Population Dynamics of Migratory Caribou in Nunavik/Nunatsiavut

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Abstract

Migratory caribou are central to the economy and traditional life of northern peoples. They are also economically important for a major outfitting industry, much of it involving Aboriginals. Scientific and Aboriginal Traditional Knowledge, however, indicate that populations of migratory caribou undergo drastic changes over several decades. Caribou herds are declining almost everywhere in Canada, and the factors responsible for those declines are still poorly known. Caribou also face the impact of expanding resource-extraction industries, and threats to their habitat will continue to increase with the development of the North, and from climate change. Through the cooperation of government agencies, Aboriginal groups and industry partners we are combining existing long-term data, population genetics studies, monitoring caribou and their predators with satellite collars, satellite-derived information on plant productivity and small-scale climate and browsing manipulations to establish how climate and population density affect the food resources of caribou, their habitat use, choice of calving site, body growth and condition, recruitment, predation and age-specific survival. These are the most important factors currently thought to affect caribou abundance and distribution in the Arctic. We are also addressing the effects of industrial activities on caribou ecology and quantifying the impact of caribou on vegetation in key seasonal ranges. In addition to identifying the factors responsible for changes in population size and distribution, our work will provide managers and Aboriginal Peoples with new tools to monitor the demography of caribou and therefore improve their conservation in the face of climate change.

Key Messages

• Caribou calves were 8% heavier at birth and 20% heavier at weaning in a herd at low population size (i.e. Rivière-George herd) compared to one at high population size (i.e. Rivière-aux-Feuilles herd). These results suggest that the impact of population size may differ depending on season, because of different energetic demands faced by mothers and offspring.
• Adult female mass and hind foot length in spring predict pregnancy rates in caribou.
• We developed a life history model that can be used to estimate population sizes between aerial censuses. Our results allowed us to close the debate about the 2001 population census for the Rivière-aux-Feuilles herd, with an estimate of 630 000.
• We found that the probability of survival of caribou with old heavy radio-collars (1.6 kg) was significantly smaller than those with light collars (0.5 kg).
• We found significant negative impacts of climatic conditions on the survival of caribou only for the declining population of Rivière-George, and those impacts were greater for yearlings than for adults.
• Despite a recent re-definition and expansion, our work revealed that legally designated Wildlife Habitats in Québec on average protected less than 20% of the Rivière-George and Rivière-aux-Feuilles calving grounds. Clearly, protection of calving grounds must consider the dynamic use of space by adult females.
• The fall migration patterns of migratory caribou in Northern Quebec and Labrador had tended to stabilise in recent years. Changes in the spring and fall migratory routes occurred simultaneously with changes in the use of winter ranges. In both seasons, snow conditions seem to be the key factor driving changes in migratory behavior.
• Our results supported by both microsatellites and mtDNA divided populations of Rangifer into two geographically structured lineages, one originating from and confined to North-Eastern America, the other originating from Euro-Beringia but also currently distributed in Western North America.
• Forecasting the range of the species in 2080, we predicted a strong modification of the distribution of caribou. Under the severe climatic warming scenario considered, our model predicted the distribution of caribou to become even more restricted to high latitudes than today, with possible extinctions in the most southern regions.

• We developed a framework for delineating conservation units for caribou that is an effective tool to disentangle units based on genetic and ecological criteria.

• We demonstrated the influence of temporal variation in individual habitat use for inferring the influence of landscape features on gene flow.

• Caribou from the Rivière-aux-Feuilles and Rivière-George herds harbored higher Besnoitia tarandi burden compared to the other herds sampled in North America.

• Our broad survey of caribou health across 13 caribou herds showed that giant liver flukes (Fascioloides magna) were present only in the two Québec herds, with Rivière-George herd having a higher prevalence than Rivière-aux-Feuilles. The prevalence of giant liver flukes was also higher during the population size peak and afterwards than at other times, suggesting the importance of population size in the transmission of these parasites.

• Our results highlighted that the potential for compensatory growth in dwarf birch is surpassed under heavy browsing pressure independently of the fertilisation regime. In the context of the worldwide decline in caribou herds, the reduction in browsing pressure could act synergistically with global climate change to promote the current shrub expansion reported in subarctic regions.

• Preliminary results on space use of wolves revealed that they undertake long migrations along side caribou. Their survival is also higher than expected. Black bears appear to concentrate on the calving grounds of the Rivière-George herd and consume on average one caribou calf per day per bear.

Objectives

1. To determine life-history variation in known-age individuals, more specifically to assess longitudinally age-specific survival and reproduction of radio-collared animals (PhD 1 – J. Taillon, MSc 1 – M. Pachkowski, MSc 5 – A. Rasiulis; Collaborators – V. Brodeur and S. Couturier).

2. To analyze habitat selection of migratory caribou at different scales in all seasons, in particular in relation to migration routes and anthropogenic disturbance. To continue modeling the effects of climate change on the distribution of caribou. To use remote sensing tools to link changes in vegetation phenology and movements of caribou. To evaluate the extent to which inter-annual variation in the range use of migratory caribou can be explained by demographic trends and spatiotemporal changes in forage availability (PhD 2 – M. Le Corre, PhD 3 – B. Dalziel, PhD 6 – S. Plante, MSc 7 – B.A. Campeau).


4. To study the impact of parasites (e.g. Besnoitia, liver flukes) on the ecology of caribou. To compare parasite diversity and abundance in caribou from Quebec with those from elsewhere in the Arctic (MSc 2 – J. Ducroq, MSc 6 – Alice-Anne Simard; Collaborators – S. Kutz, B. Elkin, S. Lair).

5. To understand the relationships between the grazing ecology of caribou and short and long term effects of climate change on the summer range of caribou (MSc 3 – E. Champagne, MSc 4 – V. Saucier; Collaborators – E. Lévesque, L. Hermannutz, P. Grogan).
6. To study the impact of predation by wolves and black bears on the population dynamics of caribou by initiating a large-scale monitoring program of predators using satellite collars (PhD 4– to be determined, PhD 5 – to be determined).

Introduction

Migratory caribou (*Rangifer tarandus*) are central to the ecology of northern areas and are at the heart of this region’s culture and economy. Despite major monitoring and research efforts, caribou remain poorly known, making their management problematic. Most caribou populations have witnessed major variations in their abundance in the past and their numbers are still changing today (Vors and Boyce 2009). Climate change will likely have multiple effects on the northern habitats of migratory caribou. For example, more snow or rain in late winter could compromise movements and foraging behaviour (Weladji and Holand 2003; Tyler 2010). A milder climate will shorten the period when hydroelectric reservoirs are frozen, which could influence the timing of migration, the choice of migratory routes and even increase the risk of mass drownings. These expected effects could have repercussions on the energy balance and survival of animals as well as on dispersal among populations (Boulet et al. 2007). Changes in the spring phenology of plants (Post and Stenseth 1999) could lead to a phase shift between the period of abundance of high-quality food and the peak of lactation (Pettorelli et al. 2007). Given the scope of anticipated climate change, there is much concern about its potential effects on caribou and on the interactions between plants and caribou.

Several major hydroelectric and mining projects have been developed within the habitat of migratory caribou in Québec and Labrador (Jean and Lamontagne 2005), and a lot more are planned. The cumulative effects of human disturbance may reduce the availability or quality of essential habitats such as calving grounds (Johnson et al. 2005; Taillon et al. 2012). The assessment of the impact of human activities on caribou space use and the habitat of caribou as well as on the choice of migratory routes is essential to understand its population dynamics (Bolger et al. 2008).

A decrease in the abundance and distribution of caribou could have negative repercussions on Aboriginal Peoples and on the outfitting industry of Northern Québec and Labrador. The recent decline of the Rivière-George herd raised questions about the sustainability of sport and subsistence harvest on this herd and a greater knowledge of population dynamics is needed to ensure the conservation of this resource. A long-term research program is essential to improve the management and conservation of migratory caribou. Several characteristics of caribou (long life expectancy, reproduction over 5 to 10 years, influence of age on reproduction and survival rates) necessarily imply major temporal variations in the dynamics of populations. To understand the impacts of factors that are dependent and independent of density (e.g. climate factors), it is necessary to analyze a long time series covering a wide range of conditions.

We concentrate our research on the two large herds of migratory caribou in northern Québec and Labrador, the Rivière-George and Rivière-aux-Feuilles herds. These populations have been monitored for >20 years through satellite collars by the Ministère du Développement durable, de l’Environnement, de la Faune et des Parcs du Québec (MDDEFP; formerly the Ministère des Ressources naturelles et de la Faune, MRNF), a major partner in our research program, and more recently by Caribou Ungava. Both herds are central to the economy and traditional life of northern peoples. The future demography of migratory caribou facing climate change and industrial development of the North is essential to understand in the context of the Integrated Regional Impact Studies of ArcticNet and the continuing development of northern Quebec and Labrador.
Activities

Fieldwork activities

- February and March 2013 – We captured 11 new caribou of the Rivière-aux-Feuilles herd and fitted them with satellite collars. We also replaced collars nearing the end of their battery life on six others and recovered two radio-collars from dead caribou. Finally, six collars were installed on wolves. This fieldwork was conducted in partnership with the MDDEFP.

- June 2013 – Two teams were simultaneously in the field to capture caribou, wolves and black bears on Rivière-aux-Feuilles and Rivière-George calving grounds. We captured and weighed 30 and 34 newborns from the Rivière-Georges and the Rivière-aux-Feuilles herds, respectively. We captured 27 yearlings and five adult female caribou from the Rivière-aux-Feuilles herd to fit them with new satellite collars. Two other caribou from this herd were captured to replace their collar and four collars from dead caribou were recovered. We also fitted 16 new satellite collars on female caribou from the Rivière-Georges herd (14 yearlings and two adults). Three black bears and one wolf from the Rivière-aux-Feuilles herd range and five black bears from the Rivière-George herd range were fitted with satellite collars. Finally, on the Rivière-aux-Feuilles herd range, a collar was replaced on one wolf while the collars of one dead wolf and two dead bears were recovered. We conducted fieldwork in partnership with the MDDEFP and the Government of Labrador.

- June to August 2013 – We monitored vegetation in our experimental design installed in the caribou summer habitat at Deception Bay, Nunavik. We also monitored shrub species in the 15 exclosures (9 m² each) installed in 2011. We conducted fieldwork in partnership with Xstrata – Mine Raglan.

- October 2013 – We continued the monitoring of reproductive success of radiocollared female caribou (calf presence/absence) from the Rivière-aux-Feuilles and Rivière-George herds. We conducted the classification of more than 4000 individuals and performed a recruitment survey. Fifteen pairs of female-calf caribou from the Rivière-aux-Feuilles herd were harvested to assess their body condition. We conducted fieldwork in partnership with the MDDEFP and Government of Labrador.

Meetings, conferences and workshops

- May 2013 – We held a spring meeting of the scientific committee of the caribou project to plan fieldwork activities for the summer.

- November 2013 – We held a fall meeting with all the collaborators of the project to present an overview of fieldwork activities in 2013, and to plan research activities for 2014.

- November 2013 – We held the 4th annual symposium of Caribou Ungava at Université Laval attended by a little more than 100 participants. We had four invited speakers coming from Canada and the United States and a total of 15 conferences were given by the researchers, students, wildlife managers, outfitters and partners of Caribou Ungava.

- Spring, Summer and Autumn 2013 – We presented our results at the joint conferences of ACFAS- Centre for Northern Studies, the annual conference of the departement de biologie de l’Université Laval, the Northern Studies Centre in Kuujjuarapik, the Université du Québec à Rimouski, the annual meeting of the Safari Club International, the 38th Annual meeting of the Société Québécoise d’Étude Biologique du Comportement and the 9th ArcticNet annual scientific meeting.

- We presented at the final workshop of OURANOS and participated in the workshop of the new OHM (Observatoire Homme-Milieu) of Kangiqsualujjuaq.
Results

**Objective 1. To determine life-history variation in known-age individuals, more specifically to assess longitudinally age-specific survival and reproduction of radio-collared animals.**

1.1 - 1.2 - 1.3 Our major results concerning the effects of maternal characteristics on juvenile mass, size and fat storage, on conception probability, and on the effects of population size on maternal phenotype and fat reserves were presented in our report last year. Most of those results are now published in:


1.4 Information on demographic parameters such as survival and reproduction is central to understand population dynamics (Lebreton et al. 1992; Sandercock 2006). Although changes in fecundity and recruitment rates may have a substantial impact on population growth (Blakesley et al. 2010), any changes in adult survival rates in long-lived species can become key drivers of temporal variation in population size (Gaillard et al. 2000; Saether and Bakke 2000).

Using data from long-term satellite monitoring of migratory caribou, we sought to evaluate the survival rate of adults from both herds in Quebec-Labrador and assess environmental factors influencing survival.

The results presented in our previous reports indicated that the survival rate of individuals of both herds were very different. In the last five years, individuals from all sex and age classes from the Rivière-aux-Feuilles herd had a higher survival than those from the Rivière-George herd (88% and 73% for adult females, 81% and 56% for adult males, 80% and 56% for female yearlings). These differences in survival rates have resulted in very different population dynamics. Although the Rivière-aux-Feuilles herd is relatively stable around 280 000 individuals since 2008, the Rivière-George herd is undergoing a drastic decline and currently has < 20 000 individuals.

We analyzed the effect of former (heavy) collars on the survival of adult females from the Rivière-George herd. We compared the survival of individuals with VHF collars (0.5 kg) versus those equipped with satellite (ARGOS) collars (1.6 kg). We found that the probability of survival of individuals with heavy collars (average 70%) was significantly smaller than for those with light collars (average 86%) in 1991-1994 and 2000 (Figure 1).

![Figure 1. Annual survival (95% confidence interval) of adult female caribou from the Rivière-George herd fitted with VHF (0.5 kg) or satellite (ARGOS) (1.6 kg) collars. The number of individuals analyzed is indicated for each year.](image-url)
We analyzed the effect of winter (December-March) climate (average temperature, total snowfall, total rainfall, total precipitation and North Atlantic Oscillation index (NAO)) as well as annual NAO on the probability of annual survival of adult and yearling females from the two herds. No effect of climate was found on the survival of individuals from the Rivière-aux Feuilles herd. Three climatic factors were however found to have a significant impact on the survival of adult and yearling females of the Rivière-George herd. Rain and winter temperatures had a negative impact on annual survival while the winter NAO was positively correlated with survival. Furthermore, the effect of these factors was greater for yearlings than for adults (Figure 2). In addition, we found that winter rain and temperature had a negative impact on winter survival, while snow had a positive impact, however these were only significant for the yearling segment of the population (Figure 3).

1.5 Our major results concerning the protection of caribou calving grounds were presented in our report last year and are now published:


Figure 2. Effect of winter (December-March) temperature, rain and NAO on average annual survival of yearling and adult female caribou from the Rivière-George herd between 2001 and 2012.

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Predicted values  • Observed values
Objective 2. To analyze habitat selection by migratory caribou at different scales in all seasons, in particular in relation to migration routes and anthropogenic disturbance. To continue modeling the effects of climate change on the distribution of caribou. To use remote sensing tools to link changes in vegetation phenology and movements of caribou. To evaluate the extent to which inter-annual variation in the range use of migratory caribou can be explained by demographic trends and spatiotemporal changes in forage availability.

2.1 In environments with high seasonal variability such as northern environments, migration is an important large-scale habitat selection process allowing animals to follow seasonal changes in resource availability (Albon and Langvatn 1992) and escape predation pressure (Hebblewhite and Merrill 2007). The migratory caribou of the Rivière-George and Rivière-aux-Feuilles herds perform a long spring migration to reach calving grounds and summer ranges, and a fall migration to return to winter ranges in the boreal forest. Our objective was to develop an objective approach to assess departure and arrival dates of the spring and fall migrations, and then identify patterns of migration. Our approach, adapted from Barraquand and Benhamou (2008), was presented with more details in the previous reports. First we characterized the movements of caribou all along the year using the First-Passage Time analysis (FPT, Fauchald and Tveraa 2003); then we segmented the FPT profiles using a statistical segmentation.
process (Lavielle 2005) in order to discriminate high FPT value segments (break in the annual movements) to low FPT value segments (long-range movements). The efficiency of our approach was tested on spring migrations of 402 females from the two herds followed from 1986 to 2012. We identified both departure and arrival dates for 89% of the 625 complete spring migrations present in our database (Rivière-George: 305, Rivière-aux-Feuilles: 249)(Figure 4).

2.2 Major effects of climate change are expected in northern environments, including changes in the timing of natural processes (Parmesan and Yohe 2003). For example, snow melt is expected to occur sooner, river and lake ice-free periods to last longer and the length of the growing season to increase, with an earlier peak in vegetation productivity. These ongoing changes in caribou habitat could directly impact the timing and course of their migrations.

Our objective here is to link changes observed in spring and fall migration patterns of the two herds since 1986 and the changes in environmental and climate variables. Patterns of migration were defined from the segmentation performed in the previous section. We used the NAO to describe climate at a large scale (Hurrell 1995). At a finer scale we used snow cover data from MODIS imagery (res: 0.5 km; Armstrong and Brodzik 2005) and monthly data (temperatures, precipitations, snow water equivalent) from the Canadian Regional Climate Model (CRCM v4.3, res: 45 km) produced by Ouranos (de Elia and Côté 2010). We used NDVI data (Normalized Difference Vegetation Index) to describe plant productivity (Couturier et al. 2009a). Finally we took into account the variations in population size of the two herds. These estimates are from the project of A. Rasiulis (1.4).

Because the number and the location of winter ranges were more variable than for calving ground, we characterized spring migration patterns according to the ecoprovince, i.e. an area with uniform physical and ecological components (Natural Resources Canada), from where females are departing. We observed three patterns of spring migration for the Rivière-aux-Feuilles herd: short migrations from the winter range located in tundra in the southern and northern arctic (Figure 5a), a long migration from the eastern taiga
shield (Figure 5b), and an "early" long migration: caribou leave the winter range located in taiga during winter, stop on the northern winter range in tundra, then ends their migration in May (Figure 5c). For the Rivière-George herd we identified four main patterns of migration: two short migrations from winter ranges located in taiga, in the Labrador uplands and in the Whale river lowland (patterns d and e Figure 6), and two long migrations from the two western winter ranges, also used by the Rivière-aux-Feuilles herd (patterns a and b Figure 6). A fifth pattern, similar to the "early" long migrations of the Rivière-aux-Feuilles herd was also observed (patterns c Figure 6) but was rare.

Both herds presented long spring migrations from winter ranges far from calving grounds and short spring migrations from nearest winter ranges. We tested the effect of climate and environmental variables on the probability to use these ranges and therefore the probability to perform short or long spring migrations. Because caribou reach winter ranges during the fall migration, we also tested the Table 1. Factors influencing the probability of performing long spring migrations for the caribou of the Rivière-aux-Feuilles (RFH) and the Rivière-George herds (RGH). The response variable is a binary variable ("short"/"long") tested with a linear mixed model: Pattern of migration ~ Demography + Summer resources + Local climate + Global climate, with the ID of the individuals as a random factor. The table represents the best model selected using AIC. The explanatory variables were selected among the following variables: Demography: RGH population size, RFH population size; Summer resources: mean and maximal NDVI observed on the summer range (July and August), the date maximal NDVI is reached; Local climate: temperatures, precipitations and snow water equivalent of November and December; Global Climate: NAO value of November and December.

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/ : no variable selected; NS: non significant effect
effect of the climatic conditions encountered during the fall. Finally, we tested the effect of the size of the two herds and the effect of the resources available on the summer ranges, because individuals in good body condition can migrate further.

Selected variables for the different effects (demography, resources, local climate, global climate) are presented in Table 1. The sign of the effect on the odds to observe a long migration is indicated when the effect is significant. Results show an effect of the Rivière-aux-Feuilles herd's population size on the odds to observe a long migration pattern for the Rivière-George herd, but also for the Rivière-aux-Feuilles herd. However, the effect is positive for Rivière-George herd and negative for Rivière-aux-Feuilles. The positive effect for Rivière-George herd indicates that the use of the furthest winter ranges could be a response to a high population size: as Rivière-George herd population was declining, its use of the western winter ranges gradually decreased in favour of the use of the closest winter ranges, leading to an increase in the odds to observe short migrations (Figure 7). The negative relationship between the Rivière-George herd population size and the odds to observe a long migration for the Rivière-aux-Feuilles herd seems to indicate that the presence of Rivière-George herd limited access to the south-western winter range. The Rivière-aux-Feuilles herd increased its use of this winter range as the Rivière-George herd progressively abandoned it (Figure 7).

Our results thus suggest a potential competition between the two herds for the use of the winter ranges. Climate encountered during the fall migration has also an effect on the odds to observe a long migration for the Rivière-aux-Feuilles herd. The negative effect of snow water equivalent indicates that the odds of observing long migrations decrease with abundant snow on the ground. However, the positive effect of temperatures and the negative effect of NAO indicate that when caribou encounter mild weather conditions during the fall migration the odds of observing long migration increase. We did not observe any effect of the summer resources for both herds.

2.3 Our third objective was to test the effect of climate and resource availability on the timing of the spring and fall migrations. The environmental and climate data as well as the analyses were presented in our previous report. We discuss briefly these results in the Discussion section.

2.4. Our fourth objective was to evaluate the extent to which inter-annual variation in the range use of migratory caribou can be explained by demographic trends and spatiotemporal changes in forage availability. For this new project, we will use historic databases on caribou locations and demography as well as remotely-sensed data allowing the determination of indices of vegetation productivity (NDVI) and lichen cover. We aim to study inter-annual changes in the average environmental conditions of caribou seasonal ranges in order to assess the importance of these changes in driving variations in caribou range use, to compare the environmental conditions of utilized areas to those measured for
unutilized areas within the historic range of the subject caribou herd, and finally, to develop a habitat selection model for each of the seasonal periods examined in earlier analyses.

Objective 3. To determine the influence of past and future climate change on genetic diversity in caribou/reindeer populations throughout their circumpolar distribution. To assess the conservation units of caribou in Québec and Labrador. To test the ability of habitat selection to predict genetic relatedness among caribou.

3.1 Climate-driven range fluctuations during the Pleistocene epoch have continuously reshaped species distribution leading to populations of contrasted genetic diversity. Contemporary climate change is similarly influencing species distribution and population structure, with important consequences for patterns of genetic diversity and species’ evolutionary potential (Parmesan 2006). Yet few studies have assessed the impacts of global climatic changes on intraspecific genetic variation (Balint et al. 2011; Alsos et al. 2012; Rubidge et al. 2012; Pauls et al. 2013). Here, combining analyses of molecular data with time series of predicted species distributions and a model of diffusion through time over the last 21 kyr, we unravel caribou response to past and future climate changes across its entire Holarctic distribution. We found that genetic diversity is geographically structured with two main caribou lineages, one originating from and confined to North-Eastern America, the other originating from Euro-Beringia but also currently distributed in Western North America (Figure 8A). Regions that remained climatically stable over the past

![Figure 8. A) Genetic structure of populations of caribou. The probability of belonging to the population for each herd clade in North America, obtained using the STRUCTURE software (Pritchard et al., 2000), based on 16 microsatellite loci typed for 1,297 caribou, given two genetic groups (blue color corresponds to the North American clade and red clade Euro - Beringian, respectively). The geographic distribution of genetic lineages modeled caribou, based on climatic envelope of the species, i.e. conditions of temperature and precipitation: B) When Denier Glacial Maximum, -21 thousand years ago, and C) currently. The clear blue regions correspond to the areas covered by glaciers during the same periods. D) The distribution of caribou in 2080, predicted by the model based on the A1B scenario IPCC4 (IPCC, 2007) from the ocean-atmosphere global climate model obtained from the Hadley Centre climate model (HadCM3). Regions red and yellow are predicted to be the most appropriate and most inappropriate for caribou in 2080, respectively zones.]
21kyr (Figure 8B) maintained a high genetic diversity and are also predicted to be those that will experience higher climatic stability under future climate change scenarios (Figure 8D). Our interdisciplinary approach, combining genetic data and spatial analyses of climatic stability and applicable to virtually any taxon, represents a significant advance in inferring how climate shapes genetic diversity and impacts genetic structure. The detailed results of this study are now in press:


3.2 In North-America and Eurasia, caribou herds are declining across much of their range, prompting the development and application of recovery strategies at the different jurisdictional levels (e.g., for woodland caribou; Environment Canada 2011a; Équipe de rétablissement du caribou forestier du Québec 2013). Given the incompatibility between intensive anthropogenic land use and viability of caribou populations (Schaefer 2003; Environment Canada 2011b; Festa-Bianchet et al. 2011), habitat protection represents a key strategy for caribou conservation (e.g., Taillon et al. 2012), and conservation biologists need objective and unambiguous criteria to characterize conservation units that are the most worthwhile preserving (Bonin et al. 2007).

Identifying conservation units (CUs) below the species level is becoming increasingly important, particularly when limited resources require focusing conservation efforts on some particular units or populations. Among the criteria used to delineate CUs, the amount of intra-specific genetic variation is now widely accepted as a key parameter to determine populations. Many animal species also harbour ecological characteristics (e.g. behaviour, habitat use, etc.) that may reflect potential adaptation to local environmental conditions (i.e., ecotypes). Genetic and ecological data provide complementary information that should be integrated to make optimal conservation decisions. Here we propose a framework based on genetic information and ecological criteria - primarily ecotype designation - to define conservation units in caribou from Québec and Labrador. To do so, we genotyped more than 560 caribou from Québec and Labrador (Figure 9) at 16 microsatellite loci and used three Bayesian clustering methods to spatially delineate and characterize regional patterns of population genetic structure. Six genetically differentiated units exist across the present-day range of caribou in the studied regions (Figure 10). The genetic units differ in their spatial extent and we observed a south-to-north positive gradient of genetic diversity. These groups are not consistent with the presently defined ecotype designations, as some genetic units comprise more than one ecotype while the same ecotypes are present in different

Figure 9. Distribution of caribou sampled for DNA analyses in Québec and Labrador. 1) Blue diamonds: Rivière-George migratory herd; 2) blue dots: Rivière-aux-Feuilles migratory herd; 3) green squares: boreal caribou ecotype; 4) orange triangles; the mountain caribou of Gaspésie and Torngat Mountains; 5) the translocated caribou herd of Charlevoix is depicted with red diamonds. Designatable unit (DU) as proposed as conservation units for caribou in Canada (COSEWIC 2011).
3.3 Gene flow among populations is modulated by landscape connectivity. While species utilisation of the landscape is usually viewed as constant within a year, the spatial distribution of individuals is likely to vary in relation to particular seasonal needs. Understanding temporal variation in landscape utilisation and connectivity among populations and how this relates to gene flow has direct conservation implications. Here we modelled the daily use of the landscape by caribou in Quebec, Canada and tested its ability to explain the genetic distance among individuals (n=480) from different herds (Figure 11).

We assessed habitat selection using locations of collared individuals in migratory herds (n=529 caribou, >60,000 locations) and static occurrences from sedentary groups (n=316 caribou). We modelled the distribution of the caribou using 12 environmental variables, some being temporally dynamic (snow cover, NDVI, temperature, precipitations), others being static (elevation, proportion of the different land cover categories). Those variables are recognized as important predictors of caribou habitat suitability and are likely to enhance or impede caribou movement (Johnson et al. 2005; Apps & McLellan 2006; Avgar et al. 2013; Weckworth et al. 2013). Pathways based on habitat use and connectivity were then compared to the genetic structure to test how well the landscape is shaped by biological processes and whether the landscape is a good predictor of evolutionary processes among populations.
Objective 4. To study the impact of parasites (e.g. Besnoitia, liver flukes) on the ecology of caribou.

to compare parasite diversity and abundance in caribou from Quebec with those from elsewhere in the Arctic.

4.1 Prevalence and intensity of parasites in caribou can affect body condition, population dynamics (May and Anderson 1978; Kutz et al. 2012) and, on the socio-economic side, meat quality for First Nations, Inuits and sport hunters. Considering these factors, prevalence and intensity of some caribou parasites were evaluated in details. Eight barren-ground caribou herds were compared for Besnoitia tarandi infection. Rangifer tarandus is considered the primary intermediate host for this protozoan tissue-dwelling parasite. Results on the prevalence and intensity of Besnoitia tarandi were detailed in the 2011-2012 report and are published:


We developed a standardized protocol to monitor prevalence and intensity of Besnoitia in barren-ground caribou herds. The best measure of infection is microscopic evaluation of a skin section of the metatarsal region. We identified some risk factors that explain variability in B. tarandi infection: males and young caribou are more at risk of being infected than adult females. These results are also published:


![Figure 12. Temporal changes in correlation coefficient (Mantel’s r) between genetic distance (i.e., relatedness among individuals) and geographic distance. Plots of genetic relatedness (Lynch and Ritland 1999 relationship coefficient) against (a) geographic distance, (b) least-cost path and (c) circuit resistance. Grey boxes delimit the calving period (Julian days 155-190) and the rut period (Julian days 260-300) for forest-dwelling caribou (Lesmerises et al. 2013) and migratory caribou (Boulet et al. 2007). Dark-grey box shows the rutting peak for migratory caribou (Julian days 285-300; Boulet et al. 2007).](image)

Finally, we evaluated infection by *Mycobacterium avium* subspecies paratuberculosis (MAP), a well-known pathogen in domestic ruminants. Wild species such as caribou also appear to be susceptible to clinical MAP infection. These results are published:


4.2 Comparative studies across a wide spatiotemporal range are useful for improving our understanding of health and the dynamics of wild animal populations. Indeed, population dynamics can be controlled by the overall health of individuals. A parasite may have an impact on the dynamics of animal populations through its effect on the life-history components of its host (May and Anderson 1978). In reindeer, anthelmintic treatments had a positive effect on fertility (Albon et al. 2002), food intake (Arneberg et al. 1996) and body condition. Individual characteristics of the host may also have an impact on their rate of parasitism. Indeed, a variation in the prevalence (percentage of infected individuals in the host population) and intensity (the average number of parasites per infected host) is expected by sex and age of individuals. The size of the host population also has an impact on the prevalence and intensity of parasites, but a delay in the response of the parasite may exist, especially for environments with high seasonality (Albon et al. 2002).

The primary objective of this study was to describe the prevalence and intensity of seven key macro-parasites of migratory caribou (*Hypoderma tarandi*, *Cephenemyia trompe*, *Taenia hydatigena*, *Fascioloides magna*, *Echinococcus granulosus*, *Dictyocaulus eckerti* and *Taenia krabbei*) across thirteen herds from Alaska to Greenland (Figure 13, Table 2) and to determine which factors such as sex, age, herd size and season best explain the prevalence and intensity of these parasites after correction for the sampling year. We used five categories of herd size, which are Low and increasing, High and increasing, around the peak, High and decreasing, and Low and decreasing. We also made comparisons of parasitism rates between herds.

In summary, a total of 1833 caribou/reindeer (*Rangifer tarandus*) were sampled across the thirteen herds studied and preliminary results show a relatively uniform distribution of parasites in all herds with the exception of nose bots (*Cephenemyia trompe*), liver cysts (*Taenia hydatigena*) and muscle cysts (*Taenia krabbei*), which are more prevalent in some herds. Giant liver flukes (*Fascioloides magna*) were present only in the two Québec herds, with Rivière-George herd (92 ± 5%; n=26) having a higher prevalence than Rivière-aux-Feuilles (33 ± 5%; n=98) (z=4.18; Figure 13. Studied caribou herds for the survey of parasites. Adapted from Hugo Ahlenius, UNEP/GRID-Arendal.)
Table 2. Comparison of prevalence (% of infected individuals in the host population) and intensity (average number of parasites per infected host) of 7 key macro-parasites studied across 13 migratory caribou herds from Alaska to Greenland (Fig. 13) sampled between 1979 and 2011.

<table>
<thead>
<tr>
<th>Parasite</th>
<th>Herds compared</th>
<th>Prevalence (C.I. 95%)</th>
<th>Intensity (C.I. 95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warbles (Hypoderma taranthe)</td>
<td>Akia-Manilisoq, Bathurst, Beverly/Aliak, Bluenose East, Cape Bathurst, Kangarussuaq-Sisimiut, Rivière-George, Southampton Island</td>
<td>Between 96 and 99% (n=111)</td>
<td>Between 91 and 111 warbles (n=47)</td>
</tr>
<tr>
<td>Nose bots (Cephenemyia trompe)</td>
<td>Akia-Manilisoq, Bathurst, Beverly/Aliak, Bluenose East, Cape Bathurst, Kangarussuaq-Sisimiut, Teshekpuk</td>
<td>Between 18 and 27% (n=335)</td>
<td>Between 15 and 72 nose bots (n=62)</td>
</tr>
<tr>
<td>Liver cysts (Taenia hydatigena)</td>
<td>Akia-Manilisoq, Bathurst, Beverly/Aliak, Bluenose East, Bluenose West, Cape Bathurst, Kangarussuaq-Sisimiut, Porcupine, Rivière-aux-Feules, Rivière-George, Teshekpuk, Western Arctic</td>
<td>Between 18 and 23% (n=975)</td>
<td>Between 2 and 3 cysts (n=180)</td>
</tr>
<tr>
<td>Giant liver flukes (Fascioloides magna)</td>
<td>Akia-Manilisoq, Bathurst, Beverly/Aliak, Bluenose East, Bluenose West, Cape Bathurst, Kangarussuaq-Sisimiut, Porcupine, Rivière-aux-Feules, Rivière-George, Teshekpuk, Western Arctic</td>
<td>All herds : between 27 and 32% (n=1285)</td>
<td>Between 11 and 14 flukes (n=212)</td>
</tr>
<tr>
<td>Hydatid cysts (Echinococcus granulosus)</td>
<td>Akia-Manilisoq, Bathurst, Beverly/Aliak, Bluenose East, Bluenose West, Cape Bathurst, Kangarussuaq-Sisimiut, Porcupine, Rivière-aux-Feules, Rivière-George, Teshekpuk, Western Arctic</td>
<td>Between 3 and 8% (n=1218)</td>
<td>Between 1 and 2 cysts (n=43)</td>
</tr>
<tr>
<td>Lungworms (Dicycaulus costei)</td>
<td>Akia-Manilisoq, Bathurst, Beverly/Aliak, Bluenose East, Bluenose West, Kangarussuaq-Sisimiut, Teshekpuk, Western Arctic</td>
<td>Between 1 and 5% (n=380)</td>
<td>N/A</td>
</tr>
<tr>
<td>Mucocysts (Taenia krabbei)</td>
<td>Akia-Manilisoq, Bathurst, Beverly/Aliak, Bluenose East, Bluenose West, Cape Bathurst, Kangarussuaq-Sisimiut, Porcupine, Rivière-aux-Feules, Rivière-George, Southampton Island, Teshekpuk, Western Arctic</td>
<td>Between 5 and 7% (n=1190)</td>
<td>Between 1 and 2 cysts (n=38)</td>
</tr>
</tbody>
</table>
p<0.001). The prevalence of giant liver flukes was also higher during the population size peak and afterwards than at other times, suggesting the importance of population size in the transmission of these parasites (Figure 14). Finally, for most parasites, there was no significant difference in terms of prevalence and intensity between sexes, age classes, and herd size (all p’s >0.05), except for liver cysts that were more prevalent in adults (27 ± 10%, CI 95%; n=822) than in calves (6 ± 4%, CI 95%; n=132; Figure 15), and for warbles (Hypoderma tarandi), that showed a higher prevalence in adult males (4.9 ± 0.4% CI 95%; n=68) than in adult females (3.9 ± 0.4%, CI 95%; n=448) (z=8.23; p<0.001). Our research provides the first comparative survey of caribou health across a broad geographic range.

**Objective 5. To understand the relationships between the grazing ecology of caribou and short and long term effects of climate change on the summer range of caribou.**

5.1 Nunavik and Nunatsiavut experienced rapid climate change during the last two decades. A reduction of the period of snow and ice cover at a rate of 1 day/year was accompanied by an increase in mean ground temperature of over 2°C (Allard and Lemay 2012). Simulations suggest that these changes will continue and will be especially important in the Ungava Peninsula. The impact of these changes on the phenology of plants could affect the availability of resources for caribou (Post et al. 2008). We aimed to evaluate the influence of climate change on the availability of caribou food resources using a simulated experiment. Since 2009, we mimic short- and long-term temperature increases with open-top chambers and nitrogen fertilization respectively, while also simulating variable browsing pressure by caribou on deciduous shrubs. Results show an advance of 4 to 7 days in vegetative phenological stages of American dwarf birch (Betula glandulosa) under an increased temperature regime (Figure 16). The advance is particularly evident in 2013 which had a relatively short growing season, supporting the idea that the effect of warming is especially important at higher latitude and longitude.

Rapid climate change in the arctic environment has also enabled higher productivity and colonization by shrubs (Myers-Smith et al. 2011; Zeng et al. 2013). Using the same experimental design, we investigated the combined influence of climate change and browsing on the abundance of forage for caribou. As related in last year’s report, results after four years of treatment suggest a reduction in the biomass of both
American dwarf birch and Gramineae in warmed plots (Figure 17). The fertilization treatment strongly increased the biomass of Gramineae (Figure 18). Those analyses are ongoing and will be completed soon.

Finally, the alteration of the shrub layer, induced by climate change, is likely to have an impact on the composition of plant communities. Because of the capacity of shrubs to dominate the community (Bret-Harte et al. 2001), they increase competition for the ground layer, mostly represented by herbaceous or moss species (Chapin et al. 1996), thus having a high influence on the structure and function of the environment (Elmendorf et al. 2012). We aimed to evaluate the influence of climate change and browsing on the composition and diversity of the plant community of arctic herbaceous tundra using the simulated experiment. Browsing tended to disrupt birch dominance in plots at ambient temperature thus, increasing species richness by 1 species. In warmed plots, the positive effect of browsing on species richness is overshot by the positive effect of warming (Figure 19). We attribute the latter response to the disruption of the dominance by shrubs. In agreement with our results on biomass, fertilisation reduced specific richness by 17%, likely because more graminoids were present.

5.2 Densification of the shrub layer has been recently reported in subarctic regions (Myers-Smith et al. 2011) including the Ungava peninsula (McManus et al. 2012; Ropars and Boudreau 2012; Tremblay et al. 2012), suggesting a potential increase in forage for caribou. Shrubs are a source of protein and constituted...
36 to 66% of the diet of lactating female caribou in the 1990's (Crête et al. 1990). We investigated the tolerance of dwarf birch to variable browsing pressures through the simulation experiment described in 5.1. As related in last year’s report, dwarf birch can tolerate moderate, but not heavy browsing pressure. Yet, the availability of birch browse is reduced even at moderate browsing pressure. We explain this apparent contradiction by a reduction in the overall number of long shoots. Long shoots are responsible for branch elongation. As they are located at the distal end of branches accessible to caribou, they can have a strong influence on browse availability from the caribou perspective. Those results are now published:


5.3 It is increasingly accepted that vertebrate herbivores may contribute to spatial variation in the responses of erect shrubs to climate change (Naito and Cairns 2011, Yu et al. 2011). Olofsson et al. (2009) even concluded that herbivores can inhibit climate-driven shrub expansion on the tundra. The change in the abundance of the Rivière-aux-feuilles herd offers an opportunity to evaluate the relationships between caribou abundance and climate on shrub densification. As related in last year’s report, a comparison of high resolution aerial photographs from 1972 and a satellite image from 2010 from the Deception River valley revealed no change in the horizontal cover of erect shrub during this period (Figure 20), while temperatures increased by 3°C in Salluit (Lévesque 2009). We attribute this stagnation to an increase in the caribou population from an estimated 56K in 1975 (Le Hénaff 1976) to 630 000 in 2001 (Couturier et al. 2004). These results have recently been accepted in Polar Biology.


5.4 Browsing effects on shrubs can persist multiple years after release from heavy browsing (Crête and Doucet 1998) and thus, affect resource availability for caribou over the long term. In 2011, we installed
a series of 15 small exclosures (9 m²) designed to protect erect heavily browsed willows (*Salix planifolia* and *S. glauca*) from browsing. In 2013, we monitored the response of willows. As from 2014, we plan to remove three exclosures per year to identify the length of recovery at low browsing pressure required for the recovery of erect willows.

5.5 While the American dwarf birch was a dominant summer forage of the Rivière-George and Rivière-aux-Feuilles herds in the 1990’s (Crête et al. 1990), there are reports of a much lower selection for birch (*Betula glandulosa* and *B. nana*) in northwest North-America. We aim to evaluate the compositional (macroelements, phenolic, lignin) and functional (digestibility) attributes of *B. glandulosa* over the North American range of migratory caribou and relate its chemical characteristics to soil fertility (C, N, P, pH and bulk density). As related in the report of last year, we collaborated with P. Grogan (Queens U.) and developed a sampling protocol for leaf, soil and caribou faeces that was sent to research teams from Alaska to Labrador. We received 115 samples from 25 sites. We recently conducted lab analyses to estimate nutritional value of samples (nitrogen, carbon and phosphorus content as well as apparent digestibility) and these data will soon be analyzed.

**Objective 6. To study the impact of predation by wolves and black bears on the population dynamics of caribou by initiating a large-scale monitoring program of predators using satellite collars.**

Wolves are considered the main predator of caribou (Bergerud et al. 2008) but their impact on the population dynamics of migratory caribou is unknown. The migration of caribou to calving grounds at high latitudes is thought to be partly a response to wolf predation. The ecology of black bears may also be greatly influenced by migratory caribou, especially on and near calving grounds where bear predation is thought to be a major source of mortality. The ecology of black bears in areas with access to caribou and in areas far from calving grounds may be very different. To investigate these questions, we began in 2011 a satellite-monitoring program of both predator species. Twenty-two black bears and 21 wolves in total on both

Figure 21. Locations of satellite-tagged wolves within the Rivière-aux-Feuilles caribou herd range between June 2011 and December 2013. Each color represents a different wolf and yellow dots represent the last location of each wolf.

Figure 22. Locations of satellite-tagged black bears within the Rivière-aux-Feuilles and Rivière-George caribou herd ranges between June 5th and December 6th 2013. Each color represents a different bear and yellow dots represent the last location of each bear.
caribou herd ranges have been equipped with satellite collars. Preliminary results show that individual wolves from the Rivière-aux-Feuilles herd range perform large seasonal movements comparable to that of the caribou migration (Figure 21). This observation is surprising because wolves in northern Quebec were expected to be non-migratory. Black bears on the Rivière-George range appear to congregate on calving grounds and locations indicate an attraction towards high-density caribou concentrations. The variation in space use of black bears is very high, with some sedentary individuals and others undertaking long movements (Figure 22). We will continue to collar predators alongside our fieldwork on caribou. The recruitment of two graduate students on this project is planned for the fall of 2014 because we need to secure other funding for the large costs of captures and the satellite program.

Discussion

Objective 1. To determine life-history variation in known-age individuals, more specifically to assess longitudinally age-specific survival and reproduction of radio-collared animals.

1.1 – 1.2 – 1.3. The discussion of these results is presented in the report from last year and the papers cited in the results section. We will focus in the sections below on new results.

1.4 Our results on the survival rate of caribou of both herds have been discussed in the report of last year. The part of our study related to the effect of collars on caribou survival rate demonstrated potentially large negative impacts of heavy collars. It is thus essential that further studies using heavy radio collars, such as those equipped with cameras, quantify the effect of these devices on the survival of animals, especially in declining populations or when body condition is below average. It is also important to note that since 2000, the collars used on caribou from both herds are much lighter than in the past, and that since June 2013, the newly deployed collars weigh <500 g. Finally, we found significant negative impacts of climatic conditions on the survival of caribou only for the declining population of Rivière-George, and those impacts were greater for yearlings than for adults. It is expected that the effects on juvenile survival are greater than for adult females because the latter are more resilient to climatic conditions (Gaillard and Yoccoz 2003). The abundance of winter rain and warm temperatures are likely to decrease caribou survival by limiting the availability of winter forage as they create a barrier of hard snow or ice difficult to dig through in order to reach nutrients such as ground lichens (Stien et al. 2010). We are still at the initial steps of these analyses and we will continue our investigation of the impacts of climatic variables on age-specific survival patterns.

1.5 The discussion of the results concerning the protection of caribou calving grounds is presented in the report from last year and the paper cited in the results section.

Objective 2. To analyze habitat selection by migratory caribou at different scales in all seasons, in particular in relation to migration routes and anthropogenic disturbance. To continue modeling the effects of climate change on the distribution of caribou. To use remote sensing tools to link changes in vegetation phenology and movements of caribou. To evaluate the extent to which inter-annual variation in the range use of migratory caribou can be explained by demographic trends and spatiotemporal changes in forage availability.

2.1 Segmentation of the FPT profiles yielded results consistent with the literature on spring migration, as well as use of winter range and calving ground, as movement rates of individuals are known to decrease during these two periods of the year (Gunn et al. 2008; Couturier et al. 2010). The segmentation process highlighted path segments with very high FPT values in winter and shorter pauses in June. Our approach was highly efficient, we successfully detected 100%
of the winter pauses and 89% of the calving ground use. Most failures at detecting pauses were related to individuals performing short stops with a low mean FPT, therefore making the discrimination between segments of high and low mean FPT values more difficult. However, failures can have a biological meaning. We assumed that females end their spring migration with calving, but pregnancy rates reported in these two herds in the past decade are lower than our detection success of the calving ground use (<80%, Couturier et al. 2009b). Thus, failures could correspond to nongravid females that have not stopped to calve but only slowed down with the herd. Our approach allows an efficient and objective segmentation of the annual movements of migratory caribou and could be easily applied to other long-distance migrant species. A methodological article, presenting the method, will be submitted soon.

2.2. Spring migration patterns of Rivière-George and Rivière-aux-Feuilles herds have changed during the past decades. These changes for the Rivière-George herd seem to follow changes in the size of the herd. Caribou from the Rivière-George herd responded to the high population level observed in the 1990's by an expansion towards the furthest winter ranges, after they were more likely to use the closest winter ranges as the herd was declining. The presence of the Rivière-George herd seemed to constrain the Rivière-aux-Feuilles herd to its northern winter range when the Rivière-George population was high, and this suggests a potential competition between the two herds for the use of the winter ranges. The main effect of climate seems to be on the ability of movements of the individuals. Harsh weather conditions with abundant snow on the ground could increase the cost of movements (Weladji and Holland 2006), and thus limit the long migrations toward the southern winter range. Conversely, mild weather conditions, with potentially late snow falls, could facilitate the migration and thus promote the access to the furthest winter range. We are currently conducting similar analyses for the fall migration patterns. Moreover, we used the snow water equivalent as an indication of snow abundance but our models did not take into account snow cover. We extracted snow cover data recently from the MODIS imagery, and the next step will be to include these data in our models.

2.3 Our third objective is to test the effect of climate and resource availability on the timing of the spring and fall migrations. The environmental and climate data as well as the analyses were presented in the previous report. Results indicated an effect of the climate on departure and arrival dates of the spring and fall migrations and suggest that the impact of expected climate change will not be the same according to the seasons. In the spring, an early snowmelt, due to an early spring, will increase the cost of the movement as the quality of snow on the ground will decrease (Weladji and Holland 2006) and an early ice break-up could increase the mortality risk during the crossing of laches and rivers (Miller and Gunn 1986). However, females need to reach the calving ground at a specific time of their life cycle. The calf survival could be negatively affected if females calve on sub-optimal calving sites or if calving is no longer synchronized with the peak in vegetation productivity (Post and Forchhammer 2008). In the fall, a late winter, with a late freeze-up and a late snow fall, will facilitate the movements during the fall migration. Moreover, caribou show a high variability in their migration patterns and the winter ranges they are using. We can expect that climate change will have a lesser impact in the fall than in the spring or could even have a positive effect. In both spring and fall, snow condition seems to be a key factor affecting the cost of movements (Weladji and Holland 2006) and access to resources (Miller and Gunn 2003).

2.4 Over the last few decades, the Rivière-George and Rivière-aux-Feuilles herds have demonstrated considerable changes in their use of seasonal ranges, complicating efforts to manage the two populations. Both herds have undergone large changes in population size over this time that can potentially explain much of the observed variation in range use, but the exact mechanisms driving range use changes are largely unknown. Changes in forage availability and predation pressure interact with
changes in population size through complex density dependent interactions (Wang et al. 2009), with density independent forcing – such as climate change and extreme weather – acting to add further complexity (Tyler 2010). It has been well documented, however, that forage availability plays a key role in determining the ‘carrying capacity’ of migratory caribou habitat, with authors attributing variable importance to the summer and winter ranges in restricting population size (Messier et al. 1988; Manseau et al. 1996; Ferguson et al. 2001). Taillon et al. (2012) observed an increase in the size of the Rivière-George herd calving grounds between 1974 and 1988 as the population was expanding, followed by an eventual range contraction after the population declined, suggesting overgrazing as a probable cause for range expansion. The Rivière-aux-Feuilles herd, in contrast, has exhibited limited variability in calving ground use (Taillon et al. 2012) and appears more demographically stable than the Rivière-George herd. It has, however, demonstrated an interesting change in its winter range use over the past few years, with individuals electing to migrate much further south to utilize a much larger winter range than it had previously (M. Le Corre, unpublished data). This change could be a result of the recent shift in relative abundance between the Rivière-George and the Rivière-aux-Feuilles herds, with the Rivière-aux-Feuilles herd now moving to occupy the areas used by the Rivière-George herd before its population crash and subsequent range contraction. However, it is also possible that the growing Rivière-aux-Feuilles herd was overgrazing its former winter range, reducing lichen abundance and thus necessitating the shift in range use. This new project aiming to evaluate the extent to which inter-annual variation in the range use of migratory caribou can be explained by demographic trends and spatiotemporal changes in forage availability will benefit from the knowledge gained in other research projects of Caribou Ungava.

Objective 3. To determine the influence of past and future climate change on genetic diversity in caribou/reindeer populations throughout their circumpolar distribution. To assess the conservation units of caribou in Québec and Labrador. To test the ability of habitat selection to predict genetic relatedness among caribou.

3.1 The discussion of the results of our work on caribou response to past and future climate change across its entire Holarctic distribution is presented in details in the report from last year and the paper cited in the results section.

3.2 The combined reconstruction of population structure based on genetic and ecological criteria provide a robust depiction of the present genetic and demographic organization of the species in the Québec/Labrador Peninsula. The overlap of genetic clustering and ecotype designation highlights the importance of differentiating groups defined using genetic criteria from those defined using ecological criteria. In the case of caribou, genetic units should be defined primarily using genetic criteria whereas ecotypes and herds within genetic units should be defined using ecological criteria for management purposes, regardless of genetic relationships. Based on the above considerations, we developed a framework for delineating CUs that is an effective tool to disentangle units based on genetic or ecological criteria. Here we combined neutral markers and ecological criteria (i.e., “ecotype” designations), ignoring, however, the potential genetic basis of ecotype differentiation and the origin of this potentially adaptive phenotypic variation. Identification of loci under ecologically-driven selection, using next generation sequencing for instance, would be the logical next step to provide a more accurate picture of adaptive genetic variation in caribou, especially in cases where individuals with different ecological criteria group together for neutral genetic markers. Finally, the genetic patterns reported here confirm the presence of major discontinuities in the distribution
of caribou, especially across the boreal forest. On this respect, landscape genetics is a promising tool for inferring more precisely how landscape features influence gene flow (Manel et al. 2003).

3.3 Maintaining connectivity among populations within increasingly fragmented landscape is among the most crucial to conservation challenges. When assessing population connectivity, temporal variation in species habitat utilisation is rarely considered, even if behaviour may vary among seasons (Avgar et al. 2013). Here we showed that the genetic distances among caribou herds, which reflect the frequency of genetic exchanges, is best explained by landscape features than simply linear distances, and that this relationship varies within the year. Daily habitat suitability models indicated that characteristics of the landscape separating populations best explain genetic distances during the rutting period, when genetic exchanges are most likely. Our dynamic temporal approach provided new insights on three interrelated components: (1) what habitats caribou are selecting, (2) whether these patterns of habitat selection predict genetic relatedness, and (3) which season is the best predictor of genetic relatedness for males and females. We showed that the relationship between connectivity and genetic distance varied in time and peaked around 300 Julian days, corresponding to the rutting period. Landscape permeability in the period of mate searching is especially important to allow gene flow among populations. Landscape features exist at multiple spatial and temporal scales, and these naturally affect spatial genetic structure and our ability to make inferences about gene flow. We have demonstrated how it is possible to use an extensive data set of ARGOS-telemetry, remote-sensed environmental variables and genetic information to link daily local conditions experienced by individual animals across a vast landscape with genetic relatedness.

In particular, our study highlights the importance of considering temporal variation in individual habitat utilisation for inferring the influence of landscape features on gene flow. Most landscape genetic approaches (but see Shafer et al. 2012) used static animal locations to infer the effect of landscape on gene flow, but we have demonstrated the influence of both daily habitat selection and seasonal behaviour on gene flow. The approach presented here has several potential applications. First, protection of habitat must consider the dynamic use of space by species. As a behaviour-based indicator for habitat preference, our approach might inform the creation of corridors for fauna or the protection of critical habitats that optimize connectivity among populations and counter habitat fragmentation.

**Objective 4. To study the impact of parasites (e.g. Besnoitia, liver flukes) on the ecology of caribou.**

To compare parasite diversity and abundance in caribou from Quebec with those from elsewhere in the Arctic.

4.1 The first part of this objective has been discussed in details in our last report and in the three papers published cited in the results sections.

4.2 Understanding the health and dynamics of wildlife populations can be enhanced by comparative studies across time and across populations and geographic regions. Our comparative approach to investigating parasite diversity and abundance across caribou herds provides first, baseline information on parasite diversity and abundance across herds, and second, novel insight into contemporary and historical factors influencing parasite distribution and transmission dynamics. Preliminary data on abundance and diversity of parasite fauna in 13 caribou herds suggest that for most parasites, their distribution is relatively uniform among all herds and that there is no significant difference in terms of prevalence and intensity between sexes, age classes, and herd size. This is an indication that macro parasites are not central in the dynamics of caribou herds because they do not covary with body condition or population density. Nonetheless, we showed that giant liver flukes (Fascioloides magna) were present only in the two Québec herds, with Rivière-George herd having a higher prevalence than Rivière-aux-Feuilles. We also
found that the prevalence of giant liver flukes in the Rivière-George herd was higher during the population size peak and afterwards than at other times, suggesting the importance of population size in the transmission of these parasites or higher susceptibility to infection when body condition is reduced at high population size. Our research will provide the first comparative survey of Rangifer health across a broad geographic range.

Objective 5. To understand the relationships between the grazing ecology of caribou and short and long term effects of climate change on the summer range of caribou.

5.1 To simulate climate change, many experiments, including ours, used portable greenhouses simulating short-term increases of ground surface temperature and active layer depth (Henry and Molau 1997; Kaarlejärvi et al. 2012). Many of those experiments suggest that simulated warming advances phenological stages (Arft et al. 1999; Aerts et al. 2006). The advance in key phenological stages in birch could influence the quality of this summer forage. We are conducting nitrogen assays to verify this proposition. Because the advance in birch phenology is variable in time, we are currently investigating if the results could be explained by an environmental variable such as humidity or length of the growing season. At this point, we are also investigating the possibility of a lag between years in the response of the birch.

Common responses of short-term increases of ground surface temperature with OTC’s are an increase in biomass (Henry and Molau 1997; Klein et al. 2007). Thus, our results indicating a reduction in both American dwarf birch and Gramineae biomass are unexpected. Because extreme events such as drought may have more impacts on plants than mean climate (Reyer et al. 2013), we think that higher evapotranspiration in open top chambers (OTC) could contribute to this result considering that our study site is relatively dry. We also observed a dramatic response of Gramineae in plots fertilized to simulate long term effects of climate warming. Greater nitrogen assimilation by Gramineae could explain their increased growth under fertilization compared to birch (Köchy and Wilson 2000). Higher Gramineae availability and the compensatory response of birch to moderate browsing pressure (Champagne et al. 2012) could maintain high forage abundance for caribou under current and climate warming.

We also used our simulation experiment to investigate the combined effects of browsing and climate change on the plant communities of the artic tundra. Caribou and warming induced changes in the dominance of specific plants or plant groups but the positive effects of warming and fertilization on the dominance of some species seems to overshoot the disruption of birch dominance imposed by browsing.

5.2 American dwarf birch is expanding in central Nunavik (McManus et al. 2012; Ropars and Boudreau 2012; Tremblay et al. 2012) and could provide an abundant summer resource for caribou. Despite the capacity of birch to compensate for tissues lost to browsing, the availability of birch browse, however, is reduced by browsing of as little as 25% of available shoots. This result is related to the structure of the shrubs since caribou preferentially use longer shoots that are easier to handle for them. This relation between browsing and resource availability could thus temper the positive effects of shrub expansion. This project is completed and a second manuscript will be submitted soon for publication.

5.3 The similar shrub cover between 1972 and 2010 in the Deception River Valley contradicts the increase reported in central Nunavik (McManus et al. 2012; Ropars and Boudreau 2012; Tremblay et al. 2012). Despite the 3C increase in temperature in the nearby village of Salluit during this time period, our results suggest that caribou browsing could have prevented shrub expansion. We cannot exclude that a threshold in temperature has yet to be attained for shrub cover to increase. In contrast to other reports of shrub cover increases, our study is located in the continuous permafrost zone and in the herbaceous tundra, which could explain the differences in the results. Our
study supports the hypothesis that grazing-controlled response to environmental change is a primary driver of shrubs densification, with climate (warming) as a secondary driver (Hofgaard et al. 2010). This herbivore-driven masking of expected climate-driven densification of the shrub layer highlights the necessity to consider changes in caribou population when studying “shrubification”. This project is completed and we have published the results in Polar Biology (Plante et al. 2014).

5.4 Studies conducted at the peak of the Rivière-George caribou herd in the late 1980’s suggested that damage to the habitat from heavy browsing is a factor influencing the initial phase of population decline in caribou (Messier 1991; Crête and Huot 1993). We also know that the suppression of erect shrubs can persist over many years (Crête and Doucet 1998). The planned unfencing experiment on willows will allow us to understand the recovery dynamics of preferred erect shrub species. Erect shrubs such as willows are key components of the tundra ecosystem contributing to the structure of the habitat and providing cover and food for different animal species.

5.5 The apparently high use of dwarf birch by migratory caribou in northern Quebec (Crête et al. 1990; Manseau 1996) compared to the rest of the Arctic is intriguing. This observation could either be related to overgrazing of the range and use of a poor resource (birch) or to regional variation in plant defense and composition (Bryant et al. 2013). This project is a large collaborative work involving 25 sites throughout the Arctic to study the chemical and functional characteristics of B. glandulosa and to relate them to soil characteristics to explain their use and non-use by caribou. The analyses are now completed and a manuscript will be produced in 2014-15.

Objective 6. To study the impact of predation by wolves and black bears on the population dynamics of caribou by initiating a large-scale monitoring program of predators using satellite collars.

Unexpectedly, we found that almost all satellite-tagged wolves were migratory, leaving the winter range just before the caribou and ‘waiting’ for them near calving grounds, and returning to the winter range in the fall approximately at the same time as caribou. We are continuing our program on wolves with new captures planned for March and June 2014. In addition to space use and migration, we will address wolf-caribou and black-bear caribou interactions spatially. The schedule of locations will allow the identification of kill sites of wolves to calculate predation rates (Webb et al. 2008). Because we will have spatial data on both predators and caribou, we will produce Resource Selection Function maps of predation risk and relate them to the spatial behavior and habitat use of caribou (Metz et al. 2012). We will also determine the contribution of caribou to the diets of wolves and black bears using analyses of faeces, stomach contents, stable isotopes, and DNA barcoding. We plan to compare life-history traits of predators that have access to caribou or not. Finally, our data will allow us to determine the impact of predation on the population dynamics of both caribou herds.

Conclusion

Recent declines in the number of migratory caribou in Northern Quebec and Labrador could have negative social and economical implications, particularly for northern arctic and subarctic native cultures that rely on caribou for subsistence as well as for the outfitting industry. Changes in the distribution of caribou, as well as decreases in abundance, are expected to continue in the near future. We anticipate that the negative effects of changes in the distribution of animals and reduced abundance of caribou will be higher than the anticipated positive effects of an earlier and longer period of vegetation growth with climate change.
Recent data suggest that caribou abundance and distribution will change in the near future and it has already started. Our recent work on the large variation in the size and distribution of calving grounds of both herds (Taillon et al. 2012), and on the large changes in migration routes as well as winter ranges, are good examples of changes to come. Managers, stakeholders and communities should be prepared for a lower abundance of animals and a less predictable distribution, further away from communities. Future research will continue to address the factors explaining variations in the population dynamics of caribou, including consequences for survival and reproduction, impacts of climate, predators and gene flow between herds, as well as the response of caribou habitat to different climate change scenarios. Management efforts focusing on preserving high quality habitat, limiting anthropogenic landscape disturbances, mitigating greenhouse gases to reduce the potential effects of climate change, and managing hunting in a sustainable manner could alleviate stressors on migratory caribou in the Québec-Labrador peninsula.

Acknowledgements

Part of this research project is funded by a Collaborative Research and Development (CRD) grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) in collaboration with Hydro-Québec, Xstrata Nickel - Mine Raglan, Makivik Corporation, First Air and the Quebec Outfitters Federation. The Ministère du Développement durable, de l’Environnement, de la Faune et des Parcs du Québec (formerly the Ministère des Ressources naturelles et de la Faune) is also an important partner providing financial and technical resources. The Government of Newfoundland and Labrador also provide technical resources and expertise for the work on the Rivière-George herd. We thank many other partners for their financial or logistic support: ArcticNet, Centre d’études nordiques, International Polar Year, Ouranos, Fédération québécoise des chasseurs et pêcheurs, Fondation de la Faune du Québec, Canada Foundation for Innovation, Institute for Environmental Monitoring and Research, Indian and Northern Affairs - Northern Scientific Training Program, the CircumArctic Rangifer Monitoring and Assessment Network, the Canadian Wildlife Federation, Safari Club International, Azimut Exploration, Conférence des élus de la Baie-James and Fonds vert du Gouvernement du Québec.

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