717	0.0896
1997	Bathurst_2	420	0.9734	0.9697	0.0899
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2000	Bathurst_9	400	0.9732	0.9739	0.0879
2000	Bathurst (average)	412	0.9734	0.9729	0.0982
2001	Bathurst_0	500	0.9734	0.976	0.0714
2001	Bathurst_1	360	0.9734	0.9717	0
2001	Bathurst_2	420	0.9734	0.9697	0.0714
2001	Bathurst_3	360	0.9734	0.9724	0
2001	Bathurst_4	380	0.9734	0.9779	0
2001	Bathurst_5	420	0.9734	0.9712	0
2001	Bathurst_6	420	0.9734	0.9651	0
2001	Bathurst_7	440	0.9734	0.9785	0
2001	Bathurst_8	420	0.9732	0.9728	0
2001	Bathurst_9	400	0.9732	0.9739	0
2001	Bathurst (average)	412	0.9734	0.9729	0.0143
2002	Bathurst_0	500	0.9734	0.976	0.1264
2002	Bathurst_1	360	0.9734	0.9717	0.0896
2002	Bathurst_2	420	0.9734	0.9697	0.0899
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2003	Bathurst (average)	412	0.9734	0.9729	0.0982
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2004	Bathurst_9	400	0.9732	0.9739	0.0879
2004	Bathurst (average)	412	0.9734	0.9729	0.0982
2005	Bathurst_0	500	0.9734	0.976	0.1264
2005	Bathurst_1	360	0.9734	0.9717	0.0896
2005	Bathurst_2	420	0.9734	0.9697	0.0899
2005	Bathurst_3	360	0.9734	0.9724	0.0915
2005	Bathurst_4	380	0.9734	0.9779	0.0875
2005	Bathurst_5	420	0.9734	0.9712	0.0895
2005	Bathurst_6	420	0.9734	0.9651	0.1096
2005	Bathurst_7	440	0.9734	0.9785	0.1162
2005	Bathurst_8	420	0.9732	0.9728	0.0935
2005	Bathurst_9	400	0.9732	0.9739	0.0879
2005	Bathurst (average)	412	0.9734	0.9729	0.0982
2006	Bathurst_0	500	0.973	0.976	0.126
2006	Bathurst_1	360	0.973	0.972	0.09
2006	Bathurst_2	420	0.973	0.97	0.09
2006	Bathurst_3	360	0.973	0.972	0.091
2006	Bathurst_4	380	0.973	0.978	0.087
2006	Bathurst_5	420	0.973	0.971	0.09
2006	Bathurst_6	420	0.973	0.965	0.11
2006	Bathurst_7	440	0.973	0.978	0.116
2006	Bathurst_8	420	0.973	0.973	0.094
2006	Bathurst_9	400	0.973	0.974	0.088

2006	Bathurst (average)	412	0.973	0.9729	0.0982

Results of the ten replicates for the Bluenose-east herd calving range Maxent model

Year	Species	Iterations	Training AUC	Test AUC	Minimum training presence logistic threshold
1998	BNE_0	200	0.9863	0.9887	0.4247
1998	BNE_1	240	0.9863	0.9845	0.426
1998	BNE_2	280	0.9863	0.9887	0.4266
1998	BNE_3	280	0.9863	0.9817	0.4236
1998	BNE_4	200	0.9863	0.9811	0.4251
1998	BNE_5	200	0.9863	0.983	0.424
1998	BNE_6	240	0.9863	0.9828	0.4525
1998	BNE_7	200	0.9863	0.991	0.4263
1998	BNE_8	200	0.9863	0.9868	0.4239
1998	BNE_9	240	0.9863	0.9933	0.4281
1998	BNE (average)	228	0.9863	0.9862	0.4281
1999	BNE_0	200	0.9863	0.9887	0.4247
1999	BNE_1	240	0.9863	0.9845	0.426
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2002	BNE_5	200	0.9863	0.983	0.424
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2004	BNE_4	200	0.9863	0.9811	0.4251
2004	BNE_5	200	0.9863	0.983	0.424
2004	BNE_6	240	0.9863	0.9828	0.4525
2004	BNE_7	200	0.9863	0.991	0.4263
2004	BNE_8	200	0.9863	0.9868	0.4239
2004	BNE_9	240	0.9863	0.9933	0.4281
2004	BNE (average)	228	0.9863	0.9862	0.4281
2005	BNE_0	200	0.9863	0.9887	0.4247
2005	BNE_1	240	0.9863	0.9845	0.426

2005	BNE_2	280	0.9863	0.9887	0.4266
2005	BNE_3	280	0.9863	0.9817	0.4236
2005	BNE_4	200	0.9863	0.9811	0.4251
2005	BNE_5	200	0.9863	0.983	0.424
2005	BNE_6	240	0.9863	0.9828	0.4525
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2006	BNE_8	200	0.9863	0.9868	0.4239
2006	BNE_9	240	0.9863	0.9933	0.4281
2006	BNE (average)	228	0.9863	0.9862	0.4281

Results of the ten replicates for the Bluenose-east herd summer range Maxent model

Year	Species	Iterations	Training AUC	Test AUC	Minimum training presence logistic threshold
1996	BNE_0	380	0.9778	0.98	0.0228
1996	BNE_1	300	0.9778	0.9845	0.0223
1996	BNE_2	280	0.9779	0.9706	0.2437
1996	BNE_3	240	0.9778	0.9769	0.0257
1996	BNE_4	320	0.9778	0.9782	0.023
1996	BNE_5	300	0.9778	0.9744	0.0318
1996	BNE_6	260	0.9778	0.9742	0.0236
1996	BNE_7	240	0.9778	0.9773	0.0248
1996	BNE_8	360	0.9778	0.979	0.0223
1996	BNE_9	380	0.9778	0.9797	0.0228
1996	BNE (average)	306	0.9778	0.9775	0.0463
1997	BNE_0	380	0.9778	0.98	0.0228
1997	BNE_1	300	0.9778	0.9845	0.0223
1997	BNE_2	280	0.9779	0.9706	0.2437
1997	BNE_3	240	0.9778	0.9769	0.0257
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1997	BNE_5	300	0.9778	0.9744	0.0318
1997	BNE_6	260	0.9778	0.9742	0.0236
1997	BNE_7	240	0.9778	0.9773	0.0248
1997	BNE_8	360	0.9778	0.979	0.0223
1997	BNE_9	380	0.9778	0.9797	0.0228
1997	BNE (average)	306	0.9778	0.9775	0.0463
1998	BNE_0	380	0.9778	0.98	0.0228
1998	BNE_1	300	0.9778	0.9845	0.0223
1998	BNE_2	280	0.9779	0.9706	0.2437
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1999	BNE_2	280	0.9779	0.9706	0.2437
1999	BNE_3	240	0.9778	0.9769	0.0257
1999	BNE_4	320	0.9778	0.9782	0.023

1999	BNE_5	300	0.9778	0.9744	0.0318
1999	BNE_6	260	0.9778	0.9742	0.0236
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2005	BNE_5	300	0.9778	0.9744	0.0318
2005	BNE_6	260	0.9778	0.9742	0.0236
2005	BNE_7	240	0.9778	0.9773	0.0248
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2006	BNE_2	280	0.9779	0.9706	0.2437
2006	BNE_3	240	0.9778	0.9769	0.0257
2006	BNE_4	320	0.9778	0.9782	0.023
2006	BNE_5	300	0.9778	0.9744	0.0318
2006	BNE_6	260	0.9778	0.9742	0.0236
2006	BNE_7	240	0.9778	0.9773	0.0248
2006	BNE_8	360	0.9778	0.979	0.0223
2006	BNE_9	380	0.9778	0.9797	0.0228

2006	BNE (average)	306	0.9778	0.9775	0.0463

Results of the ten replicates for the Bluenose-west herd calving range Maxent model

Year	Species	Iterations	Training AUC	Test AUC	Minimum training presence logistic threshold
1998	BNW_0	300	0.9945	0.9941	0.4102
1998	BNW_1	200	0.9945	0.9959	0.4052
1998	BNW_2	280	0.9943	0.996	0.4023
1998	BNW_3	300	0.9943	0.9965	0.3976
1998	BNW_4	260	0.9943	0.9915	0.3981
1998	BNW_5	260	0.9943	0.9961	0.4096
1998	BNW_6	240	0.9943	0.9965	0.4076
1998	BNW_7	220	0.9943	0.9932	0.401
1998	BNW_8	240	0.9943	0.994	0.4033
1998	BNW_9	240	0.9943	0.9912	0.3866
1998	BNW (average)	254	0.9943	0.9945	0.4021
1999	BNW_0	300	0.9945	0.9941	0.4102
1999	BNW_1	200	0.9945	0.9959	0.4052
1999	BNW_2	280	0.9943	0.996	0.4023
1999	BNW_3	300	0.9943	0.9965	0.3976
1999	BNW_4	260	0.9943	0.9915	0.3981
1999	BNW_5	260	0.9943	0.9961	0.4096
1999	BNW_6	240	0.9943	0.9965	0.4076
1999	BNW_7	220	0.9943	0.9932	0.401
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1999	BNW_9	240	0.9943	0.9912	0.3866
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2000	BNW_5	260	0.9943	0.9961	0.4096
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2002	BNW_4	260	0.9943	0.9915	0.3981
2002	BNW_5	260	0.9943	0.9961	0.4096
2002	BNW_6	240	0.9943	0.9965	0.4076
2002	BNW_7	220	0.9943	0.9932	0.401
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2003	BNW_3	300	0.9943	0.9965	0.3976
2003	BNW_4	260	0.9943	0.9915	0.3981
2003	BNW_5	260	0.9943	0.9961	0.4096
2003	BNW_6	240	0.9943	0.9965	0.4076
2003	BNW_7	220	0.9943	0.9932	0.401
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2003	BNW (average)	254	0.9943	0.9945	0.4021
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2004	BNW_2	280	0.9943	0.996	0.4023
2004	BNW_3	300	0.9943	0.9965	0.3976
2004	BNW_4	260	0.9943	0.9915	0.3981
2004	BNW_5	260	0.9943	0.9961	0.4096
2004	BNW_6	240	0.9943	0.9965	0.4076
2004	BNW_7	220	0.9943	0.9932	0.401
2004	BNW_8	240	0.9943	0.994	0.4033
2004	BNW_9	240	0.9943	0.9912	0.3866
2004	BNW (average)	254	0.9943	0.9945	0.4021
2005	BNW_0	300	0.9945	0.9941	0.4102
2005	BNW_1	200	0.9945	0.9959	0.4052

2005	BNW_2	280	0.9943	0.996	0.4023
2005	BNW_3	300	0.9943	0.9965	0.3976
2005	BNW_4	260	0.9943	0.9915	0.3981
2005	BNW_5	260	0.9943	0.9961	0.4096
2005	BNW_6	240	0.9943	0.9965	0.4076
2005	BNW_7	220	0.9943	0.9932	0.401
2005	BNW_8	240	0.9943	0.994	0.4033
2005	BNW_9	240	0.9943	0.9912	0.3866
2005	BNW (average)	254	0.9943	0.9945	0.4021
2006	BNW_0	300	0.995	0.994	0.41
2006	BNW_1	200	0.995	0.996	0.405
2006	BNW_2	280	0.994	0.996	0.402
2006	BNW_3	300	0.994	0.996	0.398
2006	BNW_4	260	0.994	0.992	0.398
2006	BNW_5	260	0.994	0.996	0.41
2006	BNW_6	240	0.994	0.996	0.408
2006	BNW_7	220	0.994	0.993	0.401
2006	BNW_8	240	0.994	0.994	0.403
2006	BNW_9	240	0.994	0.991	0.387
2006	BNW (average)	254	0.9942	0.9944	0.4022

Results of the ten replicates for the Cape Bathurst herd calving range Maxent model

Year	Species	Iterations	Training AUC	Test AUC	Minimum training presence logistic threshold
1998	Cape_Bathurst_0	120	0.9854	0.9894	0.4717
1998	Cape_Bathurst_1	100	0.9854	0.9769	0.4711
1998	Cape_Bathurst_2	100	0.9854	0.9852	0.4731
1998	Cape_Bathurst_3	100	0.9854	0.9829	0.4756
1998	Cape_Bathurst_4	100	0.9847	0.9806	0.4726
1998	Cape_Bathurst_5	120	0.9847	0.9882	0.4738
1998	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
1998	Cape_Bathurst_7	120	0.9847	0.991	0.4747
1998	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
1998	Cape_Bathurst_9	120	0.9847	0.9917	0.4746
1998	Cape_Bathurst (average)	112	0.985	0.9848	0.4733
1999	Cape_Bathurst_0	120	0.9854	0.9894	0.4717
1999	Cape_Bathurst_1	100	0.9854	0.9769	0.4711
1999	Cape_Bathurst_2	100	0.9854	0.9852	0.4731
1999	Cape_Bathurst_3	100	0.9854	0.9829	0.4756
1999	Cape_Bathurst_4	100	0.9847	0.9806	0.4726
1999	Cape_Bathurst_5	120	0.9847	0.9882	0.4738
1999	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
1999	Cape_Bathurst_7	120	0.9847	0.991	0.4747
1999	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
1999	Cape_Bathurst_9	120	0.9847	0.9917	0.4746
1999	Cape_Bathurst (average)	112	0.985	0.9848	0.4733
2000	Cape_Bathurst_0	120	0.9854	0.9894	0.4717
2000	Cape_Bathurst_1	100	0.9854	0.9769	0.4711
2000	Cape_Bathurst_2	100	0.9854	0.9852	0.4731
2000	Cape_Bathurst_3	100	0.9854	0.9829	0.4756
2000	Cape_Bathurst_4	100	0.9847	0.9806	0.4726
2000	Cape_Bathurst_5	120	0.9847	0.9882	0.4738
2000	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
2000	Cape_Bathurst_7	120	0.9847	0.991	0.4747
2000	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
2000	Cape_Bathurst_9	120	0.9847	0.9917	0.4746
2000	Cape_Bathurst (average)	112	0.985	0.9848	0.4733
2001	Cape_Bathurst_0	120	0.9854	0.9894	0.4717
2001	Cape_Bathurst_1	100	0.9854	0.9769	0.4711
2001	Cape_Bathurst_2	100	0.9854	0.9852	0.4731

2001	Cape_Bathurst_3	100	0.9854	0.9829	0.4756
2001	Cape_Bathurst_4	100	0.9847	0.9806	0.4726
2001	Cape_Bathurst_5	120	0.9847	0.9882	0.4738
2001	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
2001	Cape_Bathurst_7	120	0.9847	0.991	0.4747
2001	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
2001	Cape_Bathurst_9	120	0.9847	0.9917	0.4746
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2002	Cape_Bathurst_1	100	0.9854	0.9769	0.4711
2002	Cape_Bathurst_2	100	0.9854	0.9852	0.4731
2002	Cape_Bathurst_3	100	0.9854	0.9829	0.4756
2002	Cape_Bathurst_4	100	0.9847	0.9806	0.4726
2002	Cape_Bathurst_5	120	0.9847	0.9882	0.4738
2002	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
2002	Cape_Bathurst_7	120	0.9847	0.991	0.4747
2002	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
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2003	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
2003	Cape_Bathurst_7	120	0.9847	0.991	0.4747
2003	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
2003	Cape_Bathurst_9	120	0.9847	0.9917	0.4746
2003	Cape_Bathurst (average)	112	0.985	0.9848	0.4733
2004	Cape_Bathurst_0	120	0.9854	0.9894	0.4717
2004	Cape_Bathurst_1	100	0.9854	0.9769	0.4711
2004	Cape_Bathurst_2	100	0.9854	0.9852	0.4731
2004	Cape_Bathurst_3	100	0.9854	0.9829	0.4756
2004	Cape_Bathurst_4	100	0.9847	0.9806	0.4726
2004	Cape_Bathurst_5	120	0.9847	0.9882	0.4738
2004	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
2004	Cape_Bathurst_7	120	0.9847	0.991	0.4747
2004	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
2004	Cape_Bathurst_9	120	0.9847	0.9917	0.4746

2004	Cape_Bathurst (average)	112	0.985	0.9848	0.4733
2005	Cape_Bathurst_0	120	0.9854	0.9894	0.4717
2005	Cape_Bathurst_1	100	0.9854	0.9769	0.4711
2005	Cape_Bathurst_2	100	0.9854	0.9852	0.4731
2005	Cape_Bathurst_3	100	0.9854	0.9829	0.4756
2005	Cape_Bathurst_4	100	0.9847	0.9806	0.4726
2005	Cape_Bathurst_5	120	0.9847	0.9882	0.4738
2005	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
2005	Cape_Bathurst_7	120	0.9847	0.991	0.4747
2005	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
2005	Cape_Bathurst_9	120	0.9847	0.9917	0.4746
2005	Cape_Bathurst (average)	112	0.985	0.9848	0.4733
2006	Cape_Bathurst_0	120	0.9854	0.9894	0.4717
2006	Cape_Bathurst_1	100	0.9854	0.9769	0.4711
2006	Cape_Bathurst_2	100	0.9854	0.9852	0.4731
2006	Cape_Bathurst_3	100	0.9854	0.9829	0.4756
2006	Cape_Bathurst_4	100	0.9847	0.9806	0.4726
2006	Cape_Bathurst_5	120	0.9847	0.9882	0.4738
2006	Cape_Bathurst_6	120	0.9847	0.9764	0.4713
2006	Cape_Bathurst_7	120	0.9847	0.991	0.4747
2006	Cape_Bathurst_8	120	0.9847	0.9861	0.4742
2006	Cape_Bathurst_9	120	0.9847	0.9917	0.4746
2006	Cape_Bathurst (average)	112	0.985	0.9848	0.4733

Results of the ten replicates for the Cape Bathurst herd summer range Maxent model

Year	Species	Iterations	Training AUC	Test AUC	Minimum training presence logistic threshold
1996	CapeB_0	320	0.9351	0.9661	0.2824
1996	CapeB_1	500	0.9351	0.9314	0.2778
1996	CapeB_2	420	0.9346	0.9137	0.2863
1996	CapeB_3	360	0.9346	0.9201	0.2815
1996	CapeB_4	400	0.9346	0.945	0.2791
1996	CapeB_5	380	0.9346	0.9424	0.2809
1996	CapeB_6	440	0.9346	0.9216	0.2862
1996	CapeB_7	380	0.9346	0.9456	0.272
1996	CapeB_8	360	0.9346	0.9427	0.2775
1996	CapeB_9	420	0.9346	0.9232	0.2828
1996	CapeB (average)	398	0.9347	0.9352	0.2806
1997	CapeB_0	320	0.9351	0.9661	0.2824
1997	CapeB_1	500	0.9351	0.9314	0.2778
1997	CapeB_2	420	0.9346	0.9137	0.2863
1997	CapeB_3	360	0.9346	0.9201	0.2815
1997	CapeB_4	400	0.9346	0.945	0.2791
1997	CapeB_5	380	0.9346	0.9424	0.2809
1997	CapeB_6	440	0.9346	0.9216	0.2862
1997	CapeB_7	380	0.9346	0.9456	0.272
1997	CapeB_8	360	0.9346	0.9427	0.2775
1997	CapeB_9	420	0.9346	0.9232	0.2828
1997	CapeB (average)	398	0.9347	0.9352	0.2806
1998	CapeB_0	320	0.935	0.966	0.282
1998	CapeB_1	500	0.935	0.931	0.278
1998	CapeB_2	420	0.935	0.914	0.286
1998	CapeB_3	360	0.935	0.92	0.281
1998	CapeB_4	400	0.935	0.945	0.279
1998	CapeB_5	380	0.935	0.942	0.281
1998	CapeB_6	440	0.935	0.922	0.286
1998	CapeB_7	380	0.935	0.946	0.272
1998	CapeB_8	360	0.935	0.943	0.277
1998	CapeB_9	420	0.935	0.923	0.283
1998	CapeB (average)	398	0.935	0.9352	0.2805
1999	CapeB_0	320	0.9351	0.9661	0.2824
1999	CapeB_1	500	0.9351	0.9314	0.2778
1999	CapeB_2	420	0.9346	0.9137	0.2863
1999	CapeB_3	360	0.9346	0.9201	0.2815
1999	CapeB_4	400	0.9346	0.945	0.2791

1999	CapeB_5	380	0.9346	0.9424	0.2809
1999	CapeB_6	440	0.9346	0.9216	0.2862
1999	CapeB_7	380	0.9346	0.9456	0.272
1999	CapeB_8	360	0.9346	0.9427	0.2775
1999	CapeB_9	420	0.9346	0.9232	0.2828
1999	CapeB (average)	398	0.9347	0.9352	0.2806
2000	CapeB_0	320	0.9351	0.9661	0.2824
2000	CapeB_1	500	0.9351	0.9314	0.2778
2000	CapeB_2	420	0.9346	0.9137	0.2863
2000	CapeB_3	360	0.9346	0.9201	0.2815
2000	CapeB_4	400	0.9346	0.945	0.2791
2000	CapeB_5	380	0.9346	0.9424	0.2809
2000	CapeB_6	440	0.9346	0.9216	0.2862
2000	CapeB_7	380	0.9346	0.9456	0.272
2000	CapeB_8	360	0.9346	0.9427	0.2775
2000	CapeB_9	420	0.9346	0.9232	0.2828
2000	CapeB (average)	398	0.9347	0.9352	0.2806
2001	CapeB_0	320	0.9351	0.9661	0.2824
2001	CapeB_1	500	0.9351	0.9314	0.2778
2001	CapeB_2	420	0.9346	0.9137	0.2863
2001	CapeB_3	360	0.9346	0.9201	0.2815
2001	CapeB_4	400	0.9346	0.945	0.2791
2001	CapeB_5	380	0.9346	0.9424	0.2809
2001	CapeB_6	440	0.9346	0.9216	0.2862
2001	CapeB_7	380	0.9346	0.9456	0.272
2001	CapeB_8	360	0.9346	0.9427	0.2775
2001	CapeB_9	420	0.9346	0.9232	0.2828
2001	CapeB (average)	398	0.9347	0.9352	0.2806
2002	CapeB_0	320	0.9351	0.9661	0.2824
2002	CapeB_1	500	0.9351	0.9314	0.2778
2002	CapeB_2	420	0.9346	0.9137	0.2863
2002	CapeB_3	360	0.9346	0.9201	0.2815
2002	CapeB_4	400	0.9346	0.945	0.2791
2002	CapeB_5	380	0.9346	0.9424	0.2809
2002	CapeB_6	440	0.9346	0.9216	0.2862
2002	CapeB_7	380	0.9346	0.9456	0.272
2002	CapeB_8	360	0.9346	0.9427	0.2775
2002	CapeB_9	420	0.9346	0.9232	0.2828
2002	CapeB (average)	398	0.9347	0.9352	0.2806
2003	CapeB_0	320	0.9351	0.9661	0.2824
2003	CapeB_1	500	0.9351	0.9314	0.2778

2003	CapeB_2	420	0.9346	0.9137	0.2863
2003	CapeB_3	360	0.9346	0.9201	0.2815
2003	CapeB_4	400	0.9346	0.945	0.2791
2003	CapeB_5	380	0.9346	0.9424	0.2809
2003	CapeB_6	440	0.9346	0.9216	0.2862
2003	CapeB_7	380	0.9346	0.9456	0.272
2003	CapeB_8	360	0.9346	0.9427	0.2775
2003	CapeB_9	420	0.9346	0.9232	0.2828
2003	CapeB (average)	398	0.9347	0.9352	0.2806
2004	CapeB_0	320	0.9351	0.9661	0.2824
2004	CapeB_1	500	0.9351	0.9314	0.2778
2004	CapeB_2	420	0.9346	0.9137	0.2863
2004	CapeB_3	360	0.9346	0.9201	0.2815
2004	CapeB_4	400	0.9346	0.945	0.2791
2004	CapeB_5	380	0.9346	0.9424	0.2809
2004	CapeB_6	440	0.9346	0.9216	0.2862
2004	CapeB_7	380	0.9346	0.9456	0.272
2004	CapeB_8	360	0.9346	0.9427	0.2775
2004	CapeB_9	420	0.9346	0.9232	0.2828
2004	CapeB (average)	398	0.9347	0.9352	0.2806
2005	CapeB_0	320	0.9351	0.9661	0.2824
2005	CapeB_1	500	0.9351	0.9314	0.2778
2005	CapeB_2	420	0.9346	0.9137	0.2863
2005	CapeB_3	360	0.9346	0.9201	0.2815
2005	CapeB_4	400	0.9346	0.945	0.2791
2005	CapeB_5	380	0.9346	0.9424	0.2809
2005	CapeB_6	440	0.9346	0.9216	0.2862
2005	CapeB_7	380	0.9346	0.9456	0.272
2005	CapeB_8	360	0.9346	0.9427	0.2775
2005	CapeB_9	420	0.9346	0.9232	0.2828
2005	CapeB (average)	398	0.9347	0.9352	0.2806
2006	CapeB_0	320	0.9351	0.9661	0.2824
2006	CapeB_1	500	0.9351	0.9314	0.2778
2006	CapeB_2	420	0.9346	0.9137	0.2863
2006	CapeB_3	360	0.9346	0.9201	0.2815
2006	CapeB_4	400	0.9346	0.945	0.2791
2006	CapeB_5	380	0.9346	0.9424	0.2809
2006	CapeB_6	440	0.9346	0.9216	0.2862
2006	CapeB_7	380	0.9346	0.9456	0.272
2006	CapeB_8	360	0.9346	0.9427	0.2775
2006	CapeB_9	420	0.9346	0.9232	0.2828

2006	CapeB (average)	398	0.9347	0.9352	0.2806

Appendix B – Average of the Environmental Variables for each year used in the Maxent models

The average for each of the climatic variables included in the final calving range Maxent models. These values show the range of climate conditions that exist year to year on the calving ranges of the barren-ground caribou. Values for the DEM and land cover were not included because the average values would have changed slightly or not changed at all. GS refers to growing season, GDD growing degree days, PCA principal component analysis.

Herd	Year	Total Precipitation 1st 6 weeks of the GS	# of GDD above base temperature 1st 6 weeks of the GS	PCA of Climate Seasonality	NDVI	Snow Cover
Bathurst	1999	63.10	96.27	474.58	14470.75	2215.22
Bathurst	2000	28.8	279.77	479.79	14258.11	2402.83
Bathurst	2001	65.89	233.13	480.91	13927.49	3434.47
Bathurst	2002	48.42	201.67	532.14	14464.7	2151.47
Bathurst	2003	51.51	232.07	308.49	14550.86	1023.66
Bathurst	2004	27.61	171.25	612.56	13286.03	3628.46
Bathurst	2005	42.49	101.33	470.69	14607.867	1682.81
Bathurst	2006	39.00	206.34	293.96	5320.53	584.94
BNE	1998	40.78	235.49	233.43	14892.77	455.14
BNE	1999	53.89	93.72	297.75	14671.98	2009.63
BNE	2000	53.78	93.23	296.57	14543.58	5194.97
BNE	2001	49.88	232.963	492.89	14196.93	2982.66
BNE	2002	28.58	165.1	515.37	14840.19	845.34
BNE	2003	34.33	207.17	463.70	14650.86	1690.44
BNE	2004	33.76	176.28	576.81	13981.95	2413.43
BNE	2005	53.96	79.94	493.84	15249.05	572.49
BNE	2006	14.43	204.07	516.02	5366.58	606.44
BNW	1998	38.06	210.46	520.84	14037.04	414.46
BNW	1999	53.65	70.14	473.29	13758.45	2057.03
BNW	2000	48.83	173.31	193.25	13706.55	4222.22
BNW	2001	38.24	175.29	288.58	13662.18	3865.17
BNW	2002	16.30	107.38	479.79	13629.481	3713.67
BNW	2003	41.47	178.011	494.47	13172.87	2338.08
BNW	2004	21.53	146.61	351.10	12636.01	2747.46
BNW	2005	51.43	31.56	19.52	14353.91	533.17
BNW	2006	18.77	178.17	250.13	4988.32	1259.81
CapeB	1998	31.78	221.59	545.3	14127.08	500.46
CapeB	1999	15.80	110.77	537.76	13638.75	2227.13
CapeB	2000	25.22	148.55	514.00	13316.75	4189.23
CapeB	2001	25.09	118.68	489.48	13222.88	3801.28
CapeB	2002	27.57	83.80	487.08	13929.41	3294.27
CapeB	2003	44.30	159.80	408.85	13872.17	2193.18
CapeB	2004	18.3	139.46	569.38	12136.91	2927.16
CapeB	2005	30.0	47.41	205.49	14151.11	718.27
CapeB	2006	15.69	88.98	487.29	4908.22	2219.01

The average for each of the climatic variables included in the final summer range Maxent models. These values show the range of climate conditions that exist year to year on the calving ranges of the barren-ground caribou. Values for the DEM and land cover were not included because the average values would have changed slightly or not changed at all. GS refers to growing season, GDD growing degree days, PCA principal component analysis.

Herd	Year	Total Precipitation for the GS	# of GDD above base Temperature for the GS	PCA of Climate Seasonality	NDVI
Ahiak	2002	31.00	2.78	14236.98	13636.74
Ahiak	2003	35.45	2.93	14236.78	13511.75
Ahiak	2004	18.43	2.26	14239.01	12399.55
Ahiak	2005	19.59	2.46	14230.47	13710.24
Ahiak	2006	13.16	2.97	14141.51	4952.83
Bathurst	1996	198.26	9.80	132.21	14498.12
Bathurst	1997	123.16	9.51	514.86	14884.93
Bathurst	1998	180.62	9.86	585.71	14772.21
Bathurst	1999	159.14	7.83	196.71	14714.36
Bathurst	2000	118.69	9.80	359.50	14506.81
Bathurst	2001	116.76	9.26	251.52	14729.37
Bathurst	2002	154.19	8.72	347.11	14884.39
Bathurst	2003	139.03	9.13	117.77	14983.31
Bathurst	2004	112.94	7.92	275.38	13568.20
Bathurst	2005	113.95	7.89	423.36	14977.38
Bathurst	2006	95.56	9.73	509.98	5350.85
BNE	1996	152.51	8.06	14467.05	14047.05
BNE	1997	105.30	8.19	14454.94	14272.46
BNE	1998	134.17	9.17	14469.99	14234.98
BNE	1999	136.97	6.85	14412.76	14173.68
BNE	2000	137.50	8.28	14461.89	14132.85
BNE	2001	118.41	8.24	14437.04	13820.21
BNE	2002	83.23	6.89	14437.91	14200.62
BNE	2003	139.09	7.62	14477.78	14017.58
BNE	2004	87.77	7.18	14473.41	13340.21
BNE	2005	120.54	6.29	14434.03	14603.03
BNE	2006	62.15	9.16	14428.47	5099.65
BNW	1996	149.96	7.90	14507.53	14257.90
BNW	1997	108.09	8.12	14498.59	14500.45
BNW	1998	134.43	9.59	14511.85	14461.74
BNW	1999	133.61	6.78	14456.68	14383.16
BNW	2000	132.88	8.17	14504.53	14156.83
BNW	2001	119.57	8.15	14481.94	14154.56
BNW	2002	82.48	6.81	14479.61	14457.85
BNW	2003	134.72	7.55	14517.71	14204.68
BNW	2004	83.18	7.24	14516.02	13520.58
BNW	2005	123.12	6.21	14479.29	14825.82
BNW	2006	64.10	9.06	14472.49	5171.23
CapeB	1996	96.51	7.08	460.02	14051.58
CapeB	1997	92.87	8.34	463.93	14323.18
CapeB	1998	120.75	9.92	466.62	14352.53
CapeB	1999	90.00	7.55	474.01	14239.09
CapeB	2000	61.59	6.44	467.50	14153.73
CapeB	2001	74.85	6.76	461.96	13786.15
CapeB	2002	78.53	5.35	459.66	13431.09
CapeB	2003	94.02	6.28	456.49	13521.67
CapeB	2004	42.82	6.78	470.36	13312.75
CapeB	2005	99.23	5.15	457.24	14601.88
CapeB	2006	18.77	7.57	477.34	4999.26

Appendix C – Results from the Bathurst calving range Maxent models when built using multi year data

A high number of presence points (blue dots) located on suitable habitat (green pixels) indicate the Maxent model was accurately able to predict Bathurst calving presence points.

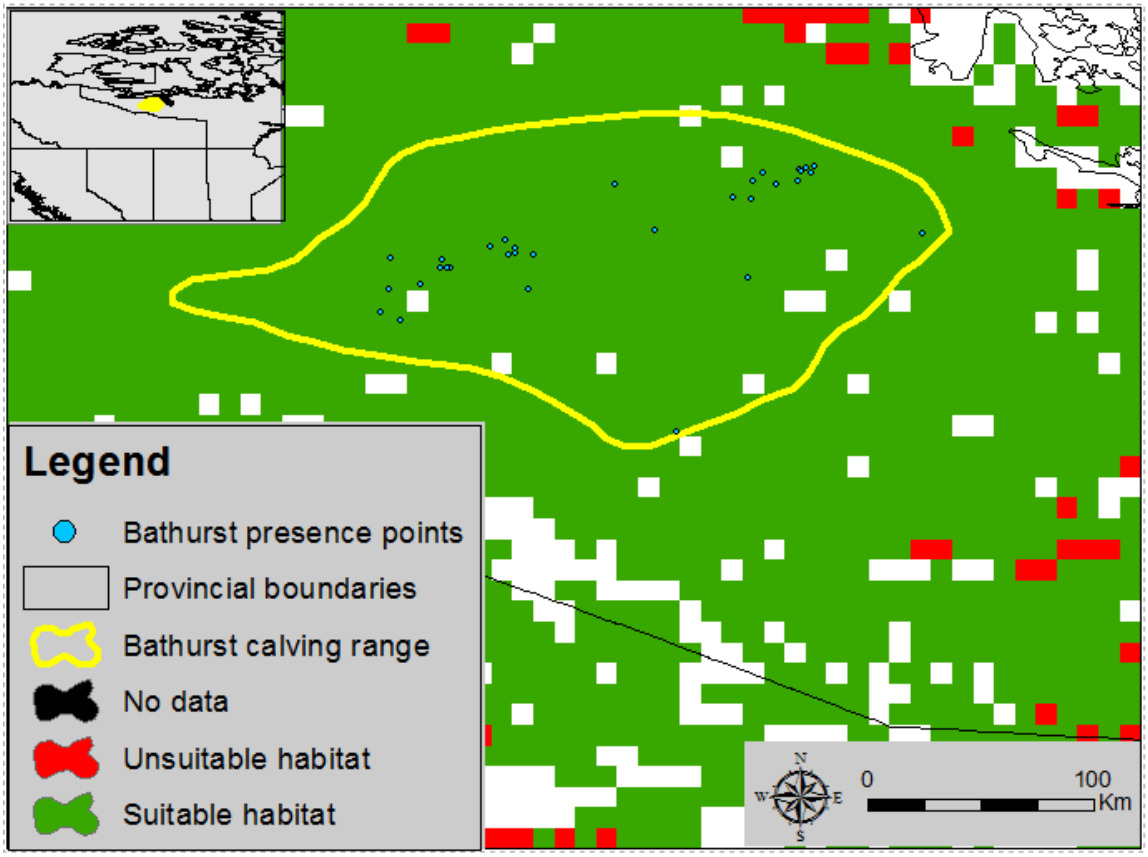

Figure 1: Results from the Bathurst calving range Maxent model, when built using environmental variables from 2000 to 2006, then projected onto the 1999 environmental variables

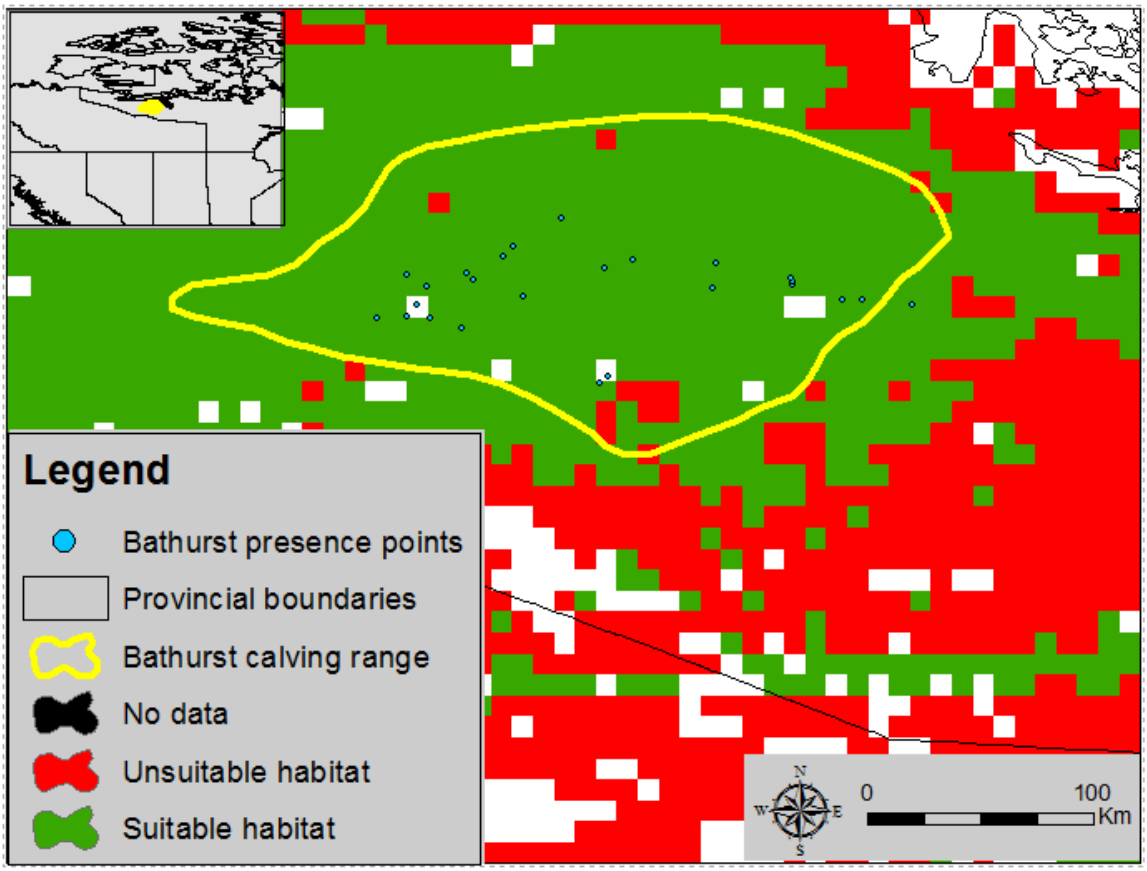

Figure 2: Results from the Bathurst calving range Maxent model, when built using environmental variables from 1999, and 2001 to 2006, then projected onto the 2000 environmental variables

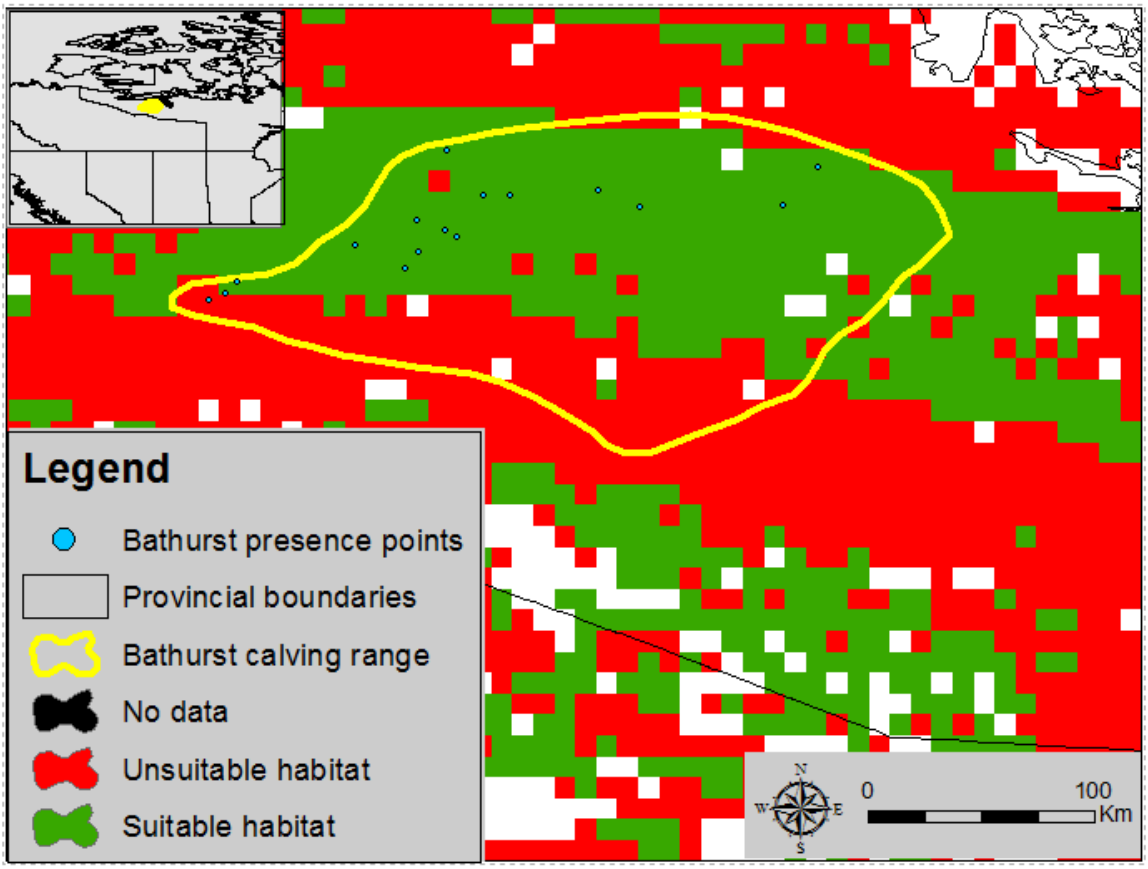

Figure 3: Results from the Bathurst calving range Maxent model, when built using environmental variables from 1999, 2000, and 2002 to 2006, then projected onto the 2001 environmental variables.

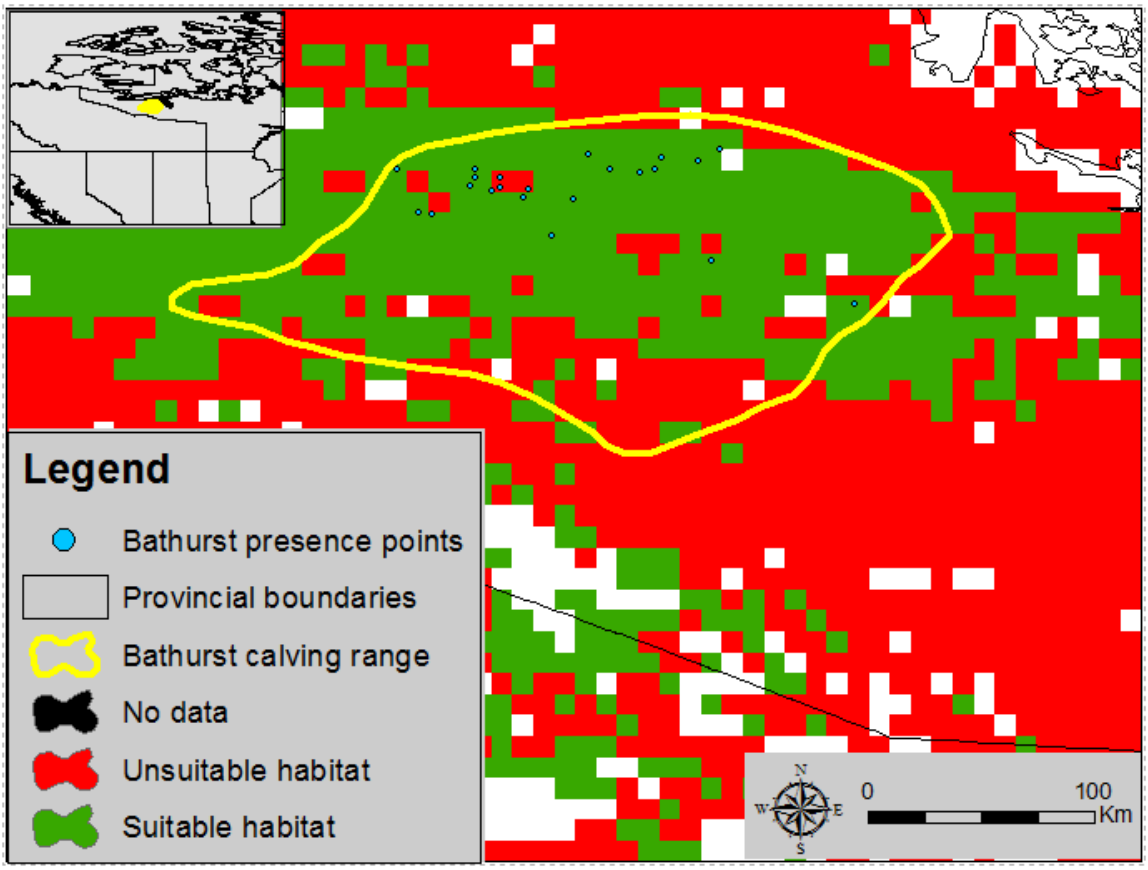

Figure 4: Results from the Bathurst calving range Maxent model, when built using environmental variables from 1999 to 2001, and 2003 to 2006, then projected onto the 2002 environmental variables.

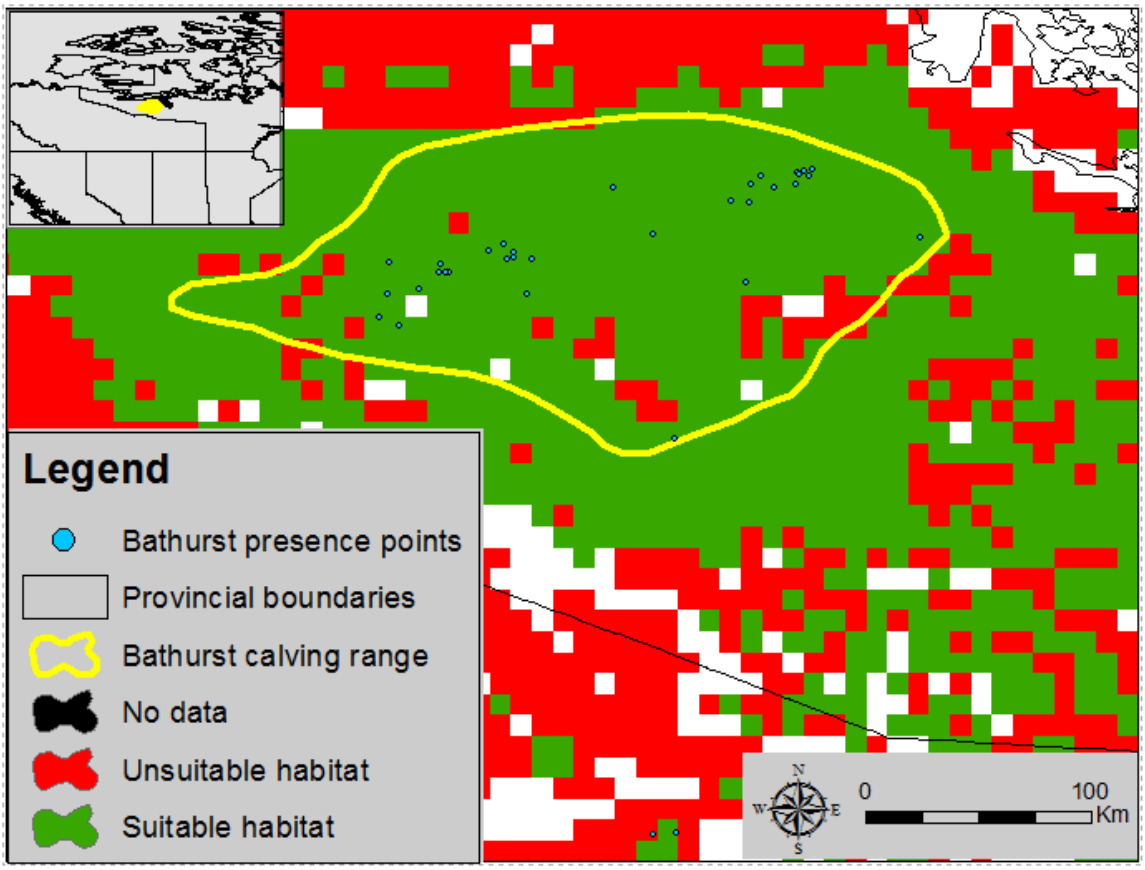

Figure 5: Results from the Bathurst calving range Maxent model, when built using environmental variables from 1999 to 2002 and 2004 to 2006, then projected onto the 2003 environmental variables.

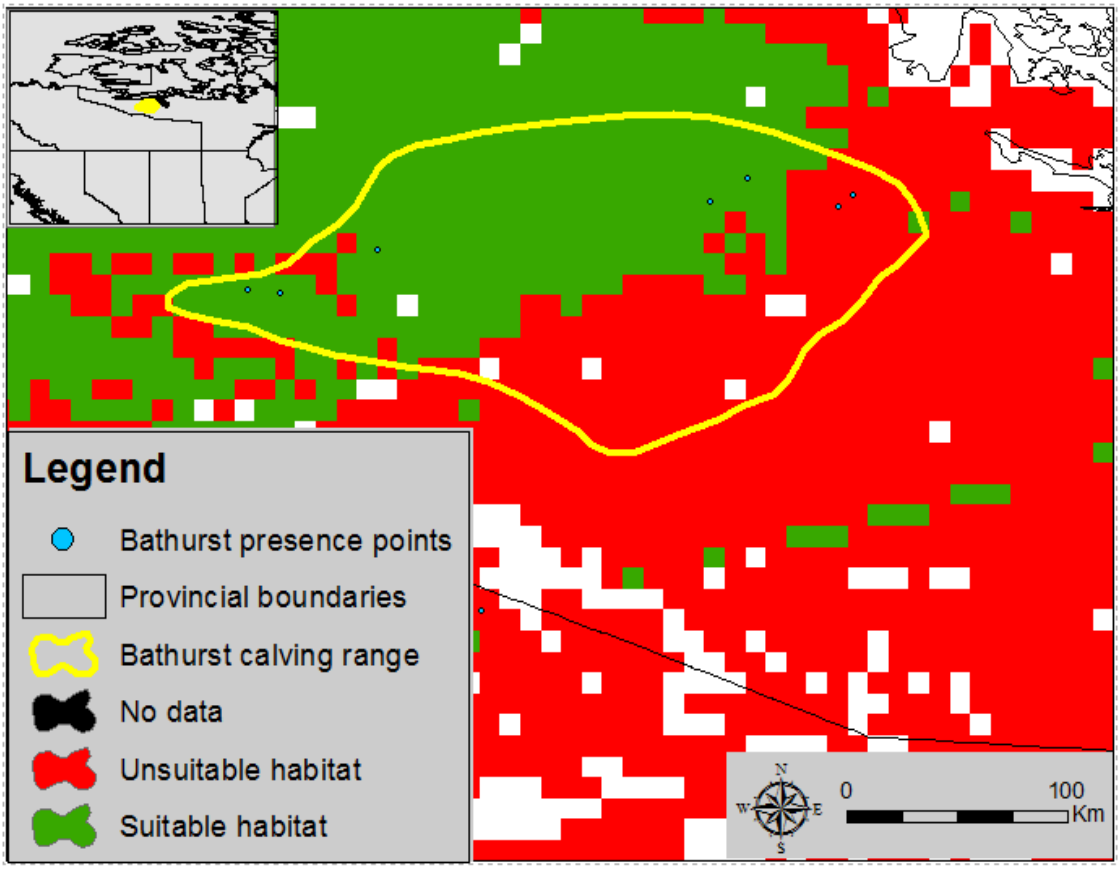

Figure 6: Results from the Bathurst calving range Maxent model, when built using environmental variables from 1999 to 2003, and 2006, and projected onto the 2004 environmental variables.

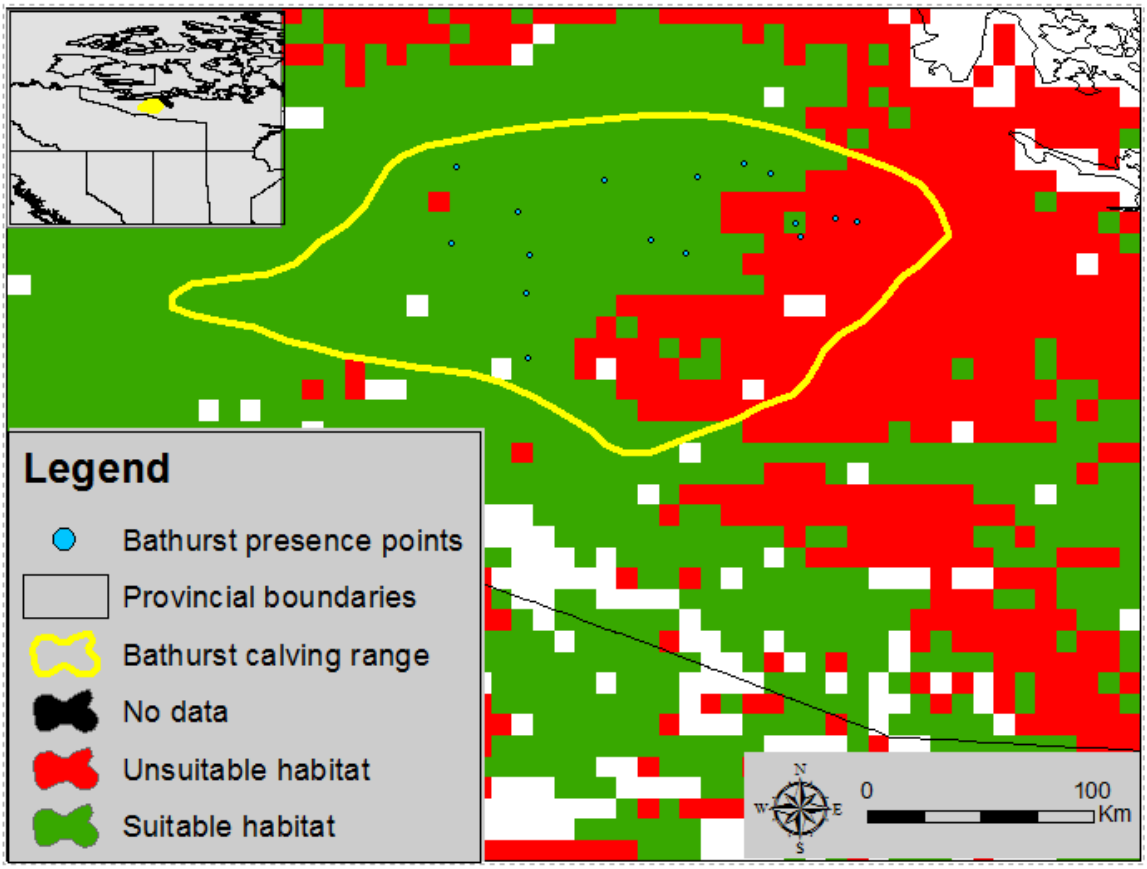

Figure 7: Results from the Bathurst calving range Maxent model, when built using environmental variables from 1999 to 2004, and 2006, and projected onto the 2005 environmental variables.

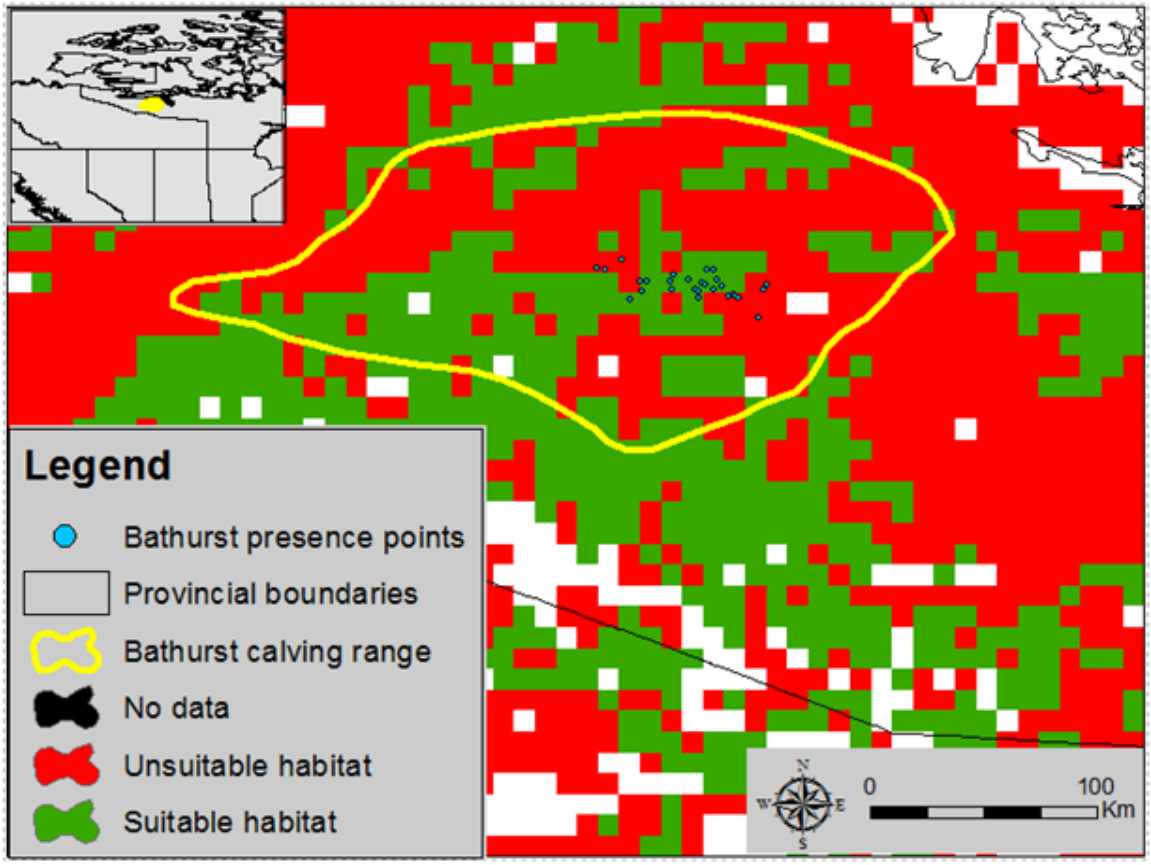

Figure 8: Results from the Bathurst calving range Maxent model, when built using environmental variables from 1999 to 2005, then projected onto the 2006 environmental variables