Biological status report of migratory caribou, Leaf River herd

ENSEMBLE on fait avancer le Québec

Québec

WORKING TEAM

Authors :

Joëlle Taillon
Direction de l'expertise sur la faune terrestre, l'herpétofaune et l'avifaune

Vincent Brodeur
Stéphane Rivard
Direction de la gestion de la faune du Nord-du-Québec

Reference to cite :

TAILLON, Joëlle, Vincent BRODEUR & Stéphane RIVARD. 2016. *Biological status of migratory caribou, Leaf River herd*, ministère des Forêts, de la Faune et des Parcs, Québec, 67 p.

The full version of this document is available on the website
mffp.gouv.qc.ca

Ministère des Forêts, de la Faune et des Parcs
Legal deposit - Bibliothèque et Archives nationales du Québec, 2016
ISBN (printed version) : 978-2-550-75731-3
ISBN (PDF) : 978-2-550-75732-0

Acknowledgements

We would like to thank Denis Vandal, former director of the Direction de la gestion de la faune du Nord-du-Québec, Serge Couturier, wildlife biologist, and their predecessors, colleagues and collaborators who participated in establishing the foundations of scientific knowledge on Québec migratory caribou. More recently, the Caribou Ungava team has made a considerable contribution to biological monitoring of migratory caribou in Québec-Labrador. The data required to ensure current monitoring of the Leaf River herd could not have been acquired without the appreciable efforts of Charles Jutras, Lyna Lambert and Pascal Ouellet, wildlife technicians in the Direction de la gestion de la faune du Nord-du-Québec, and Dominic Grenier, wildlife technician in the Direction de l'expertise sur la faune terrestre, l'herpétofaune et l'avifaune (DEFTHA). We would also like to thank Julien Mainguy, wildlife biologist, for his comments on the preliminary version of the report and Christian Dussault, a biologist in the DEFTHA, for his valuable advice. The Québec government has been largely responsible for long-term monitoring of the Leaf River herd, for a long time under the direction of Denis Vandal, and has benefited from financial support from several partners, including Hydro-Québec and Makivik Corporation. Since 2009, government and university research initiatives have converged in the establishment of the Caribou Ungava research group, which is supported by numerous partners (http://www.caribou-ungava.ulaval.ca/). Lastly, our thanks to Annie Cauchon, administrative assistant in the DEFTHA, who revised the final version of the document.

Abstract

In the Nord-du-Québec region and Labrador, the George River (GRH) and Leaf River (LRH) migratory caribou herds occupy a vast territory of several hundred thousand square kilometres located mainly north of the 53rd parallel. The LRH occupies the northwestern portion of the Nord-du-Québec region and its annual distribution area has been completely separate from that of the George River herd since 2008. Through the herd monitoring program and research conducted by the MFFP in collaboration with the academic community (Caribou Ungava research program), it is possible to obtain a detailed picture of the ecology, demographics and historic and current situation of migratory caribou in the LRH.

Scientific work on the LRH began in June 1975. Since then, six aerial surveys have been conducted to describe changes in the size of the herd and several demographic indicators such as survival, productivity, recruitment and body condition, have been compiled through the herd monitoring program. The data indicate that the size of the LRH increased until 2001, then subsequently declined. The most recent aerial survey (2011) estimated the population at around 430 000. Demographic indicators show that the population was fairly stable between 2008 and 2013 but that it appears to have declined since the fall of 2013. In the fall of 2015, the population was estimated at around 332 000 caribou. The changes observed in the size of the annual distribution area and seasonal areas used by the LRH tally with past and recent fluctuations in the population size (increasing and declining phases and recently observed stability).

The full biological data set collected since 1975 makes it possible to refine the interpretation of changes in herd size and trends in the LRH. Moreover, limiting factors and threats are known and must be considered to grasp the state of the herd. The factors and threats can act in synergy and have a direct impact (disturbance, mortality) or indirect impact (effect on spatial distribution and availability of vegetation) that vary according to herd size and trends of the populations. Recent documentary analysis has clearly revealed that the main threats to the long-term survival of migratory caribou populations are overexploitation through hunting and poaching, the expansion of occupation of the territory and the attendant industrial activities, as well as climate change.

This document compiles the biological knowledge available to assess the current state of the LRH and describes the limiting factors and main threats that may explain its demographic variations. The *Biological status of migratory caribou, Leaf River herd* is thus meant to be a factual guide to the management and conservation of this northern wildlife population.

Table of contents

List of tables

List of figures

List of appendices

1. The Leaf River migratory caribou herd

1.1 Identification of ecotypes and caribou herds

The North American caribou and the Eurasian reindeer belong to the same species (*Rangifer tarandus*). In North America, the classification of caribou into sub-groups and sub-species (Banfield, 1961) is not unanimously accepted and is subject to changes based on recent discoveries (Bergerud et al., 2008; Festa-Bianchet et al., 2011). The majority of biologists use the concept of ecotype to distinguish between caribou populations[1]. An ecotype is assigned to a herd or a population of caribou that presents characteristics, ecological preferences and particular types of behaviours that enable differentiation from other ecotypes of caribou. Identification of ecotypes requires the use of genetic data as well as the consideration of morphological and behavioural adaptations of individuals. There are four main ecotypes of caribou in North America: the Peary caribou in the Canadian Arctic archipelago, the woodland caribou, the mountain caribou and the migratory caribou (Festa-Bianchet et al., 2011). The woodland, mountain and migratory ecotypes are all found in Québec. The distinction among caribou ecotypes is essential in managing populations based on their particular characteristics.

1.2 Ecotypes

Mountain caribou

The mountain caribou ecotype is considered sedentary, lives in small groups and undertakes short altitudinal migrations in alpine environments (Gaspésie Woodland Caribou Recovery Team, 2011; Environment Canada, 2012a). The females of the mountain ecotype disperse and isolate themselves from the herd to give birth. There are two known herds[2] of mountain caribou in Québec: the Atlantic-Gaspésie herd and the Torngat Mountains herd. The Gaspésie herd is the only persistent caribou population south of the St. Lawrence River and can mainly be found within the boundaries of the Gaspésie National Park. This herd is protected by the federal *Species at Risk Act* (SARA; SC 2002, chapter 29) and mentioned in Schedule 1 of the *Act* as an “endangered species”. In Québec, the mountain caribou of Gaspésie has been designated as “threatened” by the *Act respecting threatened or vulnerable species* (ARTVS; CQLR, chapter E-12.01) since October 2009 and is the subject of a provincial recovery plan (*Plan de rétablissement du caribou de la Gaspésie*, 2011). The provincial plan is, in fact, the federal recovery plan (Woodland Caribou Recovery Plan) of this population (COSEWIC, 2002). The Torngat Mountains herd is found in the northern part of the Québec-Labrador peninsula (Torngat Mountains range). Its distribution area is shared between Québec (Nunavik) and Nunatsiavut (autonomous territory managed by the Nunatsiavut Government representing Northern Labrador Inuit). In Québec, this herd will be the subject of a management plan separate from the one for migratory caribou herds.

---

[1] A population is defined as a group of individuals of the same species that usually reproduce among themselves and that occupy the same environment at a given time. Emigration and immigration phenomena can occur with neighbouring populations, but these exchanges remain limited. An animal population is a relatively closed unit.

[2] The notion of herd is generally used to designate distinct caribou populations in the mountain and migratory caribou ecotypes.

Woodland caribou

The woodland caribou ecotype is considered sedentary, extends over an annual home range of approximately 1,000 km^2, and moves seasonally within the boreal forest (Bastille-Rousseau et al., 2012; *Équipe de rétablissement du caribou forestier du Québec,* 2013). The females of this ecotype disperse to give birth alone. Most woodland caribou populations are considered in decline throughout their North American distribution area (Environment Canada, 2012b). Woodland caribou populations have benefited from legal protection status under SARA since 2000 and are identified in Schedule 1 of this federal act as a “threatened species”. Woodland caribou also benefit from a federal recovery program (Environment Canada, 2012b). In Québec, the woodland caribou has been designated as a “vulnerable species” since March 2005 under the ARTVS and is subject to a provincial recovery program (*Équipe de rétablissement du caribou forestier du Québec*, 2013).

Since the end of the 19th century, the southern limit of the woodland ecotype distribution area has moved northwards due to habitat loss and fragmentation, and hunting pressure which is currently limited. In Québec in 2013, there were about 6,740 woodland caribou (between 5,980 and 8,570 individuals) divided into a number of herds that range over 644,000 km^2 between the 49th and 55th parallels (*Équipe de rétablissement du caribou forestier du Québec*, 2013; Figure 1). For a detailed description of woodland caribou herds, see Bastille-Rousseau et al. (2012) and the *Équipe de rétablissement du caribou forestier du Québec* (2013). These herds generally have a low recruitment rate and their habitats are subject to high levels of anthropogenic disturbance, mainly related to forestry operations. The *Plan de rétablissement du caribou forestier du Québec 2013-2023* points out the lack of knowledge about the status of populations north of the 52nd parallel, which is the northern boundary of commercial forestry. These woodland caribou are likely to share their habitat with the migratory caribou ecotype during the winter.

Sport hunting for woodland caribou has been prohibited in Québec since 2001. However, it is difficult and sometimes impossible to differentiate woodland and migratory caribou ecotypes in the field based only on their physical appearance. It is therefore possible for hunters to take woodland caribou in hunting zones 22A and 22B where migratory caribou sport hunting is authorized. Currently, part of the harvest by Aboriginal peoples for food purposes most likely includes this ecotype, but the number of harvested caribou by ecotype is unknown.

Migratory caribou

The migratory caribou ecotype[3] lives in herds of several hundreds or thousands of individuals and migrates seasonally over hundreds of kilometres between the boreal forest and the tundra (Miller, 2003; Festa-Bianchet et al., 2011). This ecotype is characterized by the use of traditional calving grounds where females aggregate to give birth (Bergerud et al., 2008; Gunn et al., 2011). The name assigned to a herd typically refers to the geographic location of its calving ground when first documented by non-Aboriginals (usually the name of a river or lake).

---

[3] The migratory ecotype can also be called the tundra ecotype. However, “migratory” was preferred by the authors and is used throughout this report.

There are 23 circumpolar migratory caribou (North America) and migratory reindeer (Eurasia) herds (Gunn et al., 2011; CARMA, 2013). Within North America, the migratory ecotype can be found from Alaska to Labrador, as well as on Baffin Island, Southampton and Coats islands at the mouth of Hudson Bay. These herds have shown major demographic annual fluctuations in their numbers over the last decades and currently represent more than four million animals (Gunn et al., 2011). However, most of these migratory herds have declined in number in recent decades (Vors and Boyce, 2009; Festa-Bianchet et al., 2011; Gunn et al., 2011; CARMA, 2013). Since the winter of 2015, COSEWIC has been reviewing the status of various populations of migratory caribou in Canada (COSEWIC, 2011).

In northern Québec and Labrador, the George River (GRH) and Leaf River (LRH) migratory caribou herds range over several thousand square kilometres, mainly North of the 53rd parallel; in winter, the range can extend to the 51st parallel (Boulet et al., 2007; Figure 1). The GRH distribution area in shared among Québec, Labrador and Nunatsiavut. This herd will be managed independently of the LRH and its plan will take intergovernmental considerations into account. The LRH uses the north-western part of northern Québec. The population monitoring program and studies based on academic partnerships (the Caribou Ungava research program) have enabled us to obtain a detailed portrait of the ecology, demography and current status of the LRH.

Genetic differentiation of three ecotypes

The recent work of the Caribou Ungava research group (G. Yannic, pers. comm.; Yannic et al., 2015) combined with the studies of Courtois et al. (2002) and of Boulet et al. (2007) suggest a genetic differentiation among the Québec caribou populations. Three main evolutionary sub-units have been identified, each of which forms a metapopulation or group of local populations that are linked together by individuals that disperse and exchange genes (gene flow), although at levels that are often low, thus maintaining a certain degree of genetic homogeneity within this metapopulation. The first sub-unit (metapopulation) in Québec is composed of woodland caribou populations located from the west of Romaine River to the east of Abitibi. The second sub-unit is composed of woodland caribou herds in the area known as Jamésie. A third sub-unit is formed by the LRH and GRH, including the Torngat Mountains herd. There are genetic exchanges between this sub-unit and the Labrador woodland caribou herds (Lake Joseph, Mealy Mountains and Red Wine Mountains herds). Some genetic exchange exists among the three sub-units, whose ranges partially overlap. This is particularly true for the Jamésie and LR herds. South of the St. Lawrence River, the Gaspésie Mountain herd can be distinguished from the three sub-units by its low genetic diversity. Individuals within these sub-units are considered to be genetically similar and cannot be differentiated into sub-species (G. Yannic, pers. comm.; Yannic et al., 2015). To obtain the detailed information on the distribution of these herds, refer to Figure 1 and the following references: Couturier et coll. (2010), Bastille-Rousseau et coll. (2012), *Équipe de rétablissement du caribou forestier du Québec* (2013).

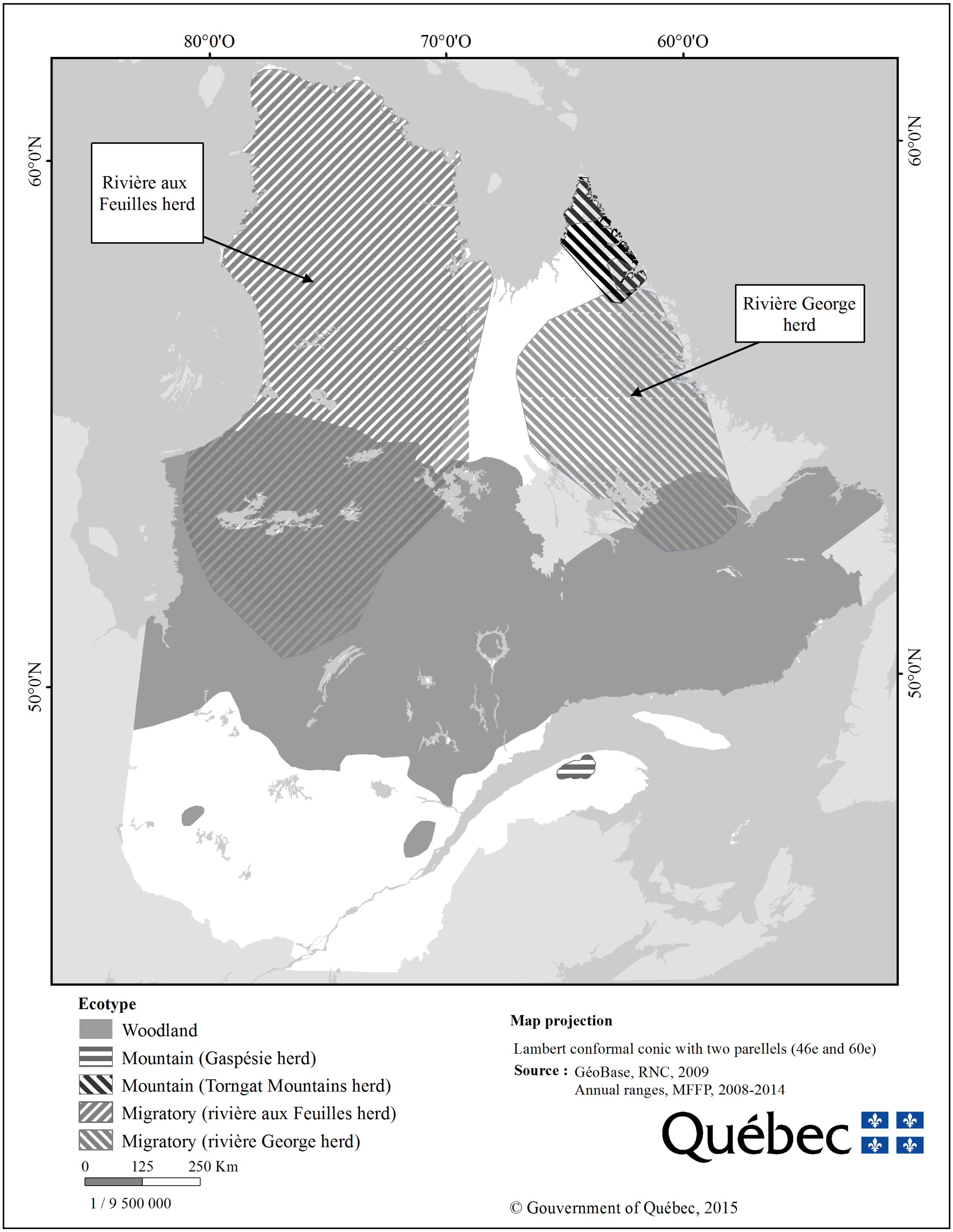


Figure 1 Distribution of ecotypes and caribou herds in Québec and in Newfoundland and Labrador.

2. Biological situation of the Leaf River herd

The long-term monitoring of the LRH was mainly led by the the Government of Québec and has benefited from funding from several partners, including Hydro-Québec and the Makivik Corporation. Since 2009, research efforts from governments and academics have converged via the establishment of the Caribou Ungava research group, which has support from numerous partners (http://www.caribou-ungava.ulaval.ca/en/accueil/).

Table 1 Summary of biological indicators collected through the long-term monitoring program of the Leaf River herd.

Biological indicator	Methodology	Available years
Estimate of population size	Aerial census Population size model	1975, 1983, 1986, 1991, 2001, 2011 Used since 2014 – track back population from 2011 to now
Survival rate	Telemetry monitoring Estimate of survival rate	Annually since 1994*
Population structure and recruitment	Fall classification	Annually since 1994
Body condition, diseases and parasites	Calf birth mass Calf fall body mass Female fall body mass Exhaustive monitoring of body condition and parasite load	Annually since 1991 1995-2002 and 2007-2009 and 2013 2000-2001 and 2007-2009 and 2013 2007-2009 and 2013
Productivity	Pregnancy rate	2001 and 2002 2011-2012
Annual and seasonal ranges and migration corridors	Telemetry monitoring Delineation of annual and seasonal ranges and migration corridors	Annually since 1994
Monitoring of caribou predators	Telemetry monitoring (grey wolf and black bear)	Annually since 2011

* No classification conducted in 1999.

2.1 Historical and current population fluctuations

Scientific studies of the LRH began in June 1975 when a group of approximately 20,000 females was observed near Leaf River (58°25'N; 73°25'W) (Le Hénaff, 1976). Since then, six aerial inventories have been conducted to describe the evolution of the size of this herd (Table 2; Figure 2). The census methods used since the 1980s generate a confidence interval that is expressed as a percentage of the estimated size. A confidence interval is higher when the estimated size of a herd is imprecise[4], which is generally related to difficult conditions encountered during the census, as was the case for the LRH in 1983, 1986 and 2001.

Table 2 History of the monitoring of the Leaf River herd population size.

Year	Methodology	Estimate	Confidence interval	Reference
1975	Calving ground count	56,000	-	Le Hénaff, 1976
1983	Calving ground census	101,000	42 %	Le Hénaff, 1983; Couturier et al., 2004
1986	Calving ground census	121,000	46 %	Crête et al., 1987; Couturier et al., 2004
1991	Calving ground census	276,000	27 %	Couturier, 1994; Couturier et al., 2004
2001	Post-calving census	1,193,000[a]	47 %	Couturier et al., 2004
2001	Post-calving census	628,000a	-	Lower limit of the confidence interval
2011	Pre-migratory (spring) and post-calving combined census	430,000	23 %	Government of Québec

[a] In the Caribou Management Plan 2004-2010 (Jean and Lamontagne, 2004), the lower limit of the confidence interval (628,000 caribou) from the 2001 census was used to describe the LRH population size. This precautionary measure was adopted because the high confidence interval suggested that the average value of the estimate was probably unreliable.

The methodology developed and used to evaluate the size of the majority of caribou herds in North America consists of an aerial census undertaken during early summer aggregations of individuals (post-calving census; Valkenberg et al., 1985; Rivest et al., 1998; Rettie, 2008; Adamzewski et al., 2009; Nagy, 2009). During the first weeks of July, caribou of all ages, males and females, gather in large groups. These aggregations coincide with the massive emergence of biting and parasitic insects that harass the caribou. Herding reduces the harassment through saturation and dilution effects (Bergerud et al., 2008)[5]. An aerial census consists in locating groups of caribou that contain at least one radio-collared individual and taking aerial photographs of these groups. The number of caribou in each photograph is then precisely counted. The size of the herd is evaluated using the capture-mark-

---

[4] A representative estimate of population size is ideally within a targeted confidence interval of less than ± 20%.

[5] The saturation or satiety effect occurs when an insect or a predator has attacked or fed on a number of prey that satisfy its need, no longer requiring to attack or take other preys. The dilution effect refers to the fact that each potential prey is "diluted" in the mass of all available prey. As a result, the possibility of being targeted by an insect, a parasite or a predator is reduced.

recapture (CMR) method that takes account of 1) the number of caribou counted in each group; 2) the number of radio-collared caribou in the photographed groups; and 3) the number of radio-collared caribou in the population being estimated (Rivest et al., 1998). The sampling method aims to cover most of the territory used by radio-collared caribou and to photograph most groups in which a collared animal is located. This census methodology is dependent on climate conditions and more particularly on biting and parasitic insect breakout, which triggers the gathering of the caribou. When caribou are widely scattered, aerial photography is laborious, the notion of group is inapplicable, and the use of the CMR methodology is no longer appropriate.

According to census results, the size of the LRH increased between 1975 and the early 2000s (Figure 2, Table 2). It is essential to explain that the 2001 census is considered imprecise due to technical and logistical problems in the field that led to the calculation of a high confidence interval associated with the estimated size (Table 2; Couturier et al., 2004). As precautionary measure, the lower limit of the confidence interval of the 2001 census (628,000 caribou) was used as a reference point in the previous LRH management plan (Jean and Lamontagne, 2004).

The most recent estimate of the size of the LRH population was made in 2011 and was based on the combination of two aerial surveys. The first census was conducted during the spring aggregation of individuals preparing for the spring migration (from April 30 to May 5, 2011). This census enabled us to take aerial photographs of groups in the open habitat of the taïga near Lac à l’Eau Claire (56°N, 75°W). The census followed the methodology used for post-calving census and made it possible to count 38 groups of caribou which included 60 individuals fitted with radio collars out of a possible total of 88 active collars (68%). This census evaluated the population at 392,000 ± 28%. The second census took place during the post-calving aggregation (from July 31 to August 2, 2011) and allowed us to count 26 groups of caribou which included 51 collared individuals out of a possible 106 active collars (48%). This census evaluated the population at 599,000 ± 38%. By combining the two aerial surveys using statistical methods (Gasaway et al., 1986), the size of the LRH population was estimated at 430,000 ± 23% in 2011.

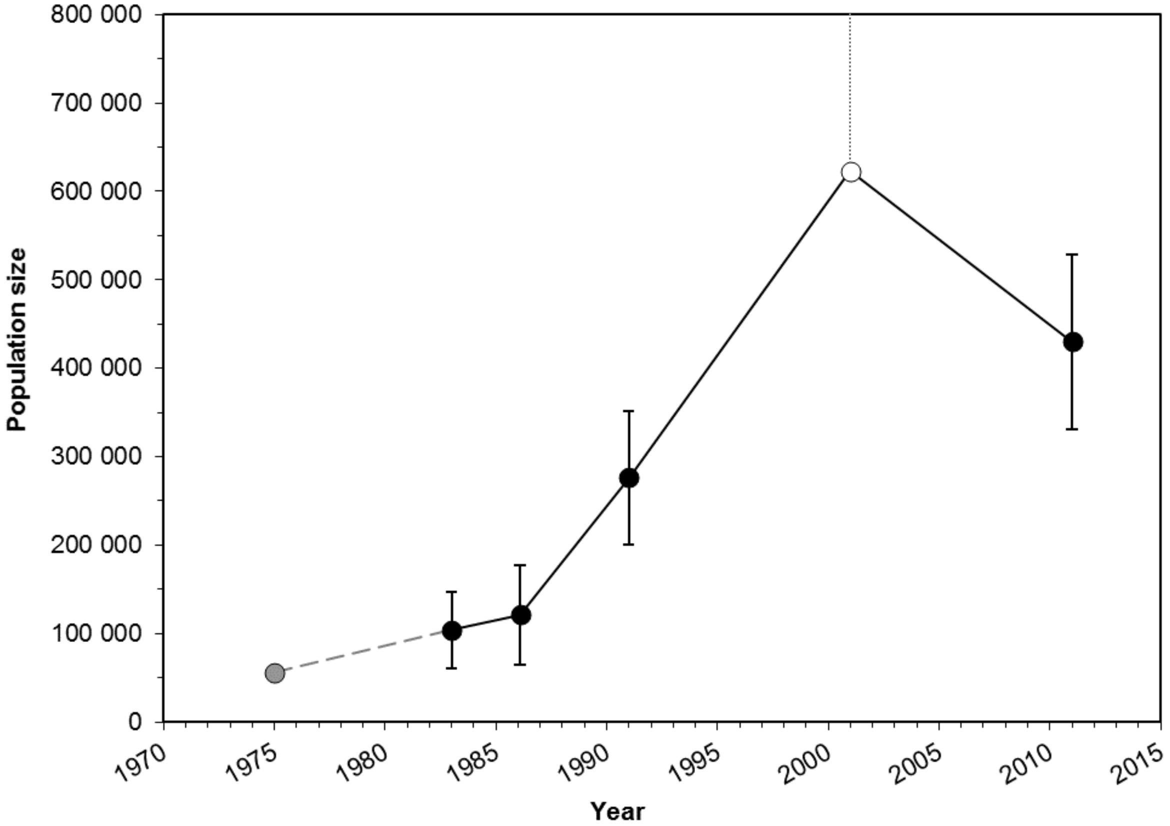


Figure 2 The size of the Leaf River herd was evaluated from aerial surveys between 1975 and 2011. The 1975 estimate (pale grey circle and dotted line) represents a minimal count of the LRH (without error estimates). For 2001 (empty circle and dotted line), the lower limit of the confidence interval (628,000 caribou) was used to describe the size of the LRH.

Based on the result of an aerial census, it is possible to follow the evolution of the population size by using annual survival and recruitment data. The analysis of the demography of the LRH based on results from a population census carried out since 1991, survival rates of radio-collared individuals, annual recruitment and harvesting monitoring has allowed us to obtain an approximate reconstruction of the population that complements the estimated size of the herd from the 2001 census (A. Rasiulis, M. Festa-Bianchet and S. D. Côté, pers. comm.). The preliminary results of these analyses suggest that the population size in 2001 was more comparable to the lower limit of the confidence interval of the aerial census (628,000 caribou) than to the average estimated size. This supports the use of the lower limit of the confidence interval of the 2001 census as a reference point for the 2004-2010 management plan.

The combined use of census results and annual demographic data allows us to assess the demographic trend of the herd (growth, decline or stability) during the interval between the 2001 and 2011 aerial census. These data demonstrate a decline in population size since 2001, a trend supported by the 2011 census (Figure 2). According to the observations of Aboriginal users, especially Inuit and Cree hunters, the LRH has decreased in population size since 2011. Demographic data (survival and recruitment) and use of space, however, indicate that the size of the LRH was most likely stable between 2008 and 2013. The biological interpretation of data must however consider the uncertainty associated with the biological indicators of the LRH (Table 1). Thus, although demographic stability remains the most likely demographic scenario for 2008 to 2013, the probability that the LRH has slightly increased or decreased in population size should still be considered. The most recent recruitment and adult survival data (see sections 2.2 and 2.4), however, indicate a significant demographic decline of the herd between 2013 and 2014, and that a more moderate decline has continued in 2014-2015. In the fall of 2015, the population was estimated at around 332,000 caribou, a decline of about 6.5% compared to the fall of 2014.

Telemetry monitoring

Telemetry monitoring of the LRH began in 1994 and continued with the annual collaring of adult males and females, and since 2006, of female yearlings (Table 3). The annual collaring of female yearlings allows us to assess their age-based survival and reproductive success

All collars in current use are equipped with Globalstar, Iridium or Argos (CLS, 2011) transmitters that allow us to locate the beacon or the transmission of locations on a regular basis through a satellite link. More recently, collars using GPS (Global Positioning System) technology have been used to improve the frequency and precision of individuals monitoring. Advances in technology over the years has allowed us to 1) reduce the size and weight of collars[6], 2) extend the useful life (number of years of use) of collars and 3) increase the number of locations and their precision. The collars in current use have a useful life of more than four years, weigh less than one kilogram and generate a variable number of programming-based locations.

The ultimate goal of the telemetry monitoring is to provide population-representative behavioural and demographic information. To do this, several individuals of both sexes must be collared (Table 3) and captures must be realized over the entire range of the herd to ensure that the telemetry monitoring represents the entire population. Achieving and maintaining this objective requires regular capture efforts in order to maintain a representative sample of the population.

Telemetry monitoring is a key tool that can improve our knowledge of the ecology of the migratory caribou and is essential to the management of the LRH as it allows us 1) to identify individuals during aerial surveys; 2) to perform the statistical analysis leading to the evaluation of population size; 3) to estimate the survival rate of different segments of the population; 4) to delineate the annual and seasonal ranges; 5) to identify the annual migratory corridors; and 6) to plan the annual monitoring of biological indicators.Le suivi télémétrique du TRAF a débuté en 1994 et s'est poursuivi par le marquage annuel de femelles et de mâles adultes et, depuis 2006, de femelles d'un an (tableau 3). Le marquage annuel de femelles d'un an permet d'évaluer la survie et le succès reproducteur de ces femelles en fonction de leur âge.

---

[6] The weight of collars has decreased from 1.6 kg in the early 1990s to about 0.8 kg since 2004 and 0.5 kg since 2013.

Table 3 Number of LRH caribou fitted with a radio-collar, by sex and age-class, from 1991 to 2015.

Year	Number of active collars			Total
	Females (>1.5 yrs.)	Males (>1.5 yrs.)	Female yearlings	
1991	2	0	-	2
1992	0	0	-	0
1993	6	1	-	7
1994	13	0	-	13
1995	15	2	-	17
1996	15	2	-	17
1997	15	2	-	17
1998	14	3	-	17
1999	14	3	-	17
2000	14	5	-	19
2001	16	4	-	20
2002	14	4	-	18
2003	17	2	-	19
2004	22	1	-	23
2005	25	0	-	25
2006	20	9	2	31
2007	27	22	12	61
2008	36	41	11	88
2009	58	38	12	108
2010	61	30	11	102
2011	68	20	18	106
2012	70	13	15	98
2013	81	23	27	131
2014	96	47	11	154
2015	78	36	0	114

2.2 Survival rate and causes of mortality

Survival rate

The estimation of the survival rate of individuals, and more particularly of adult females, is a key element in the monitoring of caribou populations. In large ungulates, adult female survival is known to show low annual variability but high elasticity, which means that a small change in survival rates can have a major impact on population dynamics (Gaillard et al., 2000). In comparison, juvenile survival is usually less elastic but more variable in time (Gaillard et al., 2000). The survival rate is currently estimated from the population trend between two consecutive censuses and from telemetry monitoring. A population of migratory caribou is predicted to remain stable or increase when adult female survival is

≥ 85%, adult male survival is ≥ 80% (Gaillard and Yoccoz, 2003; Adamczewski et al., 2009; Boulanger et al., 2011) and if combined with sufficient recruitment rates (see section 2.3).

An exhaustive analysis of annual and seasonal survival rates of LRH adults is currently being conducted (MFFP, in preparation). This analysis, based on radio-collared individuals, suggests that from 2008 to 2012, the annual survival rate was estimated at 87% for adult females (> 1.5 years old) and 78% for adult males (> 1.5 years old). The annual survival rate of adult females remained at values associated with a population showing stability or slight growth (see previous paragraph) in 2011-2012[7] (88%) and 2012-2013 (86%), while for adult males, it was 85% in 2011-2012 and in 2012-2013. However, survival rates of adult females (78%) and adult males (70%) decreased in 2013-2014. In 2014-2015, survival rates of adult females improved (83.5%) compared to the previous year, while survival rates of adult males remained low (66%).

The adult survival rates observed between 2008 and 2012 for the LRH are considered favourable to the demographic stability of a migratory caribou herd in a context where recruitment (see section 2.4) also remains at a level that could allow population stability. However, the low survival rates of adult females and adult males in 2013-2014, combined with the low recruitment recorded in fall 2014 (see section 2.4), suggest a demographic decline of the LRH in 2013-2014. Despite the improvement of adult female survival rates and recruitment in 2015 (see section 2.4), the demographic decline of the herd has continued in 2014-2015, mainly explained by the low survival rates of adult males. The interpretation of survival and recruitment data, however, must consider other biological data available (e.g., space use and body condition) to complete the demographic portrait of the LRH.

Causes of mortality

Identifying the causes of mortality with precision is a complex task, as carcasses are difficult to access and quickly become exposed to predators, scavengers, carrion insects and inclement weather. The possible causes of mortality include: 1) natural mortality (including accidents, starvation or senescence), 2) diseases and parasites, 3) predation, 4) harvest by hunting, 5) injuries caused by hunting and 6) poaching. Some factors have a direct effect (e.g., predation), while others (e.g., harsh weather conditions, parasites) contribute to the deterioration of the body condition, making individuals more vulnerable to direct causes of mortality. The current methodology does not allow us to estimate the contribution of each cause of mortality to the survival rate of LRH individuals. Monitoring of the harvest by sport hunting combined with more detailed information from harvest for food purposes by Aboriginal communities could allow us to identify more precisely the number of animals harvested and their contribution to this source of mortality.

Predation

Predation is part of the natural ecology of the caribou. Typically, predators take animals that are sick or in poor body condition, as well as young animals that are often slower and less agile than adults (Seip, 1991). The effect of predation on the population dynamics of migratory caribou herds is complex and little studied to date (Seip, 1991; Wang et al., 2009). Predation could significantly influence caribou

---

[7] The annual survival rate of individuals is measured on a one-year basis beginning in November of the current year (e.g., 2011) and ending in October of the following year (e.g., 2012).

population dynamics (Bergerud et al., 2008), especially when a population is low in numbers or in decline (Wittmer et al., 2005).

The main predators of the LRH migratory caribou are the grey wolf (*Canis lupus*) and black bear (*Ursus americanus*) (Crête et al., 1990; Miller, 2003). Knowledge on predator populations and their behaviour in northern Québec is currently limited. From 2011 to spring 2015, 22 wolves and 8 black bears were been fitted with satellite collars in the Ungava Peninsula near the calving ground and autumn migratory route of the LRH (MFFP and Caribou Ungava, unpublished data). Preliminary data suggest that the Ungava Peninsula is host to a resident black bear population (location of den sites in the tundra). This population is apparently growing, as supported by recent and more frequent observations of black bears close to Native communities. Since 2010, many Cree hunters have also noticed an increase in wolf observations in the James Bay sector. The telemetry monitoring of wolves captured within the annual range of the LRH demonstrates the great mobility of this predator. Preliminary data suggest that some wolves follow or move according to the seasonal distribution of caribou (MFFP and Caribou Ungava, unpublished data).

Ultimately, the predation rate by wolf and by black bear could be estimated in order to quantify the influence of this source of mortality on the survival rates of the different age and sex classes of caribou. Studying the relationship between the migratory caribou and its predators is essential to better interpret the variations in population size and to guide management of the caribou populations.

2.3 Productivity

In migratory caribou populations, more than 85% of sexually mature females are typically pregnant in the winter (Parker, 1980; Cameron et al., 1993; Bergerud et al., 2008). Younger females (less than 3 years old) generally have a lower and more variable annual rate of pregnancy (between 15 and 75%; Parker, 1980; Messier et al., 1988) than older ones (3 years old and over). The probability of gestation of a female increases with body mass and percentage of body fat (Pachkowski, 2012). The probability of pregnancy is estimated from blood samples (PSPB: Pregnancy-Specific Protein B), echographies performed during captures, females killed during hunting (presence/absence of foetus), or feces collected in the winter and analyzed for hormone content (progesterone; Morden et al., 2011). Some of these analyses must be treated with caution (e.g., random sampling of feces) as they do not allow us to exclude females that are not yet breeding (e.g., yearling females) or females that present a lower and more variable annual rate of pregnancy (less than 3 years old). Very few data are available to document the annual variations in pregnancy rates in the LRH. In 2001-2002, only 22 females were sampled, allowing to estimate a pregnancy rate of 52% (Couturier et al., 2009b). This pregnancy rate was calculated when the population was at its demographic peak. The pregnancy rate was then estimated at around 89%[8] (n = 45 females) in the winter of 2010-2011, 74%[9] in the winter of 2011-2012 (n = 61 females) and 67%[10] in 2012-2013 (n = 95 females). The low sample size and the potential bias related to the different sample sources suggest that the data should be used with caution, but it does

---

[8] Sampling of females harvested during winter hunting season (presence/absence of foetus).

[9] Combined samples of females harvested during winter hunting season (presence/absence of foetus; n = 42, gestation rate = 69%) and of analyses of blood samples (PSPB: n = 19, gestation rate = 84%).

[10] Sampling and analyses of feces.

indicate that the pregnancy rate of LRH females was probably lower than expected for the period from 2010-2012.

2.4 Population structure and recruitment

Population structure

The evaluation of the population structure is essential in monitoring the demography of caribou herds. It allows us to determine the proportion of adult females and males in the herd and to estimate the recruitment (number of calves) in the population each fall. This information is essential in monitoring and analyzing annual changes in population size.

The population structure of the LRH has been evaluated annually since 1994 (excluding 1999; Table 4). The classification occurs at the end of October, when individuals of all ages and sexes gather during the autumn migration, which also coincides with the rutting period (Messier and Huot, 1985; Boulet et al., 2007). The classification consists of a census of several thousand individuals (annual average (± SE): 2,658 ± 250 caribou) divided into groups of several hundred individuals. The distribution of sampling stations allows us to consider the heterogenous composition of the groups. Within the groups, individuals are assigned to a category: females with antlers (≥ 1.5 years-old), females without antlers (1.5 years-old), and calves and adult males (≥ 1.5 years-old). Adult males are classified into four categories (senile, large, medium and small) based on their body size, the presence of secondary sexual attributes (e.g., large neck, barb) and the size of antlers. Large males are characterized by a large body mass and size, the presence of distinctive reproductive attributes and impressive antlers. They are the most active males during the reproductive seasons and inseminate the majority of females (Røed et al., 2002). Medium and small males are still growing, but may also reproduce with females, especially in the absence of large males. This methodology of differentiating males remains qualitative, however, and this limit must be taken into account when interpreting the data. The proportion of large males in the fall remains a useful biological indicator that is collected annually and that contributes to describe the health of the herd (Figure 4).

In migratory caribou, the sex-ratio of adult individuals (≥ 1.5 years old) usually varies from 40 to 70 males per 100 females (Bergerud, 1980; Bergerud et al., 2008). Between 2004 and 2014, the adult sex-ratio of the LRH was estimated at around 34 ± 4 males (all categories combined) per 100 adult females (Table 4). In the early 2000s, the proportion of large males in the population, a more direct way of describing the male segment of the population, fluctuated around 12 ± 2% (Table 4; Figure 4). Between 2007 and 2011, however, the proportion of large males decreased to 5 ± 1%. Fall classification monitoring indicated that the proportion of large males increased between 2012 and 2014 (2012: 8.5% of the population; 2013: 7.8%; 2014: 11,6%; Table 4; Figure 4). However, in the fall of 2015, the proportion of large males was low (4%) and similar to levels observed from 2007 to 2011. The proportion of males in the population, and more particularly of large males, remains of concern.

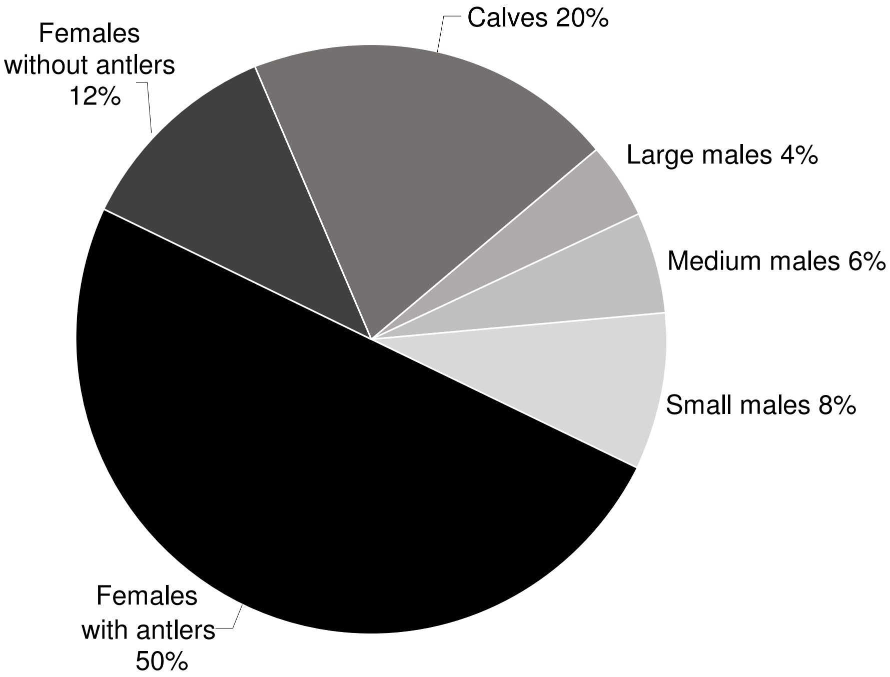


Figure 3 Population structure of the LRH in autumn 2015. Senile males are not shown because they account only for 0.1% of the population.

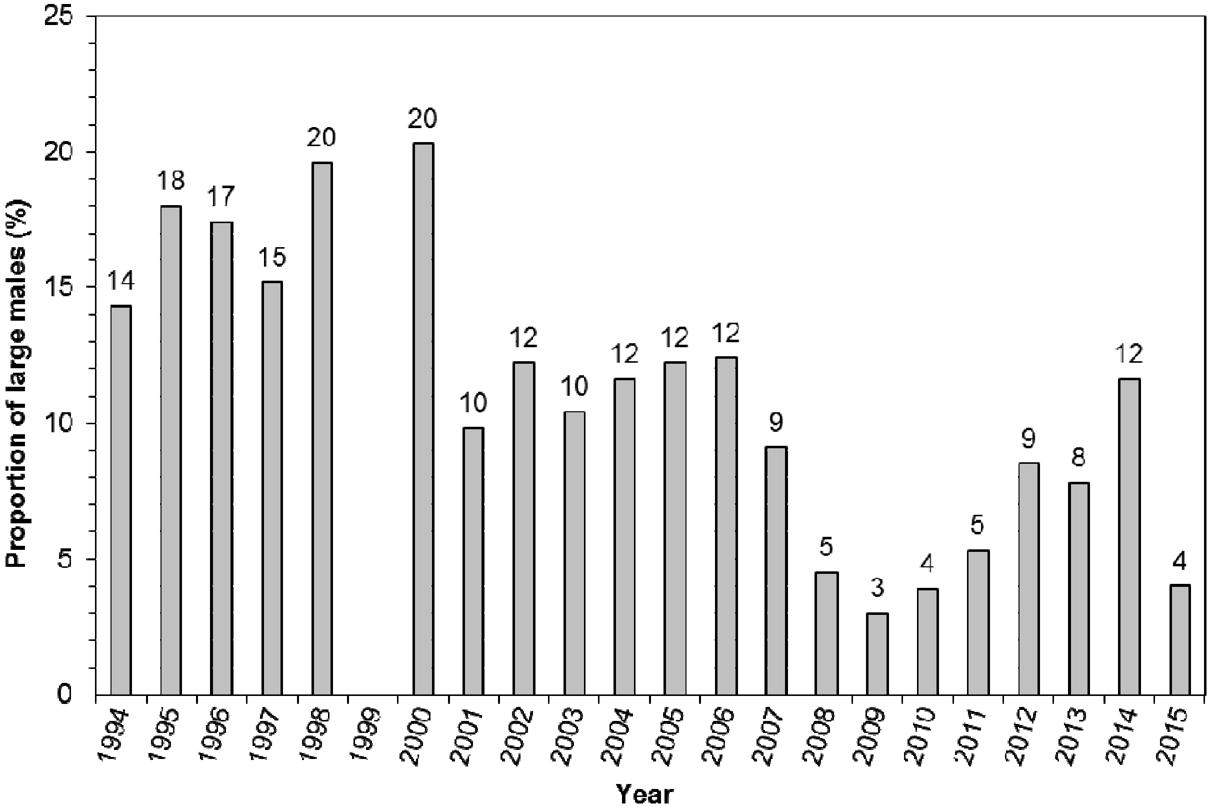


Figure 4 Variation in the proportion of large males in the Leaf River herd in fall, 1994-2015. No classification took place in 1999.

Table 4 Details of the population structure, the adult sex-ratio and the recruitment in autumn for the LRH between 1994 and 2015.
*No classification took place in 1999.

Year	Proportion of adult females (%)			Proportion of adult males (%)					Proportion of calves (%)	Males per 100 females	Calves per 100 females
	Antlers	No antlers	Total	Small	Medium	Large	Senile	Total			
1994	46.8	3.6	50.4	8.7	4.3	14.3	0.7	28.0	21.6	55.5	42.8
1995	48.0	5.9	54.0	10.5	6.2	18.0	0.0	34.7	11.3	64.3	21.0
1996	41.4	4.9	46.3	8.9	4.2	17.4	0.2	30.7	22.9	66.4	49.5
1997	42.2	7.0	49.2	8.9	6.5	15.2	0.5	31.1	19.7	63.1	40.0
1998	39.7	5.4	45.1	11.5	4.7	19.6	0.6	36.4	18.5	80.6	41.1
1999*	-	-	-	-	-	-	-	-	-	-	-
2000	43.3	5.5	48.8	8.6	4.4	20.3	0.4	33.6	17.6	68.9	36.0
2001	44.7	8.7	53.3	10.4	4.3	9.8	0.4	25.0	21.7	46.8	40.7
2002	44.8	7.9	52.7	12.3	6.1	12.2	0.4	31.0	16.3	58.8	30.9
2003	46.5	9.6	56.1	8.9	5.7	10.4	0.6	25.6	18.3	45.6	32.6
2004	54.0	10.3	64.3	7.6	5.5	11.6	0.4	25.0	10.7	38.8	16.7
2005	40.9	7.7	48.6	7.8	8.8	12.2	0.7	29.5	22.0	60.7	45.3
2006	48.3	10.6	58.9	4.7	3.7	12.4	0.1	20.9	20.1	35.5	34.1
2007	58.4	10.8	69.2	5.8	3.9	9.1	0.4	19.2	11.6	27.8	16.8
2008	52.3	11.3	64.6	5.0	5.1	4.5	0.1	14.6	20.8	22.6	32.3
2009	52.4	9.8	64.7	9.2	5.5	3.0	0.0	17.7	17.6	27.3	27.3
2010	49.4	12.7	62.4	10.2	5.1	3.9	0.1	19.2	18.4	30.9	29.5
2011	50.9	11.8	65.5	3.1	4.4	5.3	0.2	13.1	21.5	20.0	32.8
2012	51.0	10.3	61.2	4.7	2.9	8.5	0.2	16.3	22.5	26.6	36.7
2013	45.5	10.8	56.3	10.8	6.4	7.8	0.2	25.2	18.5	44.8	32.8
2014	51.5	12.5	64.0	7.6	7.5	11.6	0.2	27.0	9.0	42.1	14.0
2015	11.5	50.0	61.5	8.5	5.7	4.0	0.1	18.3	20.1	29.8	32.7

Recruitment

The annual estimation of the population recruitment is another key piece of information for the monitoring of migratory caribou populations. Recruitment is an estimation of the proportion of calves in the population in the fall (end of October) and is typically presented as the number of calves per 100 adult females (> 1.5 years). Recruitment is however easier to interpret when shown as the percentage of calves in the population. Moreover, it is important to use both indicators to get a better picture of recruitment. The recruitment observed in the fall depends on several factors that directly or indirectly influence the survival of calves, including body mass at birth, weather conditions in spring, predation rate at birth and in summer, and quality of summer habitat (Crête et al., 1990; Crête and Huot, 1993; Couturier et al., 2009a; Taillon et al., 2012a). From 1994 to 1999, when the herd was growing, recruitment was estimated at 21 ± 2% calves (or 43 ± 4 calves per 100 females) (excluding 1995; Table 4, Figure 5). Since 2001, annual recruitment has remained at around 20 ± 2% calves (or 34 ± 3 calves per 100 females) (Table 4, Figure 5). The average proportion of calves observed in the population suggests that the recent decline of the LRH was more likely related to factors influencing adult survival. Since 2001, poor recruitment was observed for three years (2004, 2007 and 2014; Table 4; Figure 5). Low annual recruitment remains of concern and could, should it remain low for consecutive years, contribute to a demographic decline of the LRH. In the fall of 2015, recruitment improved (20.1%; 32.7 calves per 100 females) compared to the previous year and was similar to the average value observed since 2001. The interpretation of recruitment data, however, must consider the other biological available (e.g., space use, body condition) to complete the demographic portrait of the LRH.

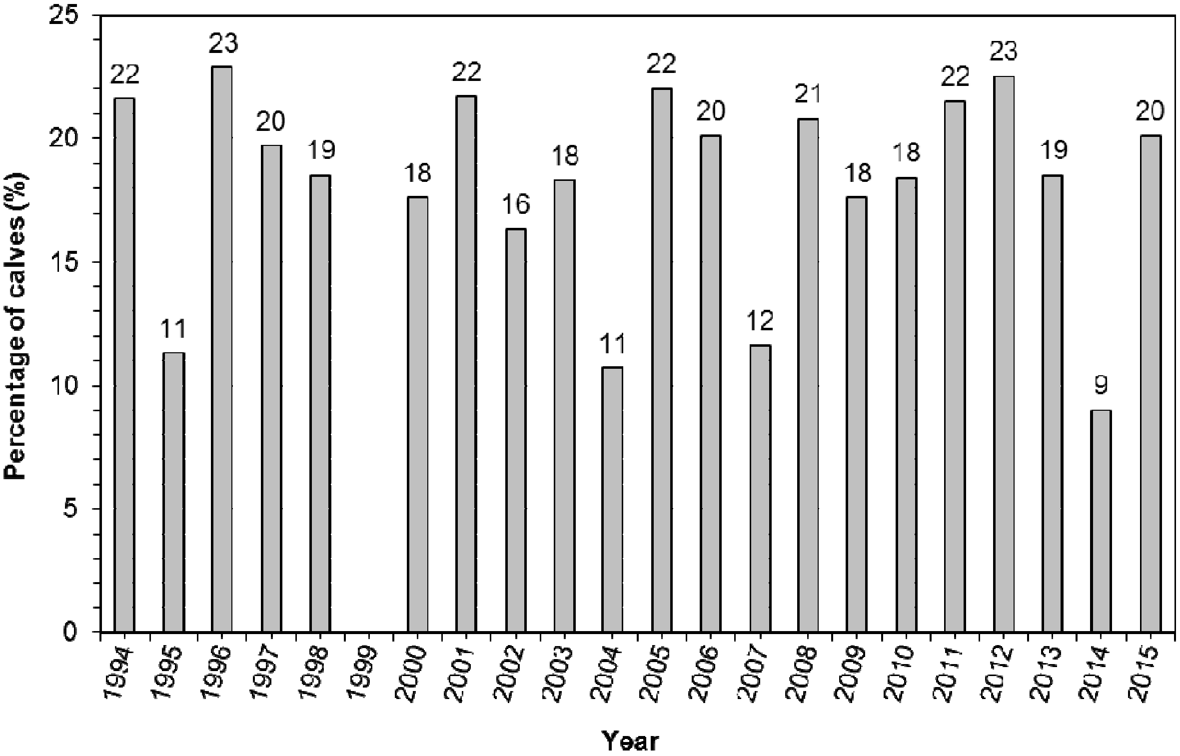


Figure 5 Variation in the percentage of calves in the fall for the Leaf River herd, 1994-2015. No classification took place in 1999.

2.5 Body condition, diseases and parasites

Several biological parameters can be influenced by body condition, such as the age of the first reproduction of females, the date of oestrus in females, the resistance to infection, the survival of calves, and the access to females by males (Barboza et al., 2009; Couturier et al., 2009a; Parker et al., 2009). Body condition also allows us to evaluate the indirect effects of habitat quality on the survival and reproductive potential of individuals within a given population (Parker et al., 2009).

Caribou body condition can be described using a number of measurements including body mass, the mass of specific muscle groups, skeletal size, fat reserves and the monitoring of diseases or parasites (Huot, 1988; Harder and Kirkpatrick, 1996; Parker et al., 2009; Taillon et al., 2011). Body mass is commonly used to describe seasonal variations in body condition and to identify annual changes in environmental conditions (Barboza et al., 2009; Parker et al., 2009). This indicator integrates the variations of the animal's fat reserves and muscle mass. The long-term monitoring of body condition relates the seasonal and annual variations in individual body condition to changes in survival rate and recruitment which influence the demography of the herd.

Calf body mass at birth

Calf body condition at birth is a factor that influences perinatal survival (Keech et al., 2000; Adams, 2005). Since 1991, newborn calves have been captured at the beginning of June to measure their body mass and size. Between 1991 and 2013, the annual birth mass of LRH calves fluctuated about 5.8 ± 0.1 kg without significant trend in time (Table 5, Figure 6). According to a study of the GRH (Couturier et al., 2009a), an average calf birth mass of ≥ 6.0 kg is, in general, related to higher recruitment in the fall. From 2007 to 2009, the birth mass of LRH calves was lower than that of GRH calves (average difference of 0.7 kg or 8% of birth mass), (Taillon et al., 2012a). This difference in body mass is likely to be related to environmental factors (e.g., climate, availability of food, displacement rate) and differences in maternal resource allocation strategies (Taillon et al., 2013) that influence foetal development.

Fall calf body mass

The study of the body condition of calves at weaning (late October to early November) provides information on growth conditions (Barboza et al., 2009; Bonenfant et al., 2009) and allows us to interpret the influence of summer habitat quality on recruitment. The body condition of LRH calves was evaluated at weaning between 1995 and 2009 (Table 5). During this period of time, the body mass of LRH calves at weaning varied annually but remained at around 41.9 ± 1.1 kg without significant trend in time (Table 5, Figure 7). Data collected in the fall suggest that the body condition of calves remained similar during the period of population growth (1995 to 1998), population decline (2000 to 2002), and apparent population stability (2008 to 2013). According to Couturier et al. (2009a), a calf's body mass at weaning seems to be positively influenced by early access to forage in June, but negatively influenced by the caribou's displacement rate during summer. Data gathered in 2007-2009 show that LRH calves are about 10 kg lighter than GRH calves at weaning (Taillon et al., 2012a). The absence of genetic differences between the two migratory herds (Boulet et al., 2007; G. Yannic, pers. comm.) suggests that calves of both herds should have the same potential for body growth. This suggests that the body mass of LRH calves at weaning can be considered low compared to that of GRH calves on the same date. The difference in the body mass of calves at weaning between the herds is apparently related to several biotic factors, such as forage quality and/or availability on summer ranges, or to difference in space use (e.g., seasonal and annual movement rates) that may impact the body mass of calves produced and raised by females.

Table 5 Compilation of body mass (mean ± standard error) collected from 1991 to 2013 on the Leaf River herd.

Year	Birth mass of calves		Body mass of calves at weaning[11]		Body mass of females at weaning	
	Mean (kg)	Standard error	Mean (kg)	Standard error	Mean (kg)	Standard error
1991	6.3	0.2	.	.	.	.
1992	.	.	.	.	.	.
1993	.	.	.	.	.	.
1994	6.6	0.6	.	.	.	.
1995	6.0	0.2	43.9	1.2	.	.
1996	5.3	0.2	39.1	0.9	.	.
1997	5.5	0.4	43.3	1.3	.	.
1998	6.0	0.2	47.4	1.1	.	.
1999	6.4	0.2	.	.	.	.
2000	5.2	0.2	37.5	1.1	.	.
2001	6.0	0.2	46.3	1.6	90.4	1.3
2002	5.3	0.2	38.3	1.5	87.5	1.6
2003	5.8	0.3	.	.	.	.
2004	.	.	.	.	.	.
2005	.	.	.	.	.	.
2006	.	.	.	.	.	.
2007	5.2	0.2	41.3	1.2	88.7	1.8
2008	5.8	0.2	44.7	1.4	97.0	1.8
2009	5.3	0.2	39.3	1.9	91.3	1.4
2010	6.5	0.2	.	.	.	.
2011	5.5	0.2	.	.	.	.
2012	6.3	0.1	.	.	.	.
2013	5.9	0.1	40.0	1.1	89.7	1.7

---

[11] Data from 1995 to 2002 are from Couturier et al. (2009a). During this period, sampling dates ranged between the October 20th and November 20th. To correct for temporal variability, Couturier et al. (2009a) adjusted the body mass of calves to the October 23rd. Data from 2007 to 2013 are from Taillon et al. (2012b) and from the MFFP database. During this period, sampling dates were centered around October 23rd.

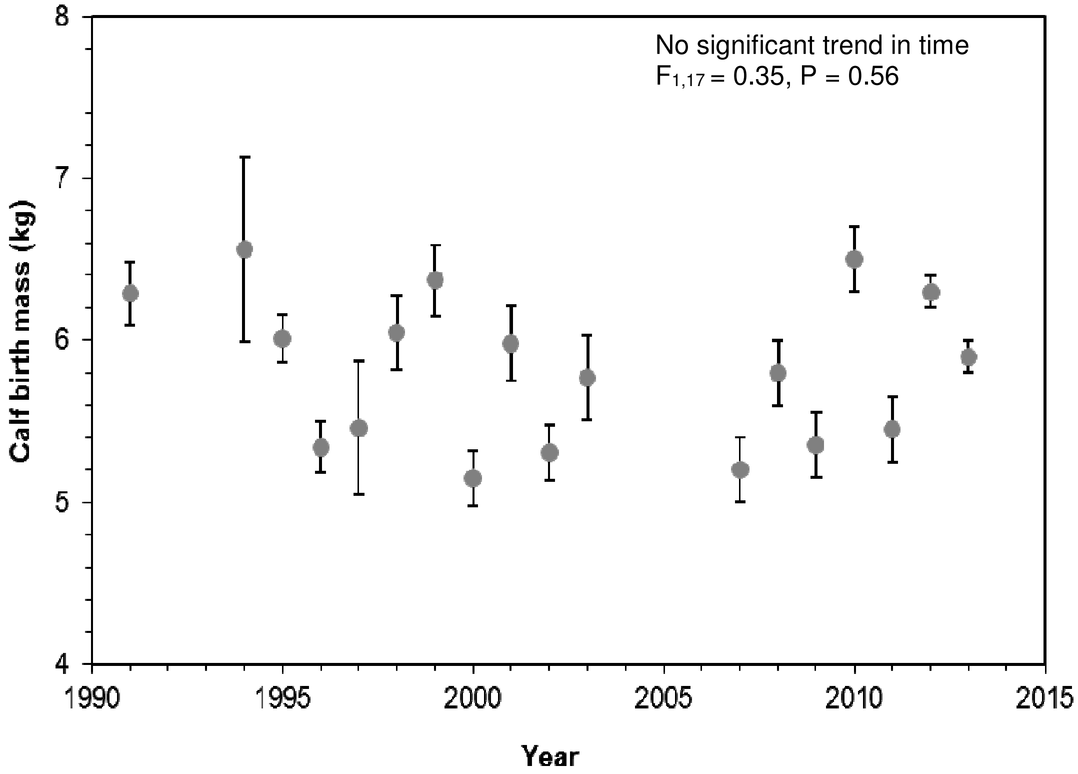


Figure 6 Annual variations of calf birth mass for the Leaf River herd, 1991-2013.

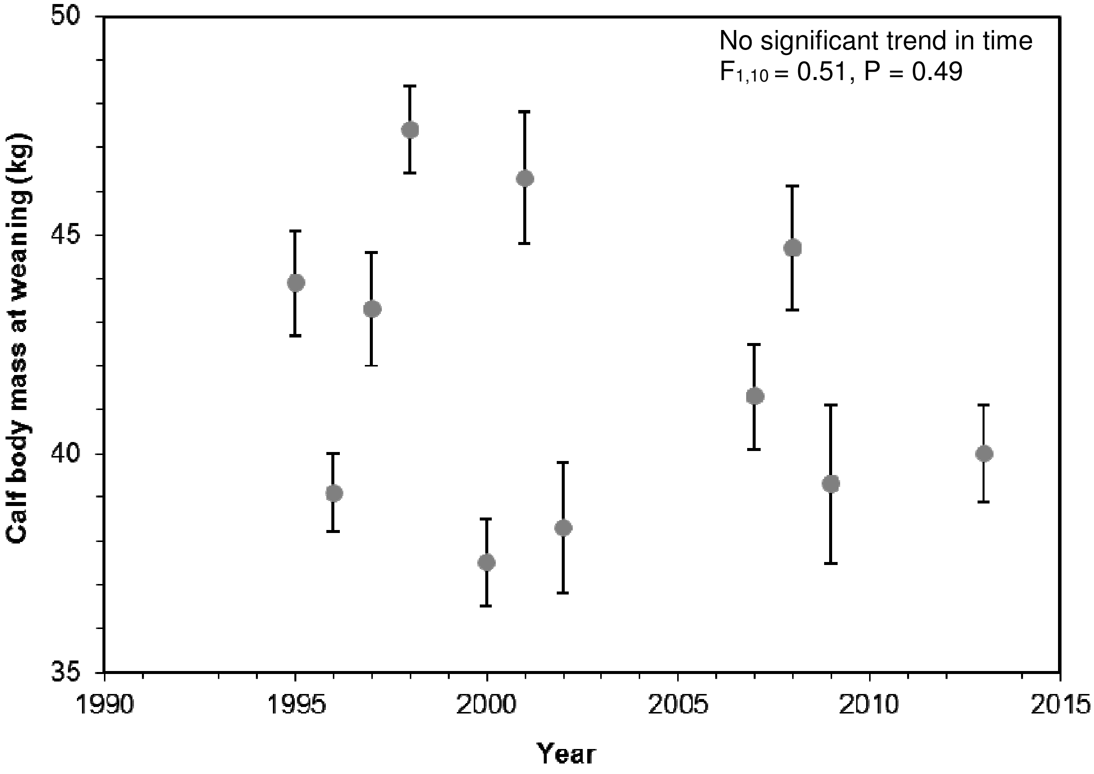


Figure 7 Annual variations of calf body mass at weaning for the Leaf River herd, 1995-2013.

Fall body mass of adult females

The fall body condition of females that have a calf at heel results mainly from the balance between energy allocated to lactation and the quality of the summer habitat (Clutton-Brock and Coulson, 2002; Landete-Castillejos et al., 2003). The body condition of females in the fall can influence the probability of oestrus, the success of gestation and the allocation of maternal reserves to the calf (Pachkowski, 2012; Taillon et al., 2012a).

The fall body mass of adult females (≥ 2.5 years old) remained similar from 2001 to 2013 (Table 5) (Couturier et al., 2009a; Taillon et al., 2011). Data collected in the fall suggest that the body condition of adult females remained similar during the period of population decline (2000-2002) and the period of population stability (2008-2013). According to data gathered between 2007 and 2009, the average fall body mass of LRH adult females was about 8 kg less than that of GRH females (Taillon et al., 2012a). In the absence of genetic differences between the two herds (Boulet et al., 2007; G. Yannic, pers. comm.), this would suggest that the fall body mass of LRH females may be considered as average compared to that of GRH females. In addition, LRH females had a low percentage of kidney fat (2007-2009: 8.3 ± 0.9%; 2013: 14.3 ± 2.1%) and only a few of them had accumulated back fat (2007-2009: 20% of all females with 0.4 ± 0.1 mm of back fat; 2013: 47% of all females with 0.4 ± 0.1 mm).

The fall body condition of LRH calves and females is influenced by habitat quality, which is characterized, among others, by weather conditions, the distribution of food resources, harassment from biting and parasitic insects, and the presence of predators (Joly et al., 2010; Witter et al., 2012). These factors may also influence the quality, availability and accessibility of food resources, and could potentially affect the rate of seasonal movements. Some studies suggest that the increase in the distances of migrations and in the rate of seasonal movements may negatively impact body condition in the fall (Hinkes et al., 2005; Couturier et al., 2010; Taillon, 2013). According to the current behaviour of the LRH, the rate of seasonal movements and the availability of food resources in summer ranges may be determining factors for the body condition of females and calves.

Age structure and skeletal size of adult females

The age of individuals can be assessed on living animals by evaluating incisor tooth replacement patterns and tooth wear, or on dead animals by counting cementum layers in incisor teeth (Hamlin et al., 2000). The evaluation of age allows us to establish the age structure of a herd, which in turn provides information on the general state of health of the population through cohort effect (i.e., identifying the more and less productive cohorts). From 2007 to 2009, age was evaluated for females sampled while conducting research on body condition (Taillon et al., 2011) at calving (June) and weaning (late October to early November). At calving, the sampled females were aged between 2.5 and 12.5 years old (n = 50; average age = 6.0 years old). At weaning, females were aged between 2.5 and 13.5 years old (n = 48; average age = 7.0 years old).

Skeletal size provides information on the impact of environmental conditions encountered by individuals at birth and during growth (Gaillard et al., 2003; Barboza et al., 2009). The size of a mature animal is, in this sense, the legacy of conditions encountered during its first 3 to 5 years of life, when the majority of skeletal growth takes place. Mandible length and hind foot length are good indicators of the skeletal size of caribou (Couturier et al., 2010; Taillon et al., 2011; Pachkowski, 2012) and allow us to carry on the long-term monitoring of the body size of LRH females. Mandibles were collected while conducting research on body condition (Couturier et al., 2010; Taillon et al., 2011) and from the sampling of animals harvested during winter sport hunting (2007 to 2011). Since 2000, the mandible length has remained around 278.3 ± 0.5 mm, suggesting the stability of the skeletal size of LRH adult females (Figure 8). In 2007, LRH calves were unusually small (Table 5; Figure 6), which could have contributed to the low skeletal size of this cohort.

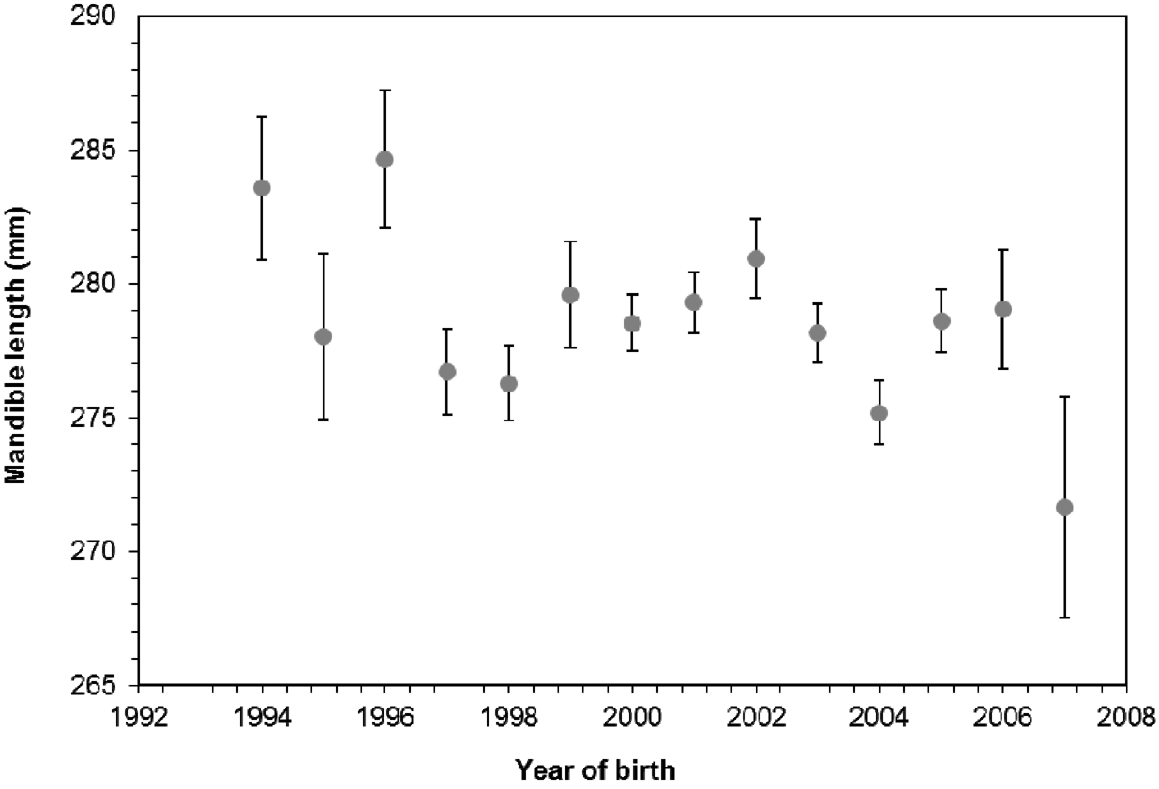


Figure 8 Variations of mandible length (mean ± standard deviation) of adult females (≥ 4 years old) from the Leaf River herd in relation to year of birth.

Diseases and parasites

Caribou are natural hosts to numerous parasites and diseases that only rarely have major deleterious effects on individuals and populations (Fréchette, 1986). The diseases and parasites usually do have significant effects on individuals in poor body condition (e.g., starvation, nutrient deficits). Caribou are more vulnerable when exposed to new parasites or diseases for which they have not developed efficient immuno-defense reactions. However, the general effect of parasites and diseases on the body condition of animals and on the population dynamics is not well known (Hughes et al., 2009).

Common parasites

Migratory caribou are affected by a number of macroparasites, including liver flukes (*Fascioloïdes magna*), tapeworms (liver: *Taenia hydatigena*; muscles: *Taenia krabbei*; hydatid cysts in lungs: *Echinococcus granulosus*), warbles (*Hypoderma tarandi*) and bot flies *(Cephenemyia trompe*), and by microscopic protozoa (e.g., subcutaneous protozoa *Besnoitia tarandi*) (Fréchette, 1986; Ducrocq et al., 2013; Simard, 2015; http://www.mffp.gouv.qc.ca/faune/sante-maladies/parasites-caribou.jsp [available in French only]). Other blood and gastrointestinal parasites are common but not easily detected. Parasite transmission comes mainly from the ingestion of eggs or larvae present on the vegetation, from insects or gastropods accidentally consumed, or directly from insects that lay their eggs on the fur of caribou (on the legs or snout) (Fréchette, 1986). The parasite load is described in terms of prevalence (absence or presence) and severity of infection (quantity or density of parasites).

The sampling of LRH caribou to monitor the parasite load has been intermittent since 1987. Between 2007 and 2009 (calving and weaning; Taillon, 2012), and in 2013 (weaning only), the parasite load of females (at calving and weaning, n = 115) and their calves (at weaning only, n = 64) underwent an exhaustive evaluation. The data reveal that approximately one-third of adult females were infected by flukes (2007-2009: 36%; 2013: 41%) and/or tapeworms (2007-2009: 22%; 2013: 47%) in the liver. Among infected females, the number of parasites in the liver was low (2007-2009: mean of 6.4 ± 0.8 flukes and 2.4 ± 0.3 tapeworms; 2013: 3.9 ± 1.5 flukes and 2.8 ± 0.9 tapeworms per infected female). The prevalence of tapeworms in muscles (2007-2009: 4%; 2013: 12%) and hydatid cysts in lungs (2007-2009: 5%; 2013: 18%) was low in females. The majority of females had larvae (at calving; 94%) or scars (at weaning; 2007-2009: 82%; 2013: 88%) of warbles under the back skin. Calves sampled at weaning (2007 to 2009 and 2013) showed no presence of liver flukes or hydatid cysts, and rarely presented tapeworms (none in 2007-2008; 2013: liver (13%) or muscles (7%)). At weaning, approximately one-third of calves had scars of warbles under the back skin (2007-2009: 37%; 2013: 40%).

Blood pathogens

From samples collected between 2007 and 2009 (Taillon, 2012), serology tests were performed to evaluate the prevalence (presence or absence) of antibodies linked to nine diseases or parasites that may affect the genus *Rangifer*: brucellosis (*Brucella sp.)*, neosporosis (*Neospora caninum*), West Nile virus, toxoplasmosis (*Toxoplasma gondii*), parainfluenza-3 virus, bovine herpes virus-1 (BoHV-1), bovine respiratory syncytial virus (BRSV), and bovine diarrhea virus types I and II. Preliminary results reveal an absence or low prevalence of the different pathogens tested (Curry, 2012). The presence of antibodies in the blood serum can be interpreted in two ways: 1) the animal was infected but is no longer carrying the disease, although it retains the antibodies; or 2) the animal was carrying the pathogenic agent at the time of blood sampling. The potential changes in the prevalence of these pathogens are currently unknown in the context of climate change and recent anthropogenic disturbances.

Besnoitia tarandi

In 2006 and 2007, the observation by some Aboriginal hunters and outfitters of caribou from the GRH and LRH infected by the protozoan *Besnoitia tarandi* was a source of concern. According to available data, it would be the first major emergence of this protozoan among eastern North American caribou (Ducrocq, 2010). Monitoring was implemented in 2006 to quantify the prevalence and intensity of infection by *B. tarandi* among LRH individuals, in close collaboration with the *Centre québécois de la santé des animaux sauvages* at the Faculty of Veterinary Medecine, University of Montréal (Saint-Hyacinthe, Québec). A specific research project on this parasite (Ducrocq et al., 2013) has allowed us to improve the sampling techniques (Ducrocq et al., 2012) and describe the rapid increase in the prevalence of the parasite within the LRH.

The analysis of metatarsal skin samples revealed that prevalence (the percentage of infected individuals) has increased from around 30% of individuals sampled in 2007 to more than 80% in 2011 (Figure 9). Between 2007 and 2009, the prevalence of *B. tarandi* was 2.3 times greater among caribou sampled in the fall than among those sampled in June of the same year (Ducrocq et al., 2013). Even if the vector of the infection is unknown, this observation suggests that there was an increase in transmission during the summer and the possible involvement of biting insects as a vector of this parasite (Ducrocq, 2010). Moreover, the lower prevalence observed in June compared to the previous fall could result from the decrease of the parasite load through the action of the immune system over the winter and/or from a lower survival rate of animals with high intensity of infection during the winter (Ducrocq, 2010).

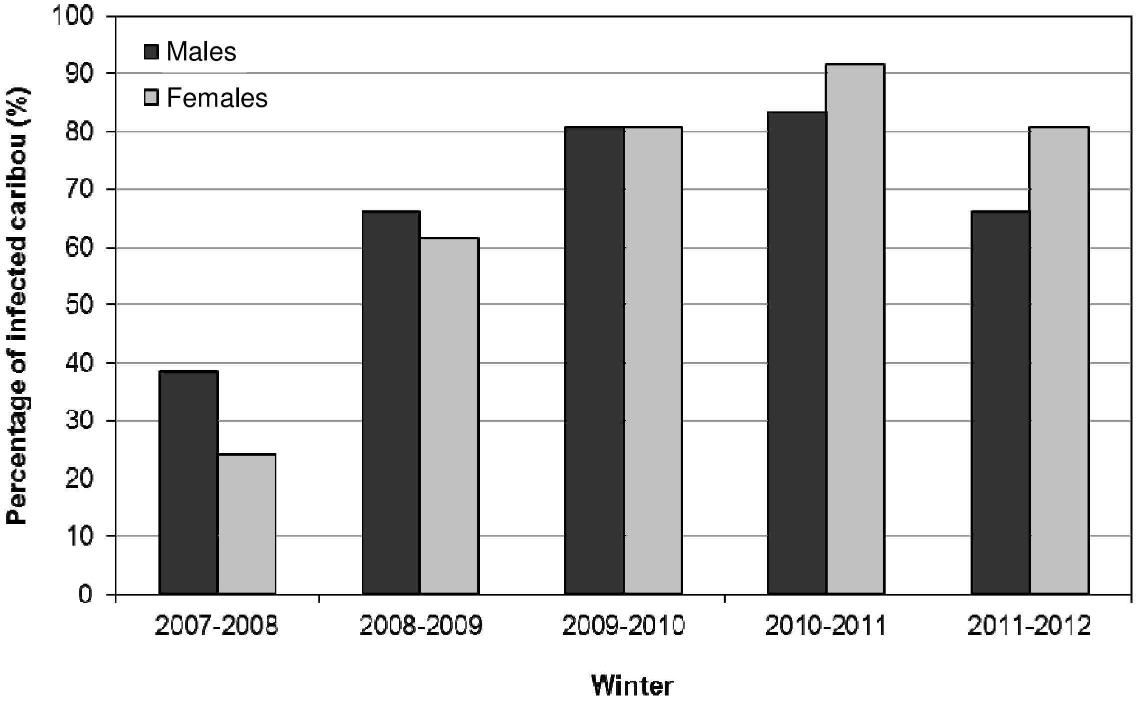


Figure 9 Annual percentage of caribou infected (prevalence) by *Besnoitia tarandi* in the LRH for caribou males and females of more than 2.5 years of age sampled during winter sport hunting from 2007 to 2012. The prevalence was estimated from the analysis of metatarsal skin samples.

The intensity of infection of LHR adult males sampled from September 2007 to June 2009 was higher than for adult females: adult males infected by this protozoan presented about 20% more cysts than adult females (Ducrocq et al., 2013). This could suggest a greater exposure or higher susceptibility to *B. tarandi* of males compared to females during that period of time (Ducrocq, 2010). The high intensity of male infection coincides with field observations and could be related to the decline in the segment of large males observed since 2007 for both herds (Figure 4). However, no causality has yet been demonstrated.

Between 2010 and 2015, about 40% of animals handled during captures for radio-collaring (n = 275; main capture periods: June and March) presented cysts of this parasite that were identified by examining the conjunctiva of the eye (Figure 10). The examination of the conjuctiva of the eye represents a minimal and approximate count of the presence of this parasite (Ducrocq et al., 2012), as some infected caribou may show no apparent cysts on this tissue. The monitoring of captured animals suggests, however, a decrease in the number of symptomatic caribou for *Besnoitia*, which coincides with field observations of outfitters and Aboriginal hunters. The effects of *B. tarandi* on the body condition and survival rate of caribou remain unkown.

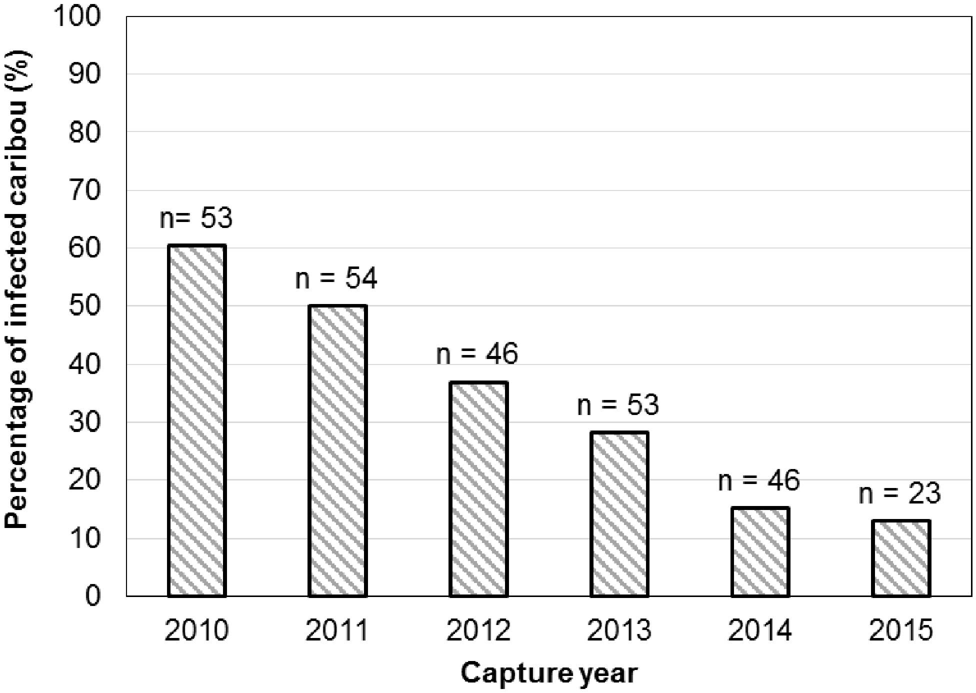


Figure 10 Percentage of caribou infected by *Besnoitia tarandi* among animals handled during captures for radio-collaring. Prevalence was established by examining the conjunctiva of the eye, which provides a minimal and approximate count of the presence of this parasite. Annual sample size (n) is provided.

Heavy metals and other contaminants

Some pollutants, released from the development of roads, from various types of industrial developments or from an atmospheric source, fall on snow cover and on the vegetation eaten by caribou. Among these pollutants are various heavy metals and other contaminants (e.g., cadmium, lead and mercury; Gamberg et al., 2005) than can accumulate in caribou tissue.

The concentrations of cadmium, lead and mercury were evaluated in samples of muscle, liver and kidney tissue collected from 15 female-calf pairs in 2007 and 2008 (Kwan, 2011; Taillon, 2012). In muscle tissue, concentrations were low and posed no risk to human health (i.e., through consumption of caribou meat). By contrast, the kidneys had a high concentration of cadmium and regular consumption of these organs could involve risks to human health (Kwan, 2011). The moderate concentrations of cadmium detected in the liver did not seem of particular concern, except if large quantities of this organ were consumed on a regular basis. The effects of these heavy metals and contaminants on the body condition, survival and reproduction rates of caribou remain poorly understood.

2.6 Annual range, use of space and migrations

Some historical reports describe, from 1975 to the beginning the 1990s, the changes in the location and size of the annual range of the LRH (Le Hénaff, 1976; Le Hénaff, 1980; Le Hénaff and Hayeur, 1983; Vandal et al., 1989; Couturier, 1994). Between 1994 and 2012, more than 489 LRH individuals were fitted with radio-collars (344 females and 145 males) (Table 3). The long-term telemetry monitoring has allowed us to delineate the annual range, seasonal ranges and migration corridors of the LRH since 1994 (Figure 4.11). The knowledge of the use of seasonal ranges is a key element for the management of the herd and its habitat.

Annual range (see Appendix 2)

Location

During the 1970s and 1980s, the winter range of the LRH was located north of the 55th parallel in the Lac Bienville sector (Le Hénaff, 1980; Le Hénaff and Hayeur, 1983; Vandal et al., 1989). These overflights indicate that the annual range was at the time limited north of the 55th parallel to sectors of the Ungava Peninsula (Figure 4.12). The population was then estimated to be less than 100,000 caribou. In the 1990s, the annual range extended southwards, while remaining north of the 52nd parallel (Figure 4.12). In the early 2000s, the southward expansion of the herd range increased toward the taiga of the Jamésie in the winter (Figure 4.12). This expansion took place while the GRH range was retreating towards the east. Consequently, the LRH locally replaced the GRH in the Jamésie sector, such as users could not really detect wide variations in the resource (local abundance of caribou).

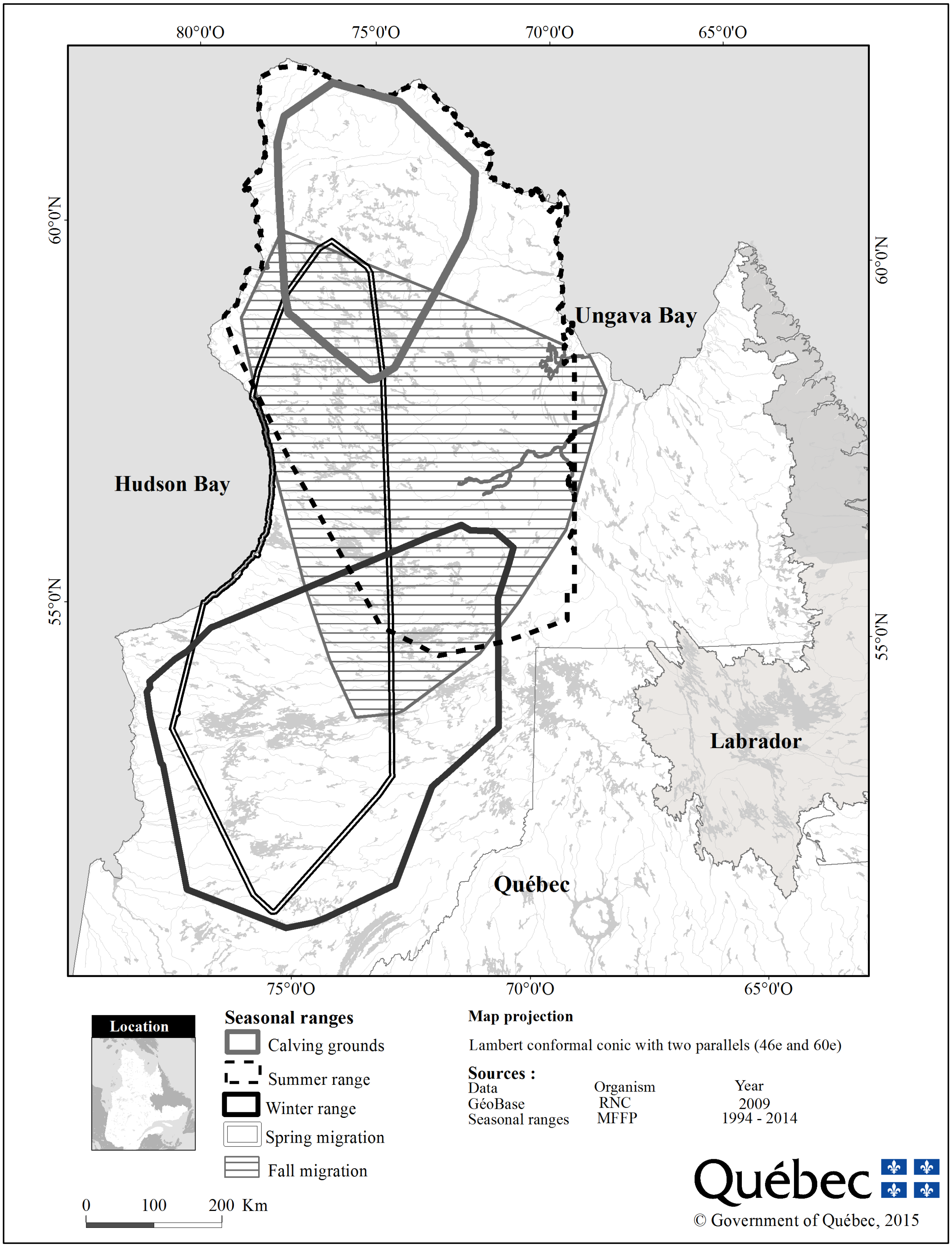


Figure 11 Location of seasonal ranges and migration corridors used by the LRH between 2008 and 2014.

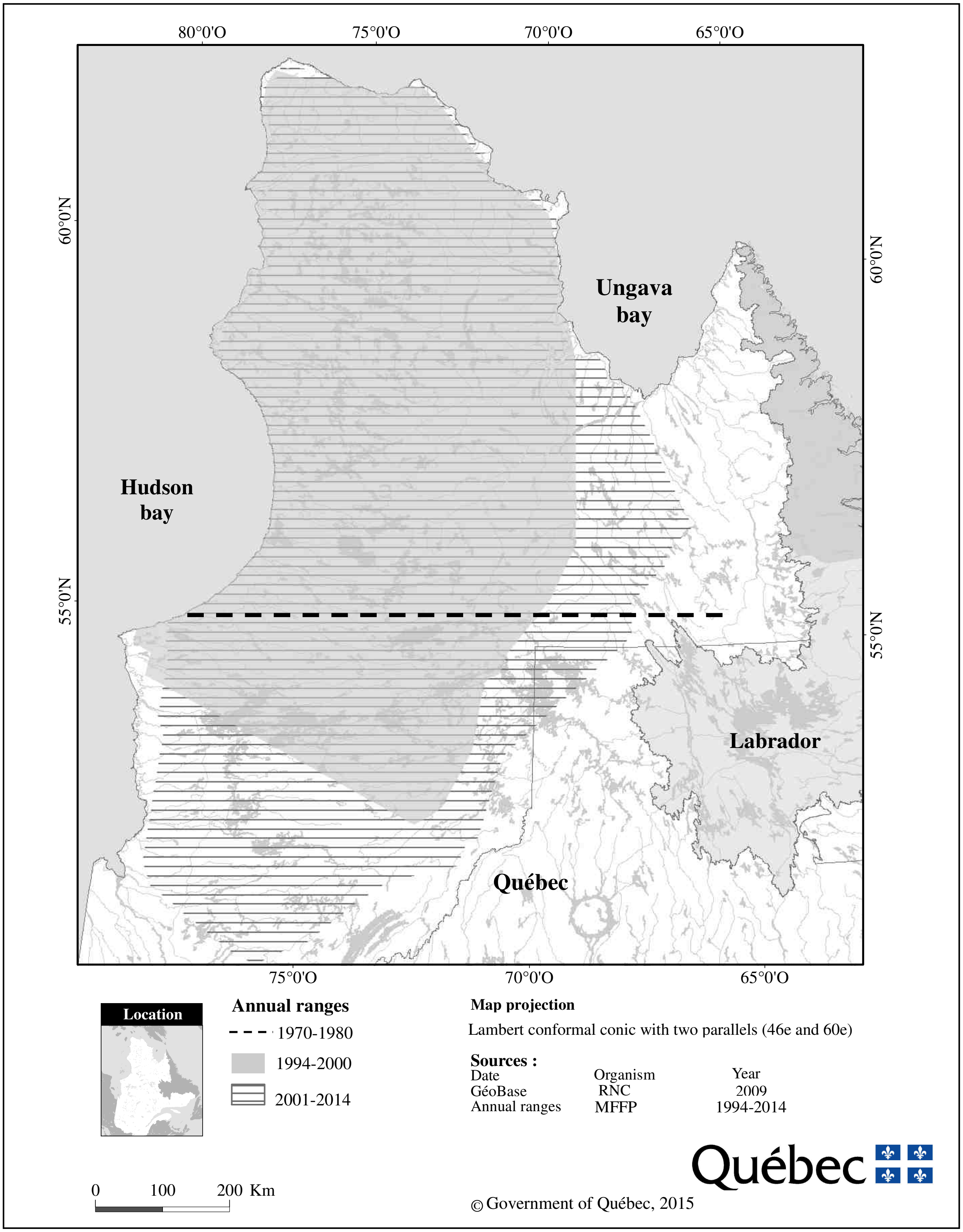


Figure 12 Expansion of the annual range of the LRH from 1994 to 2000 (dark grey) and from 2001 to 2014 (striped). The dotted line represents the southern boundary of the range used in the 1970s and 1980s (Le Hénaff and Hayeur, 1983).

Size

The size of the annual range of migratory caribou herds is generally considered to be a good indicator of population size (Couturier et al., 2010). Telemetry data collected since 1994 showed that changes in the size of the annual range of the LRH were matched by variations in herd size (Figure 4.13). The LRH annual range size was smaller in the 1990s (338,500 ± 27,770 km^2), and then increased as the herd reached its demographic peak in the early 2000s (Figure 4.13). Since the beginning of the 2000s, the size of the annual range has remained at around 489,600 ± 36,800 km^2 (Figure 4.13).

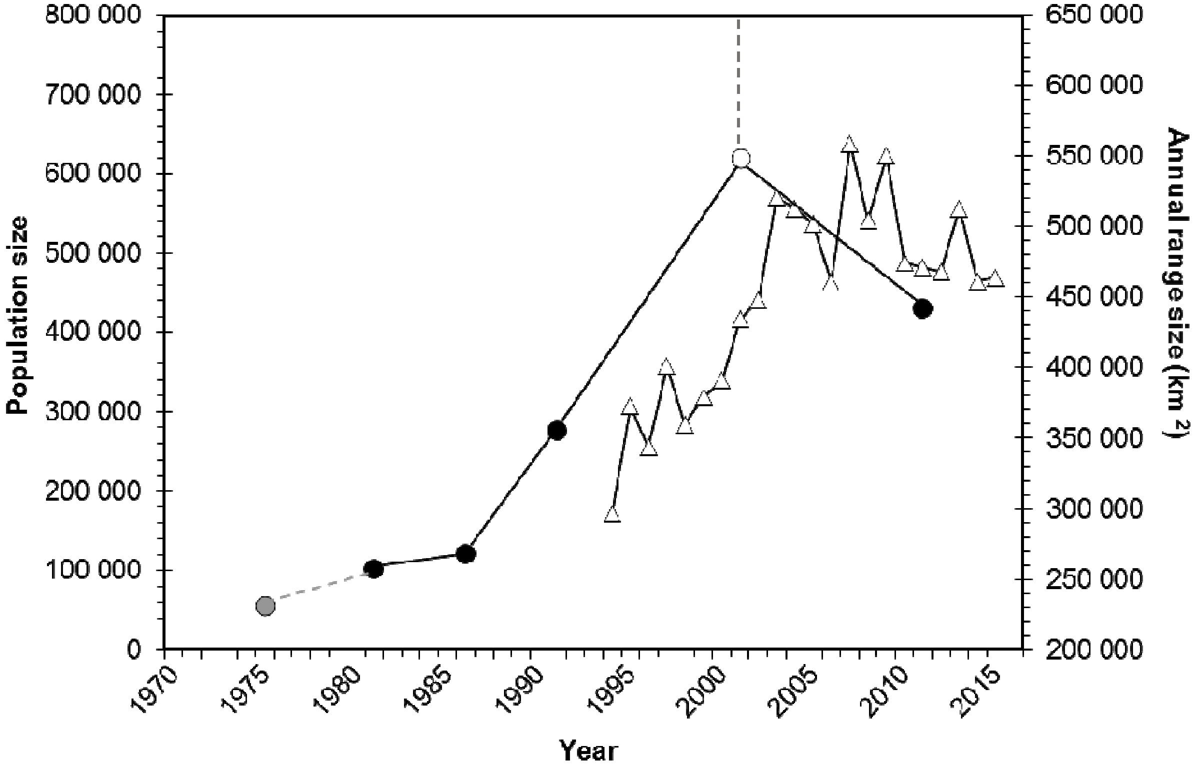


Figure 13 Annual variations in the size of the annual range (white triangles) and population size (circles) of the LRH. The population size estimate for 1975 (grey circle, dotted line) represents a minimal count (without error estimates). For 2001 (empty circle, dotted line), the lower limit of the confidence interval (628,000 caribou) of the 2001 census was used to describe the population size of the LRH.

Seasonal ranges

Winter ranges (see Appendix 3)

During the 1990s, the LRH used two distinct winter ranges: the first was located in the northern part of the Ungava Peninsula and the second was located near Lac Bienville (55°N; 74°W; see Appendix 3). In the early 2000s, the majority of individuals progressively shifted their fall migration southward, consequently increasing their daily movement rate (Couturier et al., 2010) and migration length. Between 2003 and 2009, the LRH temporarily continued its fall migration to the south towards the 51st parallel, but the most recent winter ranges were mainly located north of the 52nd parallel. Telemetry data shows that since 2006, the winter ranges have been located completely south of the

55th parallel, covering an area of more than 127,700 ± 37,300 km^2. In the winters of 2010-2011 to 2014-2015, the LRH winter ranges were located almost exclusively to the north of the La Grande hydroelectric complex. Visual observations made during field overflights and telemetry monitoring suggest that the use of more southern sectors are more likely due to the behaviour of a small proportion of the population (see Appendix 3). Despite major changes in location, there was no significant trend in the change of the size of the winter range of the LRH between the winter of 1994-1995 and the winter of 2014-2015 ($F_{1,20} = 0.02$; $P = 0.88$; see Appendix 3). Still, members of Inuit communities located in this region have mentioned the presence of caribou in the northern part of the Ungava Peninsula during the winter (V. Brodeur, pers. comm.).

In winter, migratory caribou mainly seek forest stands with arboreal and terrestrial lichen cover (Messier and Huot, 1985). During this time of year, the caribou dig and maintain snow craters that ensure access to food resources (Barrette and Vandal, 1986). The caribou generally limit their movements to less than 5 km per day, but in some cases may travel tens of kilometres (M. Le Corre, C. Dussault and S.D. Côté, pers. comm.), probably when local resources are depleted or unavailable. The quality of wintering habitats probably depend on the relative abundance and availability of lichens, as well as weather conditions which could limit the access to forage in a given sector (e.g., abundant snowfall, rain over snow or freezing rain) (Fancy and White, 1985; Messier and Huot, 1985; Barrette and Vandal, 1986; Duquette, 1988). The mapping of the vegetation and tree cover used by the caribou during the winter remains imprecise, but methods for characterizing lichen across winter ranges are currently being developed.

Calving grounds

Migratory caribou are characterized by the use of traditional calving grounds where the females aggregate to give birth (Bergerud et al., 2008; Gunn et al., 2008). Typically, the name assigned to a herd refers to the geographic location of its calving ground when first discovered (generally, the name of a river or lake). The first scientific work carried out on the LRH in 1975 showed that its calving ground covered an area of approximately 19,740 km^2 and was located close to the Leaf River (58°25'N; 73°25'W) (Le Hénaff, 1976). The caribou have subsequently moved more than 300 km towards the northern end of the Ungava Peninsula for calving (60°44'N; 74°18'W). Between 1995 and 2012, the annual size of the herd's calving ground remained relatively stable at approximately 46,600 ± 4,400 km^2 (Figure 4.14) (Taillon et al., 2012b), despite the variations in population size during this period.

The data compiled between 1995 and 2010 indicate that females reach the calving ground in early June, give birth around the 9th of June and remain in the area for about one month (Taillon, 2013). Calving is highly synchronized and the majority of calves (between 80 and 90%) are born within a period of 10 to 15 days (Taillon, 2013). The females produce a single calf per year, with observations of twins being rare or anecdotal. The date of arrival on the calving grounds and the calving date may influence the calf's perinatal survival. A longer period of use of calving grounds, for its part, could favour early growth (e.g., number of days in lactation) and development of the calf's motor skills before moving over several kilometres to summer ranges.

Females and calves are highly sensitive to disturbance from human activities when they are on the calving grounds (Wolfe et al., 2000). The importance of protecting the calving habitat motivated its identification as a wildlife habitat as defined in the *Regulation respecting wildlife habitats* (CQLR, chapter C-61.1, r 18) and in Chapter IV.1 of the *Act respecting the conservation and development of wildlife* (CQLR, chapter C-61.1). This legal designation provides temporary protection, between May 15th and July 15th, a period during which any human activity that may negatively affect caribou habitats is prohibited. The effectiveness of this measure depends, however, on the spatial correspondence between the location of the protected area and the location of the calving ground used by the caribou in any given year. As the location of LRH calving grounds has changed substantially over the years, the protection provided was limited (Taillon et al., 2012b) and requires a re-evaluation, which is currently in progress.

Summer ranges (see Appendix 4)

Since 1994, the LRH caribou have been concentrated in the northern part of the Ungava Peninsula during the summer (Figure 4.11). The size of the summer ranges increased from 177,600 ± 21,200 km^2 in the mid 1990s to 275,000 ± 44,700 km^2 at the end of the 2000s, thus covering most of the Ungava Peninsula. Between 2010 and 2015, annual summer ranges covered more than 252,000 ± 26,500 km^2. The spatial distribution and availability of vegetation in the summer ranges is generally thought to play a key role in the dynamics of caribou populations (Crête and Huot, 1993). It has been suggested that the availability of vegetation in these areas would be the main factor regulating the size of caribou herds (Messier et al., 1988). The degradation of summer ranges could lead to a decline in the body condition of individuals, in the fecundity of females and in juvenile survival rates (Crête and Huot, 1993; Couturier et al., 2009a), thus negatively impacting the demography of caribou herds. The body condition of LRH calves and females at weaning (see section 2.5) could be explained by the intensive use of the summer ranges over the last 15 years (heavy browsing and trampling). This hypothesis has not yet been tested and several other factors may also have influenced the quality of the LRH summer habitat, including activities related to land development (see section 3). In addition to the quantity and quality of available forage resources, the quality of the summer habitat may also depend on the presence of predators and other biotic factors, such as harassment by biting and parasitic insects. These predators and biting and parasitic insects may influence the choice of habitats used and reduce the time allocated to foraging by caribou (Miller, 2003; Witter et al., 2012b).

Migration

The LRH caribou are among the mammals that undertake the longest known terrestrial migrations (Milner-Gulland et al., 2011). These recurring displacements of hundreds of thousands of caribou created trails that shaped the landscape of the tundra and taiga in northern Québec. This behavioural adaptation allows migratory caribou to complete its life cycle and benefit from various productive seasonal ecosystems (e.g., herbaceous arctic tundra).

Spring migration

The LRH caribou undertake large spring migrations in order to exploit seasonal food resources and avoid predators at calving time. Such migration is characterized by extensive directional movements, generally between 15 and 50 km per day (Taillon, 2013). The females initiate the migration and males follow later on, with most routes leading to the calving grounds. The segregation of sexes during the spring migration increases as the herd approaches the calving grounds. Males typically stop migrating to the south and join the females during the summer when calves begin to integrate vegetation into their diet.

The distance, date of initiation and duration of the spring migration have been evaluated through monitoring of the radio-collared females between 1995 and 2010 (a total of 97 different females were monitored; mean of 14 females monitored per year; Taillon, 2013). The females undertake annual spring migrations of around 689 ± 12 km and usually begin migrating in early April. However, the initiation date of the spring migration varies widely (from mid-February to early May), such that females can spend from 20 to 100 days in migration before reaching their calving grounds (Taillon, 2013). In years when the spring migration begin early, females seem more prone to use stopover sites (i.e., sites where animals take a break and temporarily stop migrating), which can prolong the time spent in migration (M. Le Corre, C. Dussault and S. D. Côté, pers. comm.).

The females begin their spring migration earlier when the distance from the wintering to the calving grounds is greater and when temperatures in April are higher (Taillon, 2013). April temperatures may be an indicator of early spring and therefore be related to snow and ice conditions of lakes and rivers (Tyler, 2010). In this sense, migrating earlier when temperatures in April are higher than average may allow female caribou to benefit from better conditions during migration (e.g., hard snow cover and frozen lakes) (Sharma et al., 2009). In the current context of climate change, female caribou could advance both their spring migration and use of calving grounds in response to changes in migration conditions and plant phenology (Sharma et al., 2009).

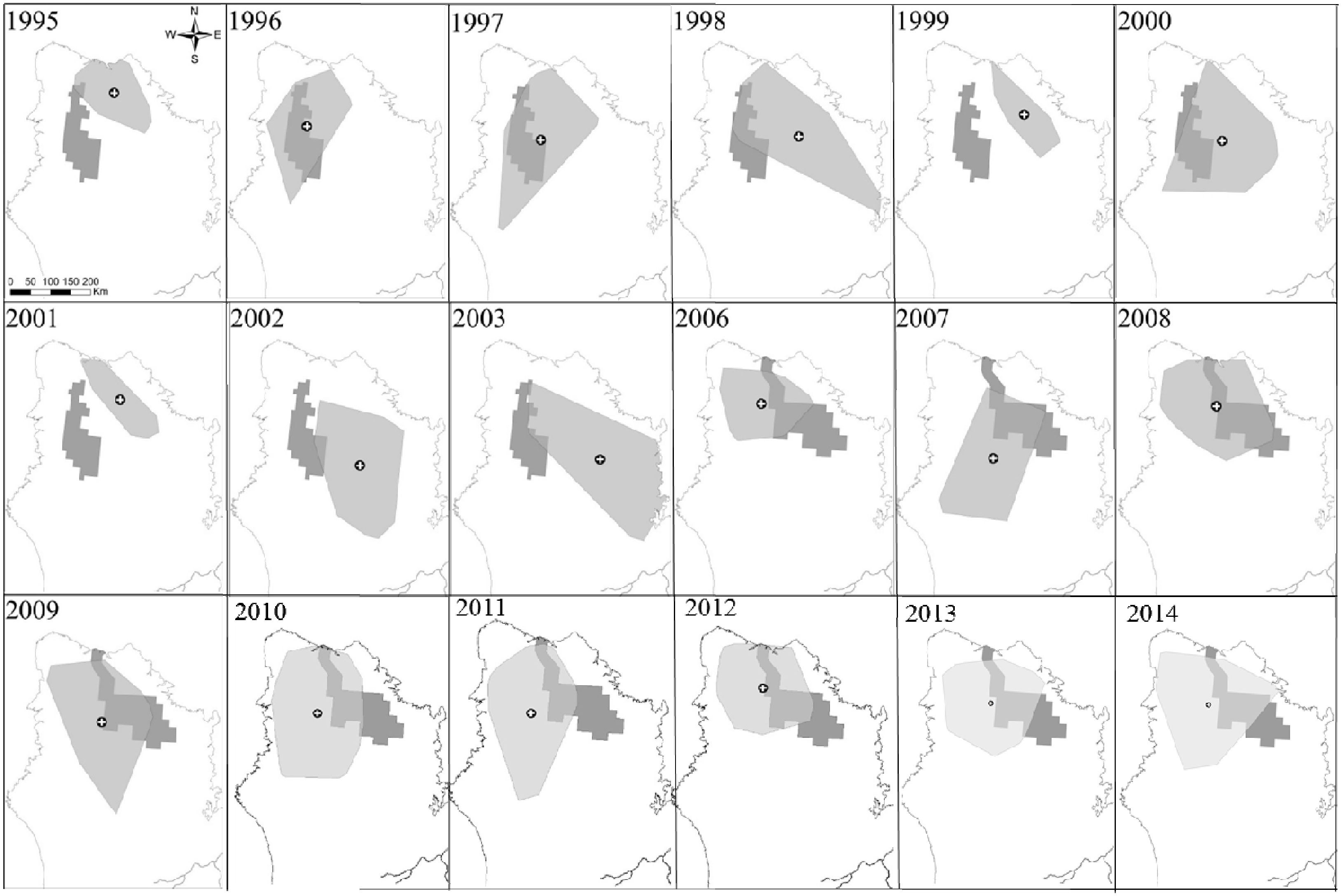


Figure 14 Map of the spatial evolution of LRH calving grounds (light grey) since 1995. The black dot represents the centroid of the annual calving ground. The legal wildlife habitat is shown in dark grey. Its spatial location was redefined in 2004 (maps: Taillon et al. 2012b for 1995-2009).

Between 1990 and the early 2000s, LRH females performed two types of spring migration between their winter and summer ranges: 1) short migrations from winter ranges located near the Ungava Peninsula and 2) longer migrations from winter ranges located in the La Grande hydroelectric complex region. Since 2005, LRH caribou are almost exclusively undertaking long migrations between the La Grande hydroelectric complex region (winter range) and the Ungava Peninsula (calving grounds and summer range). A small proportion of the herd migrates only a short distance during the rut and remains in the northern portion of its winter range. However, these occurrences are not well documented. The telemetry monitoring allows us to document the spring migration corridors and to consider the seasonal displacements of caribou in land-use planning.

Fall migration

The telemetry monitoring has allowed us to analyze fall migratory corridors since 1995. In the 1990s, migratory routes led to the different winter ranges and since the mid-2000s, they have been concentrated along a northeast-southwest axis (Figure 4.15). The fall migration is preceded by a pre-migratory movement in September, during which males and females gather mainly in the Leaf River sector (58°N; 72°W) (M. Le Corre, C. Dussault and S. D. Côté, pers. comm.). Migration begins in October and continues until the herd reaches its winter ranges between the end of November and mid-December. Mating takes place between late October and early November, during the fall migration when the rut occurs for this species (Messier and Huot, 1985; Boulet et al., 2007). This period lasts about one month and is associated with significant energy expenditures for large males, who practically cease foraging in order to actively defend their access to females while continuing their migration. At end of the rut, mature males often show a significant loss of the body mass they accumulated during the summer (up to 20%; Kojola, 1991; mean of 15%; Mysterud et al., 2003; up to 30%; Barboza et al., 2004) and are subject to injuries from aggressive interactions with other males (Mysterud et al., 2003), which make them more vulnerable to predators and harsh weather conditions at the beginning of winter.

Rutting season, late October/early November

Fall migration – Phase 2, October/ December

Winter ranges, December/late March

Figure 15 Pattern of seasonal movements of the Leaf River herd. Based on the monitoring of adult females and males fitted with radio-collars between 2008 and 2014.

Overlap with the annual range of the George River herd

Partial overlap of the annual and seasonal ranges of the LRH and GRH was observed during the 1990s and the early 2000s (Couturier et al., 2004; Boulet et al., 2007). Since 1991, 16 females fitted with radio-collars which were traditionally using the GRH calving grounds were observed leaving the winter range used by both herds and migrating to the LRH calving grounds. The opposite behaviour has never been observed based on the telemetry monitoring. In total, these emigration events from the GRH to the LRH involved 5% of the 328 GRH females that were monitored by telemetry. The emigration of a female should not be considered as definitive, since at least 5 of the 16 documented emigrants returned to the GRH calving grounds in subsequent years. The telemetry data therefore suggest that immigration and emigration events cannot explain the recent variations in the size of the two herds. Moreover, the telemetry monitoring shows that, since 2006, the overlap between the two herds is almost nonexistent and that no radio-collared females have switched herds since 2008. The current annual ranges of the two herds were separated by nearly 200 km (Figure 1).

2.7 Interactions with woodland caribou and muskox

The annual range of the LRH migratory caribou overlaps the habitat used by other ungulate populations such as the woodland caribou, the moose (*Alces americanus*) and the muskox (*Ovibos moschatus*) (Couturier et al., 2004; Boulet et al., 2007).

Woodland caribou

The theoretical annual range of the woodland caribou in Québec is defined by the northern limit of black spruce stands. According to this definition, woodland and migratory caribou share the portion of the annual range of the LRH that is used during the winter (from mid-November to mid-April). However, the distribution and number of woodland caribou north of the 52nd parallel is unknown and characterizing the mix of ecotypes on this basis is not possible. Three woodland caribou herds (Nottaway, Assinica and Témiscamie) (Rudolph et al., 2012) are likely to interact with the LRH at the southern limit of its winter range. While studies based on molecular ecology indicate possible genetic exchanges between the LRH and the Jamésie herds (Boulet et al., 2007), it is currently impossible to quantify the interactions between the two ecotypes.

Bœuf musqué

Muskoxen were introduced in captivity to Nunavik in 1967 and released into the natural environment between 1973 and 1983 in the regions of Kuujjuaq and Tasiujaq (Le Hénaff, 1986). Subsequent colonization took place towards the west of the Ungava Peninsula (MFFP, unpublished data). The population increased from 55 individuals (introduced population) to 553 in 1991, and to an estimated 1,400 in 2003 established following an aerial survey (Jean et al., 2004). The current size of this population is unknown. The estimated distribution of muskoxen in northern Québec comes from a compilation of observations. A few groups were first observed near Kuujjuaq, Tasiujaq, Kangirsuk and Quaqtaq, on Diana Island, near Innuksuak River and the Little Whale River (Jean et al., 2004; Jean and Rivard, 2005). It is currently estimated that the distribution of the muskoxen covers most of the coast of the Ungava Peninsula and the banks of the Aux Mélèzes River (MFFP, unpublished data).

The interactions between migratory caribou and muskoxen in northern Québec are poorly documented. However, they are of concern for several Inuit communities who have suggested that muskoxen displace the caribou from some sectors (Hunting, Fishing and Trapping Coordinating Committee, 2010; 2012). The potential competition between migratory caribou and muskoxen has been the subject of research projects, especially on Banks Island in the Northwest Territories. Some studies suggested that the two species can cohabit with little competition (Wilkinson et al., 1976; Vincent and Gunn, 1981) due to differences in habitat preference and diet (Wilkinson et al. 1976; White, 1983). However, one study did suggest that competition between the two species for winter food resources increases significantly with muskoxen density (Larter and Nagy, 1995). It is important to consider that muskoxen are a species with a strong potential for population growth and that they can reach a high density (Shank, 1991; Jean and Rivard, 2005). The recent expansion of the muskoxen distribution in Nunavik could therefore result in increased overlap with the areas used by the LRH.

2.8 Summary

Current trend

The results of aerial surveys and the monitoring of demographic indicators (survival rates and recruitment) indicate that the size of the LRH increased until 2001 and then declined. The most recent census estimated the population at around 430,000 in 2011. According to the observations of Aboriginal users, especially Inuit and Cree hunters, the LRH is declining in population size. The annual monitoring of survival rates and recruitment suggest that the size of the LRH was stable between 2008 and 2013. However, the most recent recruitment and adult survival data (see sections 2.2 and 2.4) suggest that the LRH experienced a significant demographic decline between 2013 and 2014, and that a more moderate decline continued in 2014-2015. In the fall of 2015, the population was estimated at around 332,000 caribou, a decline of approximately 6.5% compared to the fall of 2014. In addition to demographic indicators, changes observed in the size of the annual and seasonal ranges of the LRH followed past and recent fluctuations (growth, decline and stability phases) in population size. Since the early 2000s, the annual range has remained stable at around 489,600 ± 36,800 km^2. Since 2001, monitoring of the different demographic indicators (e.g., survival, recruitment and delineation of annual and seasonal ranges) has allowed us to refine the interpretation of the LRH trend.

3. Limiting factors and threats

3.1 Limiting factors

3.1.1 Habitat availability and quality

Maintaining the availability and functionality of seasonal habitats and their connectivity is crucial to the persistence of large herds of migratory caribou (Festa-Bianchet et al., 2011). For example, the spatial distribution and availability of vegetation on the summer ranges seem to play a key role in the population dynamics of the migratory caribou of northern Québec (Crête and Huot, 1993). However, there is currently little data available to evaluate the availability and quality of seasonal ranges used by the LRH (see section 2.6). These areas could potentially be affected by current and future activities associated with land-use development and climate change (see sections 3.1.7 and 3.2). Current or future industrial activities in proximity to the range of the LRH could, for example, interfere with the access to habitats and the seasonal movements of caribou (see section 3.2). To date, no research has been conducted to evaluate the cumulative effects of anthropogenic activities on the territory and the use of space by the LRH. This information is essential, however, to ensure the persistence of this herd.

3.1.2 Natural population fluctuations

Through grazing and trampling, the caribou have an impact on their habitat (Crête and Huot, 1993; Couturier et al., 2004). When present in large numbers, the caribou degrade their habitat, which generally results in lower food quantity and quality per individual (Crête and Doucet, 1998; Crête et al., 1990; Crête et al., 1996; Manseau et al., 1996). According to GRH studies conducted at the beginning of the 1990s, while this herd was at high population size, the degradation of summer habitats was accompanied by a decline in the body condition of individuals, in female fecundity and in calf survival (Crête and Huot, 1993; Crête et al., 1996). This can have a regulating role (limiting factor) on population size (Messier et al., 1988), which partly explains the natural variations in the demography of migratory caribou herds.

3.1.3 Diseases and parasites

As mentioned in section 2.5, caribou are natural hosts to numerous parasites and diseases that only rarely have major deleterious effects on individuals and populations (Fréchette, 1986). However, the general effect of parasites and diseases on the body condition of animals and on population dynamics is not well known (Hughes et al., 2009).

Some studies suggest that parasites and diseases can affect the activity budget[12] of individuals, along with their aggregation and movement behaviours (Fauchald et al., 2007; Witter et al., 2012a). Infestations of warble flies (parasitic flies; *H. tarandi* and *Cephenemyia trompe*) can result in a reduction of time spent foraging in adults and of time spent suckling in calves (Fauchald et al., 2007; Witter et al., 2012a), which could result in reduced calf growth, adult body condition and pregnancy rates in the fall

---

[12] Activity budget: Allocation of time to different daily activities, including feeding, resting, movement, social interactions and reproduction.

(Weladji et al., 2003; Cuyler et al., 2012; Pachkowski, 2012). The increase in temperatures in northern regions could favour the emergence of such parasitic insects, thus resulting in a longer season of infestation and of harassment of caribou (Witter et al., 2012a; Witter et al., 2012b).

Parasites and diseases usually have more direct effects on individuals that are in poor body condition (e.g., famine, nutritional deficits, etc.). Caribou are also more sensitive and vulnerable when exposed to new parasites and diseases for which they have not developed effective immune responses. For example, as moose and white-tailed deer expand their range northwards, this could expose the caribou to potentially fatal parasites (e.g., brain worm, *Parelaphostrongylus tenuis*) and to the prion responsible for chronic wasting disease in cervids. The potential changes in the prevalence of these pathogens are currently unknown in the context of climate change and recent anthropogenic disturbances.

3.1.4 Predation

As explained in section 2.2, predation is part of the natural ecology of migratory caribou. The caribou is a prey species for the wolf and black bear. Wolves are effective predators of both calves and adults, while black bears focus more on calves during the calving season. Black bears can however take down adults when the latter are caught by surprise, particularly by being ambushed along a migration route. Typically, predators take animals that are sick or in poor body condition, as well as young animals that are often slower and less agile than adults (Seip, 1991). The effect of predation on the population dynamics of migratory caribou herds is complex and little studied to date (Seip, 1991; Wang et al., 2009). Predation may have a considerable effect on the population dynamics of caribou, especially when a population is low in number or in decline (Wittmer et al., 2005).

The direct (e.g., mortality) and indirect (e.g., avoidance of a habitat by the prey) effects of predation can interact with those of human activities, leading to stronger negative impacts on a given herd (Wittmer et al., 2005; Wang et al., 2009). Generally, the impact of predation is inversely proportional to the abundance of prey, i.e., as a population of prey decreases, a greater proportion of it is removed. This can continue until the scarcity of the prey (in the absence of alternative prey species) affects the population dynamics of the predators. The effect of predation on caribou populations is of particular concern in the current context of a northward expansion of other cervids (e.g., white-tailed deer and moose). These cervids are usually accompanied by their guilds of predators and contribute to the maintenance of wolf and black bear populations (Wang et al., 2009), thus exposing the caribou to more intense predation pressure (Schaefer et al., 1999; Vistnes and Nellemann, 2008), even when caribou populations (whether migratory or other ecotype) are in decline.

3.1.5 Forest fires

Forest fires of natural or human origin may contribute to the destruction of vast stretches of winter habitat that are suitable for woodland caribou and migratory caribou. Forest fires can also disturb habitat use and migration patterns (Joly et al., 2010). The risks associated with forest fires could increase with the expansion of human activities in the boreal forest, as well as with climate change (Rupp et al., 2006). For example, since the 1960s, the average annual area of boreal forest burned by large fires has increased in the taiga ecozones of Canada (Krezek-Hanes et al., 2011). The increase in the size, intensity and frequency of forest fires could result from changes in temperature and precipitation regimes (Rupp et al., 2006; Krezek-Hanes et al., 2011).

3.1.6 Contaminants

Some pollutants released from the development of roads, from various types of industrial developments or from atmospheric sources fall on snow cover and on the vegetation eaten by caribou. Among these pollutants are various heavy metals and other contaminants that can accumulate in the caribou's tissue (e.g., cadmium, lead and mercury; Gamberg et al., 2005). The monitoring of heavy metal and contaminant concentrations collected from LRH caribou is detailed in section 2.5. The effects of these heavy metals and contaminants on the body condition, behaviour, survival and reproduction rates of caribou remain poorly understood.

3.1.7 Climate change

In northern environments, climate change is happening more quickly and often with greater magnitude than in temperate or tropical environments (Gilg et al., 2012). The models developed by the Ouranos Consortium (Ouranos, 2010) suggest that climate change will take place over all of Québec by changes in the average and the distribution of temperature and precipitation patterns. These models suggest more important changes in the northern regions than in the southern regions of Québec. By 2050, these models predict that winter temperatures could increase by 4.5°C to 6.5°C and summer temperatures by 1.6°C to 2.8°C in northern Québec (Ouranos, 2010). These models also suggest, by 2050, an increase in winter precipitations of 16.8 to 29.4% and of summer precipitations of 3.0 to 12.1% in northern Québec (Ouranos, 2010). The pressures exerted by such changes on northern ecosystems and wildlife species like the migratory caribou are expected to become increasingly pronounced in the future.

Climate change implies changes in temperature and precipitation patterns that can have impacts on the habitat, movements, body condition and productivity of caribou (see Table 1 in Gunn et al., 2011; Joly et al., 2011). An increase in temperatures can lead, among others, to faster vegetation growth, greater access to plant biomass and increases in shrub cover (Tremblay, 2010). For example, increased shrub cover has been documented in many subarctic regions and more recently on the summer grounds of the GRH, where the woody cover increased by over 32% between the 1960s and 2000s (Tremblay, 2010). An increase in shrub cover was also monitored on the LRH range (Ropars and Boudreault, 2011). The change in shrub cover raises questions about the interaction between caribou herds and their summer food resources. However, a change in temperature patterns can also lead to decreased lichen cover, permafrost melting, longer season of harassment by biting and parasitic insects, and more frequent events of rain on snow during the winter (Tyler, 2010; Witter et al., 2012a; Witter et al., 2012b).

Climate change will probably alter the conditions encountered during migrations (Sharma et al., 2009). Changing patterns of snowmelt and spring break-up of lake and river ice, as well as freeze-up in fall, will probably force the caribou to modify the timing of their movements or their traditional migration patterns.

Sharma et al. (2009) suggest that the seasonal ranges of the LRH will change substantially over the next 50 years. According to climate projections, the LRH will increase its range over all seasonal ranges used (see Sharma et al. 2009 for details). This will potentially modify the herd's use of space, access to resources and migration distances. The capacity of migratory caribou to adjust their use of space in response to changing precipitation and temperature regimes is not known. The effects of climate change could potentially act in synergy with the effects of land-use development on caribou habitat (see section 3.2).

3.1.8 Hunting and poaching

Hunting is central to the relationship between humans and caribou, and is often a privileged source of information on the body condition, distribution and ecology of caribou. As with predation, the harvest rate from hunting may be inversely proportional to abundance, i.e., as the caribou population declines, a higher proportion of it is removed by hunting. As was seen with the Cap Bathurst, Bluenose-West and Bathurst herds in Western Canada, hunting can accelerate the decline of caribou herds (Adamczewski et al., 2009; Boulanger et al., 2011).

The growing human population in northern regions has inevitably led to a greater demand for food resources. Recently, the access to powerful motorized vehicles (snowmobiles, all-terrain vehicles and aircraft) and technological advances (tracking and telecommunication devices, GPS devices, satellite telephones) have modified harvesting practices for food purposes and practices of sport hunters, leading to easier and more efficient harvesting (Nesbitt and Adamczewski, 2009; Adamczewski et al., 2009). Moreover, the development and maintenance of roads and the frequent use of aircraft offer privileged access to various hunters while facilitating the tracking and locating of caribou.

Many Aboriginal and non-Aboriginal users have been and are still harvesting the LRH. The main users known for harvesting or having harvested LRH caribou in recent decades are:

- the Inuit of Québec;
- the Cree of Québec;
- the Naskapi of Québec;
- non-Aboriginal residents of Québec;
- non-residents of Québec.

The LRH was also subjected to commercial hunting in Québec between 1994 and 2002. The harvest management history and changes in the harvest of the LRH (sport harvest by non-Aboriginal, harvest for food purposes by Aboriginals, and commercial harvest) will be detailed in the next management plan (MFFP, unpublished data).

3.2 Identification of activities related to land development

Recent literature reviews have indicated that the major threats to the persistence of the migratory caribou are exploitation (including hunting and poaching), expanding land uses associated with industrial activities, and climate change (Festa-Bianchet et al., 2011; Gunn et al., 2011). Limiting factors (see section 3.1) and different threats can act in synergy, with varying effects based on population size and trend.

3.2.1 Mining exploration and exploitation

In recent decades, industrial development has increased in northern regions mostly due to the exploitation of hydrocarbon mining and hydroelectric energy (Wolfe et al., 2000; Vistnes and Nellemann, 2001; Haskell et al., 2006; Reimers et al., 2007). The exploration and exploitation activities contribute to habitat loss, increase disturbance and facilitate human access to the territory. In Alaska and Western Canada, several infrastructures and industrial developments have been established in proximity to the calving grounds and summer ranges of migratory caribou herds. At this period of their life cycle, females and calves are particularly sensitive to disturbance by anthropogenic activities (Nellemann and Cameron, 1998; Wolfe et al., 2000). The presence of infrastructures and human activities can lead to decreased use by the caribou within a radius of 10 to 15 km, and can even lead to the abandonment of critical seasonal ranges (Boulanger et al., 2004). The caribou can then move to less favourable areas where food resources are less available but where the presence of predators may be increased (Cameron et al., 1992; Nellemann and Cameron, 1996).

During recent decades, several exploration initiatives have been undertaken in northern Québec (Government of Québec, 2015). Rich deposits were discovered within the LRH range and in 2015, there were three active[13] mines: Raglan Mine, Glencore Xstrata (nickel, copper, PGE and cobalt); Nunavik Nickel, Canadian Royalties (nickel and copper); and Éléonore, Goldcorp (gold), as well as a mineral resources development project[14], Hopes Advance Bay, Oceanic Iron Ore (iron).

These mining activities (ongoing or under development), are taking place in the LHR range and could potentially interfere with the access to seasonal habitats (calving and summer ranges) and with seasonal movements (migratory corridors) (Boulanger et al., 2012). Mining exploitation requires access to deep water ports from which to export the minerals (Government of Québec, 2015). This generally involves the establishment of overland routes (roads or railways) for transporting the minerals to the coast of the Ungava Bay or the Hudson Bay. The development of roads and infrastructures to improve access to the territory could result in a net loss of habitat, disrupt migratory routes (Vistnes and Nellemann, 2001; Vistnes et al., 2004) and lead to increased human presence in the territory used by the LRH (see section 3.1.8).

Restoration of mining sites

Northern ecosystems have low resilience to disturbances; their ability to return to their initial state after a disturbance is limited and can take years or even decades. The regeneration of vegetation following a disturbance is thus a very slow process in northern environments (Forbes et al., 2001). The ecological footprint left by anthropogenic activities is even more apparent when the restoration of mining sites is

---

[13] Active mine: Site with active exploitation of minerals (metallic and non-metallic minerals) (Government of Québec, 2012).

[14] Mineral resources development project: Step divided into four sub-steps, including the definition of tonnage deposit assessed under Standard 43-101 of the Canadian Institute of Mining, Metallurgy and Petroleum, the definition of technical parameters (engineering), and the definition of economic parameters, until the conclusion of the feasibility study (Government of Québec, 2012).

neglected. Moreover, caribou usually avoid areas that have been disturbed by industrial activities (Nellemann and Cameron, 1998; Vistnes and Nellemann, 2001). Measures to restore mining sites should therefore take into account the resilience capacity and particular characteristics of northern environments (Government of Québec, 2015).

3.2.2 Hydroelectric development

Since the 1970s, the development of the La Grande complex has led to the conversion of some 2,000 km^2 of bodies of water and 11,000 km^2 of land into vast reservoirs (Therrien et al., 2004). The construction of reservoirs and the flooding of large areas of taiga may have reduced the availability of winter habitats that are rich in lichens for migratory caribou. The presence of these vast artificial bodies of water and their seasonal icing and melting patterns can result in the modification of the migratory routes of caribou (Tyler, 2010). For example, the sections of open water located downstream from hydroelectric plants can represent additional risks of drowning, while the water build-up in spring can create ice barriers that are a major obstacle for the caribou. Hydroelectric development also involves building new roads and infrastructures as well as maintaining power line corridors, which may impact the behaviour and migratory routes of caribou (Vistnes et al., 2004; Vistnes and Nelleman, 2008). The development of new hydroelectric projects in Québec and Labrador could therefore interfere with the use of seasonal ranges and the migratory movements of the LRH.

3.2.3 Access to the territory

The expansion of human populations and the increase in land-use development require new transportation infrastructures to facilitate access to the territory. Transportation infrastructures can have various impacts on wildlife and their habitats. These structures can, among others, 1) reduce the accessibility and quality of food resources as the landscape is fragmented (Dyer et al., 2001; Nellemann and Cameron, 1998); 2) result in direct mortality due to road collisions (Dussault et al., 2006); 3) increase the predation risks when the caribou aggregate near roads or predators take advantage of easier movements through their territory (Courbin et al., 2009; Whittington et al., 2011); 4) act as physical barriers to the caribou's seasonal movements (Vistnes et al., 2004). The presence of transportation infrastructures can also have indirect impacts on body condition and survival due to behavioural changes and the displacement of seasonal ranges (Vistnes and Nellemann, 2001; Leblond et al., 2013). Lastly, roads provide privileged access to hunters and can thereby facilitate poaching activities. So far, increased access via transportation infrastructures, mostly from hydroelectric development, has been restricted to the southern part of the LRH range.

3.2.4 Parks and protected areas

Despite their vocation of wildlife protection and conservation, national parks and other wildlife development areas offer privileged access to areas that are of vital importance to the caribou. Ecotourism activities necessarily involves the development of transportation infrastructures and sometimes the construction of temporary or permanent buildings. Numerous studies have shown that anthropogenic disturbance through tourism activities has direct and indirect impacts on the habitat use behaviour of wildlife (Knight and Gutzwiller, 1995; Duchesne et al., 2000; Vistnes and Nellemann, 2001;

Stankowich, 2008). The presence of hikers and recreotourism activities can affect caribou behaviour by causing the animals to avoid quality habitats that are essential to their life cycle (Nellemann et al., 2000).

In the context of development in northern Québec, a number of areas for the creation of parks and wildlife development territories are targeted (MFFP, 2015). Some of them overlapped, in 2015, with the summer range and migratory corridors of the LRH: the *Parc national des Pingualuit* (1,133.9 km^2), the *Parc national Tursujuq* (26,106.7 km^2) and a few parcels of land reserved for national parks: Baie-aux-Feuilles (about 3,868 km^2) and Cap-Wolstenholme (about 777.5 km^2) (MFFP, 2015). The planning and creation of these parks and reserves, including the activities to be allowed within them[15], should attempt to minimize repercussions on the caribou and its habitat.

---

[15] According to chapter 24 of the *James Bay and Northern Québec Agreement* and the *Act respecting hunting and fishing rights in the James Bay and New Québec territories* (CQLR, chapter D-13.1), beneficiaries of northern agreements (JBNQA and NEQA) can enjoy their right to harvest within national parks and reserves located in the Nunavik region.

References

ADAMCZEWSKI, J. Z., J. BOULANGER, B. CROFT, D. CLUFF, B. ELKIN, J. NISHI, A. KELLY, A. D'HONT and C. NICOLSON (2009). *Decline in the Bathurst Caribou Herd 2006-2009: A Technical Evaluation of Field Data and Modeling*: Wildlife Division, Government of Northwest Territories, Yellowknife, NT, 105 p.

ADAMS, L. G. (2005). “Effects of maternal characteristics and climatic variation on birth masses of Alaskan caribou.” *Journal of Mammalogy*, 86: 506-513.

BANFIELD, A. W. F (1961). *A revision of the reindeer and caribou, genus* Rangifer: National Museum of Canada Bulletin, Biol. Ser. No. 66, 137 p.

BARBOZA, P. S., K. L. PARKER and I. D. HUME (2009). *Integrative Wildlife Nutrition*: Springer, Berlin, Germany, 342 p.

BARBOZA, P. S., D. W., Hartbauer, W. E., Hauer and J. E. BlakE (2004). “Polygynous mating impairs body condition and homeostasis in male reindeer (*Rangifer tarandus tarandus*).” *Journal of Comparative Physiology series B*, 174: 309-317.

BARRETTE, C. and D. VANDAL (1986). “Social Rank, Dominance, Antler Size, and Access to Food in Snow-Bound Wild Woodland Caribou.” *Behaviour*, 97: 118-146.

BASTILLE-ROUSSEAU, G., C. DUSSAULT, S. COUTURIER, D. FORTIN, M.-H. ST-LAURENT, P. DRAPEAU, C. DUSSAULT and V. BRODEUR (*in revision*). *Sélection d’habitat du caribou forestier en forêt boréale québécoise*, Direction de l’expertise sur la faune et ses habitats, Faune Québec, ministère du Développement durable, de l’Environnement, de la Faune et des Parcs, 48 p.

BERGERUD, A. T. (1980). *A review of the population dynamics of caribou and wild reindeer in North America*. p. 556-581 in: *Proceedings of the Second International Reindeer/Caribou Symposium*, 1979, Roros, Norway.

BERGERUD, A. T., S. N. LUTTICH and L. CAMPS (2008). *The Return of Caribou to Ungava*, McGill-Queen's University Press, Montreal & Kingston, 586 p.

BONENFANT, C., J.-M. GAILLARD, T. COULSON, M. FESTA-BIANCHET, A. LOISON, M. GAREL, L. E. LOE, P. BLANCHARD, N. PETTORELLI, N. OWEN-SMITH, J. DU TOIT and P. DUNCAN (2009). “Empirical Evidence of Density – Dependence in Populations of Large Herbivores.” *Advances in Ecological Research*, 41: 313-357.

BOULANGER, J., K. POOLE, B. FOURNIER, J. WIERZCHOSWSKI, T. GAINES and A. GUNN (2004). *Assessment of Bathurst Caribou Movements and Distribution in the Slave Geological Province*, Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, Yellowknife, NT., 108 p.

BOULANGER, J., A. GUNN, J. Z. ADAMCZEMSKI and B. CROFT (2011). “A data-driven demographic model to explore the decline of the Bathurst caribou herd.” *Journal of Wildlife Management*, 75: 883-896.

BOULANGER, J., K. G. POOLE, A. GUNN and J. WIERZCHOSWSKI (2012). « Estimating the zone of influence of industrial developments on wildlife: a migratory caribou *Rangifer tarandus groenlandicus* and diamond mine case study», *Wildlife Biology*, 18: 164-179.

BOULET, M., S. COUTURIER, S. D. CÔTÉ, R. D. OTTO and L. BERNATCHEZ (2007). “Integrative use of spatial, genetic, and demographic analyses for investigating genetic connectivity between migratory, montane, and sedentary caribou herds.” *Molecular Ecology*, 16: 4223-4240.

CAMERON, R. D., D. J. REED, J. R. DAU and W. T. SMITH (1992). “Redistribution of Calving Caribou in Response to Oil Field Development on the Arctic Slope of Alaska”, *Arctic*, 45: 338-342.

CAMERON, R. D., W. T. SMITH, S. G. FANCY, K. L. GERHART and R. G. WHITE (1993). “Calving success of female caribou in relation to body weight.” *Canadian Journal of Zoology*, 71: 480-486.

CARIBOU UNGAVA (2015). http://www.caribou-ungava.ulaval.ca/en

CARMA (CircumArctic Rangifer Monitoring and Assessment Network) (2015). Available at http://caff.is/carma

CLS (2011). Argos User's Manual. Worldwide tracking and environmental monitoring by satellite. Available at http://www.argos-system.org/manual/

CLUTTON-BROCK, T. H. and T. COULSON (2002). “Comparative ungulate dynamics: the devil is in the detail.” *Philosophical Transactions of the Royal Society of London, Series B*, 357: 1285-1298.

COSEWIC (2002). *COSEWIC Assessment and Update Status Report on the Woodland Caribou* Rangifer tarandus caribou *in Canada*. Committee on the Status of Endangered Wildlife in Canada. Ottawa, Ontario: xii + 112 p.

COSEWIC (2011). *Designatable Units for Caribou (*Rangifer tarandus*) in Canada*. Committee on the Status of Endangered Wildlife in Canada. Ottawa, Ont., 88 p.

COURBIN, N., D. FORTIN, C. DUSSAULT and R. COURTOIS (2009). “Landscape management for woodland caribou: the protection of forest blocks influences wolf-caribou co-occurrence”, *Landscape Ecology*, 24: 1375-1388.

COURTOIS, R., L. BERNATCHEZ, J.-P. OUELLET and L. BRETON (2002). *Les écotypes de caribou forment-ils des entités génétiques distinctes?* Direction de la recherche sur la faune, Société de la faune et des parcs du Québec, Québec City, Québec, 35 p.

COUTURIER, S. (1994). *Estimation des effectifs du troupeau de caribous de la rivière aux Feuilles en juin 1991, Nord-du-Québec.* Ministère du Loisir, de la Chasse et de la Pêche. Québec City, Québec, 18 p.

COUTURIER, S., D. JEAN, R. OTTO and S. RIVARD (2004). *Demography of the migratory tundra caribou* (Rangifer tarandus) *of the Nord-du-Québec region and Labrador*, Direction de l'aménagement de la faune du Nord-du-Québec et Direction de la recherche sur la faune, ministère des Ressources naturelles, de la Faune et des Parcs, Québec City, Québec, 68 p.

COUTURIER, S., S. D. CÔTÉ, R. OTTO, R. B. WELADJI and J. HUOT (2009a). “Variation in Calf Body Mass in Migratory Caribou: The Role of Habitat, Climate, and Movements.” *Journal of Mammalogy*, 90: 442-452.

COUTURIER, S., S. D. CÔTÉ, J. HUOT and R. D. OTTO (2009b). “Body-condition dynamics in a northern ungulate gaining fat in winter.” *Canadian Journal of Zoology*, 87: 367-378.

COUTURIER, S., R. D. OTTO, S. D. CÔTÉ, G. LUTHER and S. P. MAHONEY (2010). “Body size variations in caribou ecotypes and relationships with demography.” *Journal of Wildlife Management*, 74: 395-404.

CRÊTE, M., D. LE HÉNAFF, R. NAULT, D. VANDAL and N. LIZOTTE (1987). *Estimation du nombre de caribous associés aux aires de mise bas de la rivière aux Feuilles et de la rivière George en 1986.* Ministère du Loisir, de la Chasse et de la Pêche. Québec City, Québec, 31 p.

CRÊTE, M., J. HUOT and L. GAUTHIER (1990). “Food Selection During Early Lactation by Caribou Calving on the Tundra in Quebec.” *Arctic*, 43: 60-65.

CRÊTE, M. and J. HUOT (1993). “Regulation of a large herd of migratory caribou: summer nutrition affects calf growth and body reserves of dams.” *Canadian Journal of Zoology*, 71: 2291-2296.

CRÊTE, M., S. COUTURIER, B. J. HEARN and T. E. CHUBBS (1996). “Relative contribution of decreased productivity and survival to recent changes in the demographic trend of the Rivière George Caribou Herd.” *Rangifer*, 9: 27-36.

CRÊTE, M. and G. J. DOUCET (1998). “Persistent Suppression in Dwarf Birch after Release from Heavy Summer Browsing by Caribou.” *Arctic and Alpine Research*, 30: 126-132.

CURRY, P.S. (2012) *Blood on Filter Paper for Monitoring Caribou Health: Efficacy, Community-Based Collection, and Disease Ecology in Circumpolar Herds*, doctoral thesis, department of ecosystem and public health, University of Calgary, Calgary, Alberta, 308 p.

CUYLER, C., R. WHITE, K. LEWIS and C. SOULLIERE (2012). « Are warbles and bots related to reproductive status in West Greenland caribou ? », *Rangifer*, 32: 243–257.

DUCHESNE, M., S. D. CÔTÉ and C. BARRETTE (2000). “Responses of woodland caribou to winter ecotourism in the Charlevoix Biosphere Reserve, Canada.” *Biological Conservation*, 96: 311-317.

DUCROCQ, J. (2010) *Écologie de la besnoitiose chez les populations de caribous* (Rangifer tarandus) *des régions subarctiques,* Master thesis, département des sciences cliniques, faculté de médecine vétérinaire, Université de Montréal, Montréal, Québec, 95 p.

DUCROCQ, J., G. BEAUCHAMP, S. J. KUTZ, M. SIMARD, B. Elkin, J. TAILLON, S. D. CÔTÉ, V. BRODEUR, M. Campbell, D. Cooley, C. Cuyler and S. LAIR (2012). “Comparison of gross visual and microscopic assessment of four anatomic sites to monitor *Besnoitia tarandi* in barren-ground caribou (*Rangifer tarandus*).” *Journal of Wildlife Diseases*, 48: 732-738.

DUCROCQ, J., G. BEAUCHAMP, S. J. KUTZ, M. SIMARD, J. TAILLON, S. D. CÔTÉ, V. BRODEUR and S. LAIR (2013). “Variables associated with *Besnoitia tarandi* prevalence and cyst density in barren-ground caribou (*Rangifer tarandus*) populations.” *Journal of Wildlife Diseases*, 49: 29-38.

DUQUETTE, L. S. (1988). “Snow Characteristics along Caribou Trails and within Feeding Areas during Spring Migration.” *Arctic*, 41: 143-144.

DUSSAULT, C., M. POULIN, R. COURTOIS and J. P. OUELLET. (2006). « Temporal and spatial distribution of moose vehicle accidents in the Laurentides Wildlife Reserve, Quebec, Canada. », *Wildlife Biology*, 12: 415-425.

DYER, S. J., J. P. O'NEILL, S. M. WASEL and S. BOUTIN (2001). “Avoidance of industrial development by woodland caribou.” *Journal of Wildlife Management*, 65: 531-542.

ENVIRONNEMENT CANADA (2012a). *Management Plan for the Northern Mountain Population of Woodland Caribou* (Rangifer tarandus caribou) *in Canada.* Species at Risk Act Management Plan Series. Environment Canada. Ottawa, Ont., viii + 91 p.

ENVIRONNEMENT CANADA (2012b). *Recovery Strategy for the Woodland Caribou* (Rangifer tarandus caribou)*, Boreal population, in Canada*. Species at Risk Act Management Plan Series. Environment Canada. Ottawa, Ont., xii + 152 p.

ÉQUIPE DE RÉTABLISSEMENT DU CARIBOU DE LA GASPÉSIE (Gaspésie Woodland Caribou Recovery Team) (2011). *Bilan du rétablissement du caribou de la Gaspésie* (Rangifer tarandus caribou) *pour la période 1990-2009*. Direction de l'expertise Énergie-Faune-Forêts-Mines-Territoire de la Gaspésie–Îles-de-la-Madeleine et Direction de l'expertise sur la faune et ses habitats, Faune Québec, ministère des Ressources naturelles et de la Faune, 25p.

ÉQUIPE DE RÉTABLISSEMENT DU CARIBOU FORESTIER DU QUÉBEC (2013). *Plan de rétablissement du caribou forestier* (Rangifer tarandus caribou) *au Québec – 2013-2023*, produit pour le compte du ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec, Faune Québec, Québec City, Québec 110 p.

FANCY, S. G. and R. G. WHITE (1985). "Energy expenditures by caribou while cratering in snow." *Journal of Wildlife Management*, 49: 987-993.

FAUCHALD, P., R. RØDVEN, B.-J. BÅRDSEN, K. LANGELAND, T. TVERAA, N. G. YOCCOZ and R. A. IMS. (2007) « Escaping parasitism in the selfish herd: Age, size and density-dependent warble fly infestation in reindeer», *Oikos* 116: 491–499.

FESTA-BIANCHET, M., J. C. RAY, S. BOUTIN, S. D. CÔTÉ and A. GUNN (2011). "Caribou conservation in Canada: an uncertain future." *Canadian Journal of Zoology*, 89: 419-434.

FORBES, B. B., J. J. EBERSOLE and B. STRANDBERG (2001). « Anthropogenic disturbances and patch dynamics in circumpolar arctic ecosystems », *Conservation biology* 15: 954-969.

FRÉCHETTE, J.-L. (1986). *Guide pratique des principaux parasites et maladies de la faune terrestre et ailée du Québec,* Distribution Pisciconsult inc., Saint-Hyacinthe, Québec, 280 p.

GAILLARD, J. M., M. FESTA-BIANCHET, N. G. YOCCOZ, A. LOISON and C. TOÏGO (2000). "Temporal Variation in Fitness Components and Population Dynamics of Large Herbivores." *Annual Review of Ecology and Systematics*, 31:367-393.

GAILLARD, J. M., A. LOISON, C. TOÏGO, D. DELORME and G. VAN LAERE (2003). "Cohort effects and deer population dynamics." *Écoscience*, 10: 412-420.

GAILLARD, J. M. and N. G. YOCCOZ (2003). "Temporal variation in survival of mammals: a case of environmental canalization?" *Ecology*, 84: 3294-3306.

GAMBERG, M., B. BRAUNE, E. DAVEY, B. ELKIN, P. F. HOEKSTRA, D. KENNEDY, C. MACDONALD, D. MUIR, A. NIRWAL, M. WAYLAND and B. ZEEB (2005). "Spatial and temporal trends of contaminants in terrestrial biota from the Canadian Arctic." *Science of the Total Environment*, 351: 148-164.

GASAWAY, W. C., S. D. DUBOIS, D. J. REED and S. J. HARBO (1986). *Estimating moose population parameters from aerial surveys*, Biological papers of the University of Alaska, Institute of Arctic Biology, University of Alaska-Fairbanks, Fairbanks, Alaska, 108 p.

GILG, O., K. M. KOVACS, J. AARS, J. FORT, G. GAUTHIER, D. GRÉMILLET, R. A. IMS, H. MELTOFTE, J. MOREAU, E. POST, N. M. SCHMIDT, G. YANNIC and L. BOLLACHE (2012). “Climate change and the ecology and evolution of Arctic vertebrates.” *Annals of the New York Academy of Sciences*, 1249: 166-190.

GOUVERNEMENT DU QUÉBEC (2015). *Rapport sur les activités minières au Québec 2014*, Québec, Direction générale de géologie Québec, secteur des opérations régionales et secteur des mines, Gouvernement du Québec, 128 p.

GUNN, A., K. G. POOLE and J. WIERZCHOWSKI (2008). *A Geostatistical Analysis for the Patterns of Caribou Occupancy on the Bathurst Calving Grounds 1966–2007.* Indian and Northern Affairs Canada, Yellowknife, NWT, 54 p.

GUNN, A., D. RUSSELL and J. EAMER (2011). *Northern Caribou Population Trends in Canada.* Canadian Biodiversity: Ecosystem Status and Trends 2010 – Technical Thematic Report No. 10. Canadian Councils of Resource Ministers, Ottawa, Ont., v + 78 p.

HAMLIN, K. L., D. F. PAC, C. A. SIME, R. M. DESIMONE and G. L. DUSEK (2000). “Evaluating the accuracy of ages obtained by two methods for Montana ungulates.” *Journal of Wildlife Management*, 64: 441–449.

HARDER, J. D. and R. L. Kirkpatrick (1996). *Physiological Methods in Wildlife Research.* p. 275-306 in: *Research and Management Techniques for Wildlife and Habitats. Fifth edition* (T. A. Bookhout, editor). The Wildlife Society, Bethesda, Md.

HASKELL, S. P., R. M. NIELSON, W. B. BALLARD, M. A. CRONIN and T. L. MCDONALD (2006). “Dynamic Responses of Calving Caribou to Oilfields in Northern Alaska.” *Arctic*, 59: 179-190.

HINKES, M. T., G. H. COLLINS, L. J. VAN DAELE, S. D. KOVACH, A. R. ADERMAN, J. D. WOOLINGTON and R. J. SEAVOY (2005). “Influence of population growth on caribou herd identity, calving ground fidelity, and behavior.” *Journal of Wildlife Management*, 69: 1147-1162.

HUGHES, J., S. D. ALBON, R. J. IRVINES and S. WOODIN (2009). “Is there a cost of parasites to caribou?” *Parasitology*, 136: 253-265.

HUNTING, FISHING AND TRAPPING COORDINATING COMMITTEE (2010). *Proceedings and summaries of the migratory caribou workshop, Montreal – January 20-22, 2010*. Prepared by P. F. Wilkinson and Associates, Montreal, 55 p.

HUNTING, FISHING AND TRAPPING COORDINATING COMMITTEE (2012). *Final proceedings and summaries of the migratory caribou workshop: Declining caribou: shared concerns, shared solutions – Montreal – September 11-13, 2012*. Prepared by T. D. Rudolph and A. Bourbeau-Lemieux, Montreal, 93 p.

HUOT, J. (1988). “Review of Methods for Evaluating the Physical Condition of Wild Ungulates in Northern Environments.” Nordicana. Ser. No. 50. Centre d’Études Nordiques, Université Laval, Québec. 30 p.

JEAN, D. and G. LAMONTAGNE (2004). *Plan de gestion du caribou (*Rangifer tarandus*) de la région Nord-du-Québec 2004-2010.* Ministère des Ressources naturelles et de la Faune. Québec City, Québec. 96 p.

JEAN, D., S. RIVARD and M. BÉLANGER (2004). *Inventaire et structure de population du bœuf musqué* (Ovibos moschatus) *au sud-ouest de la baie d'Ungava, août 2003.* Ministère des Ressources naturelles, de la Faune et des Parcs, Secteur Faune Québec. Chibougamau, Québec. 22 p.

JEAN, D. and S. RIVARD (2005). *Inventaire de la population de bœufs musqués* (Ovibos moschatus) *sur l'île Diana, près de Quaqtaq en juin 2005*. Ministère des Ressources naturelles et de la Faune, Secteur Faune Québec, Direction de l'aménagement du la faune du Nord-du-Québec, Chibougamau, Québec. 8 p.

JOLY, K., F. S. CHAPIN III and D. R. KLEIN (2010). « Winter habitat selection by caribou in relation to lichen abundance, wildfires, grazing, and landscape characteristics in northwest Alaska », *Ecoscience*, 17: 321-333.

JOLY, K., D. R. KLEIN, D. L. VERBYLA, T.S. RUPP and F.S. CHAPIN III (2011). "Linkages between large-scale climate patterns and the dynamics of Arctic caribou populations." *Ecography*, 34: 345-352.

KEECH, M. A., R. T. BOWYER, J. M. VER HOEF, R. D. BOERTJE, B. W. DALE and T. R. STEPHENSON (2000). "Life-history consequences of maternal condition in Alaskan moose." *Journal of Wildlife Management*, 64: 450-462.

KNIGHT, R. L. and K. J. Gutzwiller (1995). *Wildlife and Recreationists: Coexistence Through Management and Research*, Island Press, Washington, D.C. 372 p.

KOJOLA, I. 1991. "Influence of age on the reproductive effort of male reindeer." *Journal of Mammalogy*, 72: 208–210.

KREZEK-HANES, C. C., F. AHERN, A. CANTIN and M. D. FLANNIGAN (2011). *Trends in large fires in Canada, 1959-2007. Canadian Biodiversity: Ecosystem Status and Trends 2010,* Technical report No. 6, Canadian Councils of Resource Ministers, Ottawa, ON., vi + 48 p. http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-0

KWAN, M. K. H. (2011). *Heavy metals in Leaf River herd caribou and Nunavik muskoxen*, Nunavik Research Centre, Makivik Corporation, 33 p.

LANDETE-CASTILLEJOS, T., A. GARCIA, J. A. GOMEZ, A. MOLINA and L. GALLEGO (2003). "Subspecies and body size allometry affect milk production and composition, and calf growth in red deer: comparison of *Cervus elaphus hispanicus* and *Cervus elaphus scoticus.*" *Physiological and Biochemical Zoology*, 76: 594-602.

LARTER, N. C. and J. A. NAGY (1995). "Peary caribou, muskoxen and Banks Island forage: Assessing seasonal diet similarities." *Rangifer*, 17: 9-16.

LEBLOND, M., C. DUSSAULT and J.-P. OUELLET (2013). "Avoidance of roads by large herbivores and its relation to disturbance intensity." *Journal of Zoology*, 289: 32-40.

LE HÉNAFF, D. (1976). *Inventaire aérien des terrains de vêlage du caribou dans la région nord et au nord du territoire de la municipalité de la Baie James (mai – juin 1975).* Ministère du Tourisme, de la Chasse et de la Pêche, Direction de la recherche faunique, Québec City, Québec, 20 p.

LE HÉNAFF, D. (1980). *Inventaire national du caribou au nord du 55ème parallèle, mars et avril 1980.* Ministère du Loisir, de la Chasse et de la Pêche. Québec City, Québec, 14 p.

LE HÉNAFF, D. (1983). *Troupeau de caribous de la rivière aux Feuilles Nouveau-Québec – Recensement du terrain de vêlage.* Ministère du Loisir, de la Chasse et de la Pêche. Québec City, Québec, 14 p.

LE HÉNAFF, D. et G. HAYEUR (1983). *Résultat d'une étude télémétrique sur la population de caribous de la région du lac Bienville, mars 1977 à juin 1979.* Projet conjoint entre le Ministère du Loisir, de la Chasse et de la Pêche et Hydro-Québec. Québec City, Québec, 59 p.

LE HÉNAFF, D. (1986). *Inventaire, recensement et structure de population de boeuf musqué au nord-ouest de Kuujjuaq, Nouveau Québec juin 1983.* Ministère Loisir, Chasse et Pêche, Direction faune terrestre. Québec City, Québec, 10 p.

MANSEAU, M. (1996) *Relation réciproque entre les caribous et la végétation des aires d'estivage: le cas du troupeau de caribous de la rivière George*, Master thesis, Université Laval, Québec City, Québec, 168 p.

MFFP (2015). *Projets de parc national et de territoires de mise en valeur de la faune*, Québec, Ministère des Forêts, de la Faune et des Parcs. En ligne : http://mffp.gouv.qc.ca/parcs/reseau-parcs-nationaux/projets-parcs-nationaux.jsp

MESSIER, F. and J. HUOT (1985). *Connaissances sur le troupeau de caribous de la Rivière George,* Ministère du Loisir, de la chasse et de la Pêche, Québec, 98 p.

MESSIER, F., J. HUOT, D. LE HÉNAFF and S. LUTTICH (1988). "Demography of the George River Caribou Herd: Evidence of Population Regulation by Forage Exploitation and Range Expansion." *Artic*, 41: 279-287.

MILLER, F. L. (2003). "Caribou," in FELDHAMER, G. A., B. C. THOMPSON and J. A. CHAPMAN, *Wild Mammals of North America – Biology, Management, and Conservation*, The Johns Hopkins University Press, Baltimore and London, 965-997.

MILNER-GULLAND, E. J., J. M. FRYXELL and A. R. E. SINCLAIR (2011). *Animal Migration: A synthesis*. Oxford University Press, Oxford, 269 p.

MORDEN, C.-J. C., R. B. WELADJI, E. ROPSTAD, E. DAHL, Ø. HOLAND, G. MASTROMONACO and M. NIEMINEN (2011). "Fecal hormones as a non-invasive population monitoring method for reindeer." *Journal of Wildlife Management*, 75:1426-1435.

MYSTERUD, A., Ø. HOLAND, K. H. ROED, H. GJOSTEIN, J. KUMPULA and M. NIEMINEN (2003). "Effects of age, density and sex ratio on reproductive effort in male reindeer." *Journal of Zoology*, 621: 341-344.

NAGY, J. A. (2009). *Population Estimates for the Cape Bathurst and Bluenose-West Barren-Ground Caribou Herds Using Post-Calving Photography.* Draft Manuscript Report. Department of Environment and Natural Resources. Government of the Northwest Territories, Yellowknife, 212 p.

NELLEMANN, C. and R. D. CAMERON (1998). "Cumulative impacts of an evolving oil-field complex on the distribution of calving caribou." *Canadian Journal of Zoology*, 76: 1425-1430.

NELLEMAN, C., P. JORDHOY, O.-G. STOEN and O. STRAND (2000). "Cumulative Impacts of Tourist Resorts on Wild Reindeer (*Rangifer tarandus tarandus*) During Winter." *Arctic*, 53: 9-17.

NESBITT, L. and J. Z. ADAMCZEMSKI (2009). *Decline and recovery of the Bathurst caribou herd: workshops Oct. 1 & 2 and 5 & 6 in Yellowknife,* Department of Environment and Natural Resources. Government of the Northwest Territories, Yellowknife, TNO, 35 p.

OURANOS (2010). *Savoir s'adapter aux changements climatiques*, Ouranos, Montréal, Québec, 124 p.

PACHKOWSKI, M. D. (2012) *Dynamique des populations de caribous migrateurs* (Rangifer tarandus) *basée sur des indices de condition corporelle,* master thesis, Université de Sherbrooke, Sherbrooke, Québec, 69 p.

PARKER, G. R. (1980). *Physical and reproductive parameters of pre-calving caribou* (Rangifer tarandus caribou) *in northern Labrador*, Canadian Wildlife Service, Sackville, New Brunswick, 86 p.

PARKER, K. L., P. S. BARBOZA and M. P. GILLINGHAM (2009). "Nutrition integrates environmental responses of ungulates." *Functional Ecology*, 23: 57-69.

REIMERS, E., B. DAHLE, S. EFTESTOL, J. E. COLMAN and E. GAARE (2007). "Effects of a power line on migration and range use of wild reindeer." *Biological Conservation*, 134: 484-494.

RETTIE, J. 2008. *Determining optimal satellite collar sample sizes for monitoring barren-ground caribou populations.* Contract Report, Department of Environment and Natural Resources. Government of the Northwest Territories, Yellowknife, 31 p.

RIVEST, L.-P., S. COUTURIER and H. CRÉPEAU (1998). "Statistical Methods for Estimating Caribou Abundance Using Postcalving Aggregations Detected by Radio Telemetry." *Biometrics*, 54: 865-876.

RØED, K. H., O. HOLAND, M. E. SMITH, H. GJOSTEIN, J. KUMPULA and M. NIEMINEN (2002). "Reproductive success in reindeer males in a herd with varying sex ratio." *Molecular Ecology*, 11: 1239-1243.

ROPARS, P., and S. BOUDREAULT (2011). "Shrub expansion at the forest–tundra ecotone: spatial heterogeneity linked to local topography." *Environmental Research Letters*, 7: 1-9.

RUDOLPH, T. D., P. DRAPEAU, M.-H. ST-LAURENT and L. IMBEAU (2012). *Situation du caribou forestier* (Rangifer tarandus caribou) *sur le territoire de la Baie James dans la région Nord-du-Québec*, Montréal, Québec, 77p.

RUPP, T. S., M. OLSON, L. G. ADAMS, B. W. DALE, K. JOLY, J. HENKELMAN, W. B. COLLINS and A. M. STARFIELD (2006). "Simulating the influences of various fire regimes on caribou winter habitat." *Ecological Applications*, 16: 1730-1743.

SCHAEFER, J. A., A. M. VEITCH, F. H. HARRINGTON, W. K. BROWN, J. B. THEBERGE and S. N. LUTTICH (1999). "Demography of decline of the Red Wine Mountains caribou herd." *Journal of Wildlife Management*, 63: 580-587.

SEIP, D. R. (1991). "Predation and caribou populations." *Rangifer*, 7: 46-52.

SHANK, C. C. (1991). *Assessing management options for a rapidly expanding muskox population*. Manuscript Report No. 36. Department of Renewable Resources, Government of the Northwest Territories, Yellowknife, NWT, 29p.

SHARMA, S., S. COUTURIER and S. D. CÔTÉ (2009). "Impacts of climate change on the seasonal distribution of migratory caribou." *Global Change Biology*, 15: 2549-2562.

SIMARD, A.-A. (2015). *Parasitisme chez le caribou migrateur : une étude quasi-circumpolaire*, master thesis, Québec, Université Laval, 81 p.

STANKOWICH, T. (2008). “Ungulate flight responses to human disturbance: A review and meta-analysis.”, *Biological Conservation* 141: 2159-2173.

TAILLON, J. (2012). *Bilan de la récolte des données de condition corporelle sur les paires de femelle-faon des troupeaux Rivière-George et Rivière-aux-Feuilles de 2007 à 2009*, Caribou Ungava, Université Laval, Québec City, Québec, 95 p.

TAILLON, J. (2013) *Condition physique, allocation maternelle et utilisation spatio-temporelle des aires de mise bas du caribou migrateur,* Rangifer tarandus. Doctoral thesis, Université Laval, Québec City, Québec, 233 p.

TAILLON, J., V. BRODEUR, M. FESTA-BIANCHET and S. D. CÔTÉ (2011). “Variation in body condition of migratory caribou at calving and weaning: Which measures should we use?” *Ecoscience*, 18: 295-303.

TAILLON, J., V. BRODEUR, M. FESTA-BIANCHET and S. D. CÔTÉ (2012a). “Is mother condition related to offspring condition in migratory caribou (*Rangifer tarandus*) at calving and weaning?” *Canadian Journal of Zoology*, 90: 393-402.

TAILLON, J., M. FESTA-BIANCHET and S. D. CÔTÉ (2012b). “Shifting targets in the tundra: Protection of migratory caribou calving grounds must account for spatial changes over time.” *Biological Conservation*, 147: 163–173.

TAILLON, J., P. S. BARBOZA and S. D. CÔTÉ (2013). « Nitrogen allocation to offspring and milk production in a capital breeder », *Ecology*, 94: 1815-1827.

THERRIEN, J., R. VERDON and R. LALUMIÈRE (2004). *Environmental monitoring at the La Grande complex. Changes in fish communities. Summary report 1977-2000*, GENIVAR groupe conseil inc. et Direction barrages et environnement, Hydro-Québec production, Québec City, Québec, 129 p.

TREMBLAY, B. (2010) *Augmentation récente du couvert ligneux érigé dans les environs de Kangiqsualujjuqaq (Nunavik, Québec)*, Master thesis, Université du Québec à Trois-Rivières, Trois-Rivières, Québec, 63 p.

TYLER, N. J. C. (2010). “Climate, snow, ice, crashes, and declines in populations of reindeer and caribou (*Rangifer tarandus L.*).” *Ecological Monographs*, 80: 197-219.

VALKENBERG, P., D. A. ANDERSON, J. L. DAVIS and D. J. REED (1985). *Evaluation of an aerial photocensus technique for caribou based on radio-telemetry.* p. 287-299 in *Proceedings of the second North American caribou workshop.* T. C. Meredith, A. M. Martell and T. R. Moore, editors. McGill Subarctic Research Paper No. 40, McGill Subarctic Research Station, Schefferville, Québec.

VANDAL, D., S. COUTURIER, D. RÉMILLARD and S. LUTTICH (1989). *Distribution saisonnière et migrations des caribous des Rivières George et aux Feuilles de 1983 à 1987*. Ministère des Loisirs, de la Chasse et de la Pêche. Québec City, Québec, 87 p.

VINCENT, D. and A. GUNN (1981). “Population Increase of Muskoxen on Banks Island and Implications for Competition with Peary Caribou.” *Arctic*, 34: 175-179.

VISTNES, I. and C. NELLEMANN (2001). “Avoidance of cabins, roads, and power lines by reindeer during calving.” *Journal of Wildlife Management*, 65: 915-925.

VISTNES, I., C. NELLEMANN, P. JORDHØY and O. STRAND (2004). “Effects of infrastructure on migration and range use of wild reindeer.” *Journal of Wildlife Management* 68: 101-108.

VISTNES, I. and C. NELLEMANN (2008). “The matter of spatial and temporal scales: a review of reindeer and caribou response to human activity.” *Polar Biology*, 31: 399-407.

VORS, L. S. and M. S. BOYCE (2009). “Global declines of caribou and reindeer.” *Global Change Biology*, 15: 2626-2633.

WANG, G., N. T. HOBBS, S. TWOMBLY, R. B. BOONE, A. W. ILLIUS, I. J. GORDON and J. E. GROSS (2009). “Density dependence in northern ungulates: interactions with predation and resources.” *Population Ecology*, 51: 123-132.

WELADJI, R.B., O. HOLAND and T. ALMOY (2003). « Use of climatic data to assess the effect of insect harassment on the autumn weight of reindeer (*Rangifer tarandus*) calves », *Journal of Zoology*, 260: 79-85.

WHITE, R. G. (1983). “Foraging patterns and their multiplier effects on productivity of northern ungulates.” *Oikos*, 40: 377-384.

WHITTINGTON, J., M. HEBBLEWHITE, N. J. DECESARE, L. NEUFELD, W. BRADLEY, J. WILMSHURST and M. MUSIANI (2011). “Caribou encounters with wolves increase near roads and trails: a time-to-event approach.” *Journal of Applied Ecology*, 48: 1535-1542.

WILKINSON, P. F., C. C. SHANK et D. F. PENNER (1976). “Muskox-caribou summer range relations on Banks Island, N.W.T.” *Journal of Wildlife Management*, 40: 151-162.

WITTER, L. A., C. J. JOHNSON, B. CROFT, A. GUNN and L. M. POIRIER (2012a). “Gauging climate change effects at local scales: weather-based indices to monitor insect harassment in caribou.” *Ecological Applications*, 22: 1838-1851.

WITTER, L. A., C. J. JOHNSON, B. CROFT, A. GUNN and M. P. GILLINGHAM (2012b). “Behavioural trade-offs in response to external stimuli: time allocation of an Arctic ungulate during varying intensities of harassment by parasitic flies.” *Journal of Animal Ecology*, 81: 284-295.

WITTMER, H. U., A. R. E. SINCLAIR and B. N. MCLELLAN (2005). “The role of predation in the decline and extirpation of woodland caribou.” *Œcologia*, 144: 257-267.

WOLFE, S. A., B. GRIFFITH and C. A. GRAY WOLFE (2000). “Response of reindeer and caribou to human activities.” *Polar Research*, 19: 63-73.

YANNIC, G., M.-H. ST-LAURENT, J. ORTEGO, J. TAILLON, A. BEAUCHEMIN, L. BERNATCHEZ, C. DUSSAULT et S. D. CÔTÉ (2015). “Integrating ecological and genetic structure to define management units for caribou in Eastern Canada.” *Conservation Genetics*, DOI 10.1007/s10592-015-0795-0.

Sources of personal communication

Brodeur, Vincent	Biologist, *Ministère des Forêts, de la Faune et des Parcs*, *Direction de la gestion de la faune du Nord-du-Québec*, Chibougamau, Québec
Côté, Steeve D.:	Professor responsible for the Caribou Ungava research program, Université Laval, Québec City, Québec
Curry, Patricia:	Post-doctoral researcher, Faculty of Veterinary Medicine, University of Calgary, Calgary, Alberta
Dussault, Christian:	Biologist and researcher, *Ministère des Forêts, de la Faune et des Parcs*, *Direction de l'expertise sur la faune terrestre, l'herpétofaune et l'avifaune*, Québec City, Québec
Festa-Bianchet, Marco:	Professor, Caribou Ungava, Université de Sherbrooke, Sherbrooke, Québec
Kutz, Susan:	Associate professor, Faculty of Veterinary Medicine, University of Calgary, Calgary, Alberta
Le Corre, Mael:	Doctoral candidate, Caribou Ungava, Université Laval, Québec City, Québec
Rasiulis, Alexandre:	Master's candidate, Caribou Ungava, Université Laval, Québec City, Québec
Yannic, Glenn:	Post-doctoral researcher, Caribou Ungava, Université Laval, Québec City, Québec.

Appendices

Appendix 1 – Acronyms used in this report

ARTVS: *Act respecting threatened or vulnerable species* (Québec)

COSEWIC: Committee on the Status of Endangered Wildlife in Canada

GRH: George River herd

JBNQA: James Bay and Northern Quebec Agreement

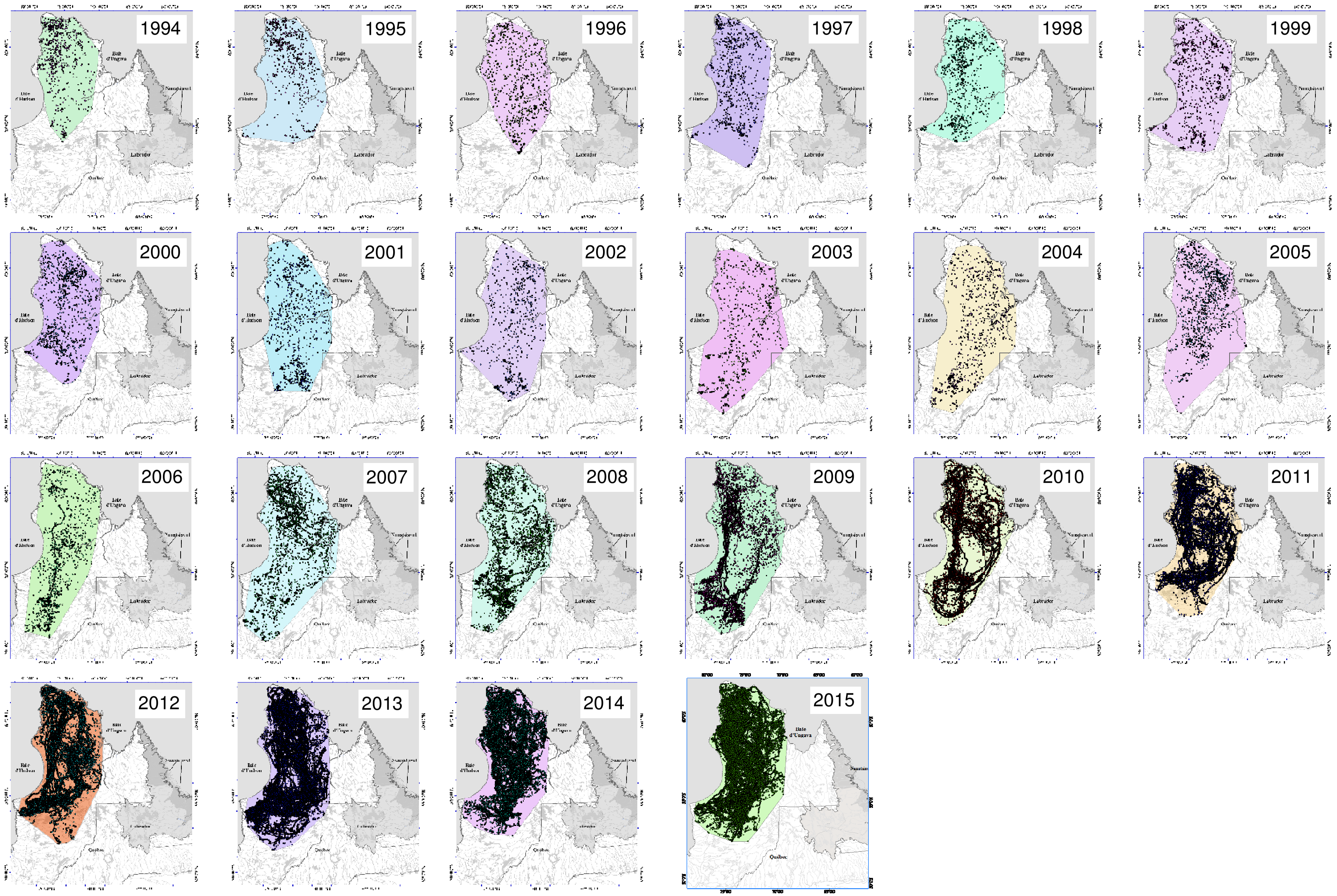
LRH: Leaf River herd

NEQA: Northeastern Quebec Agreement

SARA: *Species at Risk Act* (Canada)

Appendix 2 – Delineation of the annual range of the Leaf River herd, 1994-2015

The period corresponding to the use of the annual range is based on the cohort and extends from June 1st (year 1) to May 31st (year 2). This period of use includes the calving ground (year 1), summer range (year 1), fall migration (year 1), winter range (year 2) and spring migration (year 2). The delineation is based on data from all radio-collared individuals, males and females, of all ages. The cloud of points does not represent the number of caribou in the herd, but the number of locations of radio-collared individuals. The number of caribou fitted with a radio-collar and the frequency of the locations' transmission have increased gradually over the years (Table 3). For each year, all selected locations are represented by a cloud of points and the annual range is delineated by a minimum convex polygon (100%).



Appendix 2 (cont'd) – Delineation of the annual range of the Leaf River herd, 1994-2015

Table A1. Number of radio-collared individuals used to delineate and calculate the size of LRH annual ranges, 1994-2015.

Year	Number of individuals	Size (km^2)
1994	13	295,925
1995	17	372,635
1996	17	343,610
1997	17	401,143
1998	17	359,690
1999	17	379,311
2000	19	391,143
2001	20	434,325
2002	18	448,162
2003	19	520,890
2004	23	512,736
2005	25	502,097
2006	31	460,406
2007	61	558,511
2008	88	504,782
2009	108	549,823
2010	102	474,811
2011	106	470,967
2012	98	468,154
2013	147	513,112
2014	125	461,465
2015	141	463,781

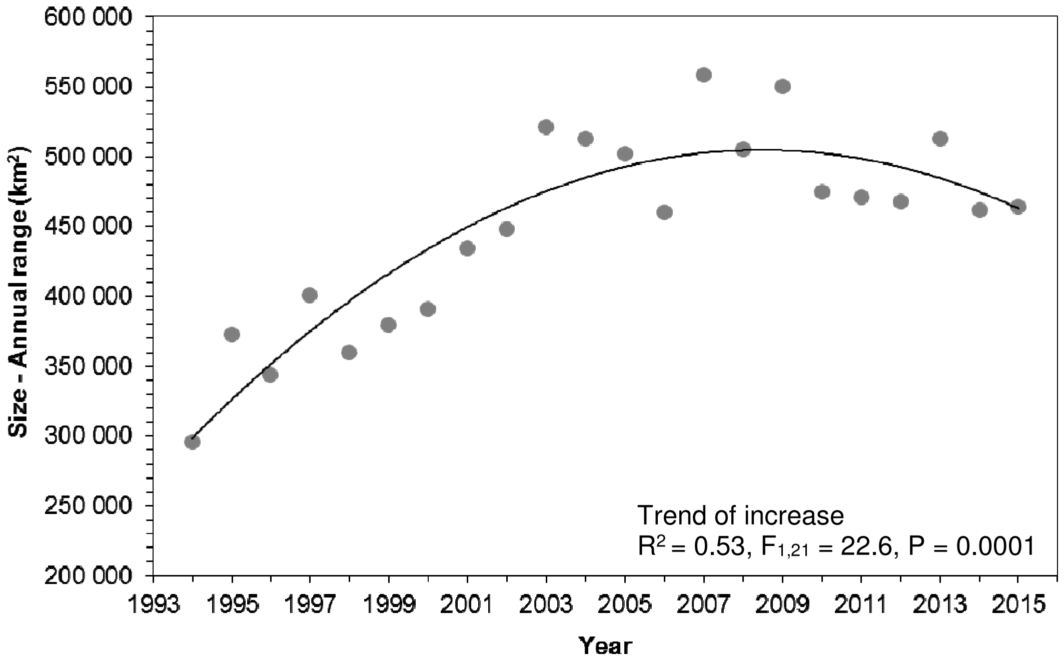
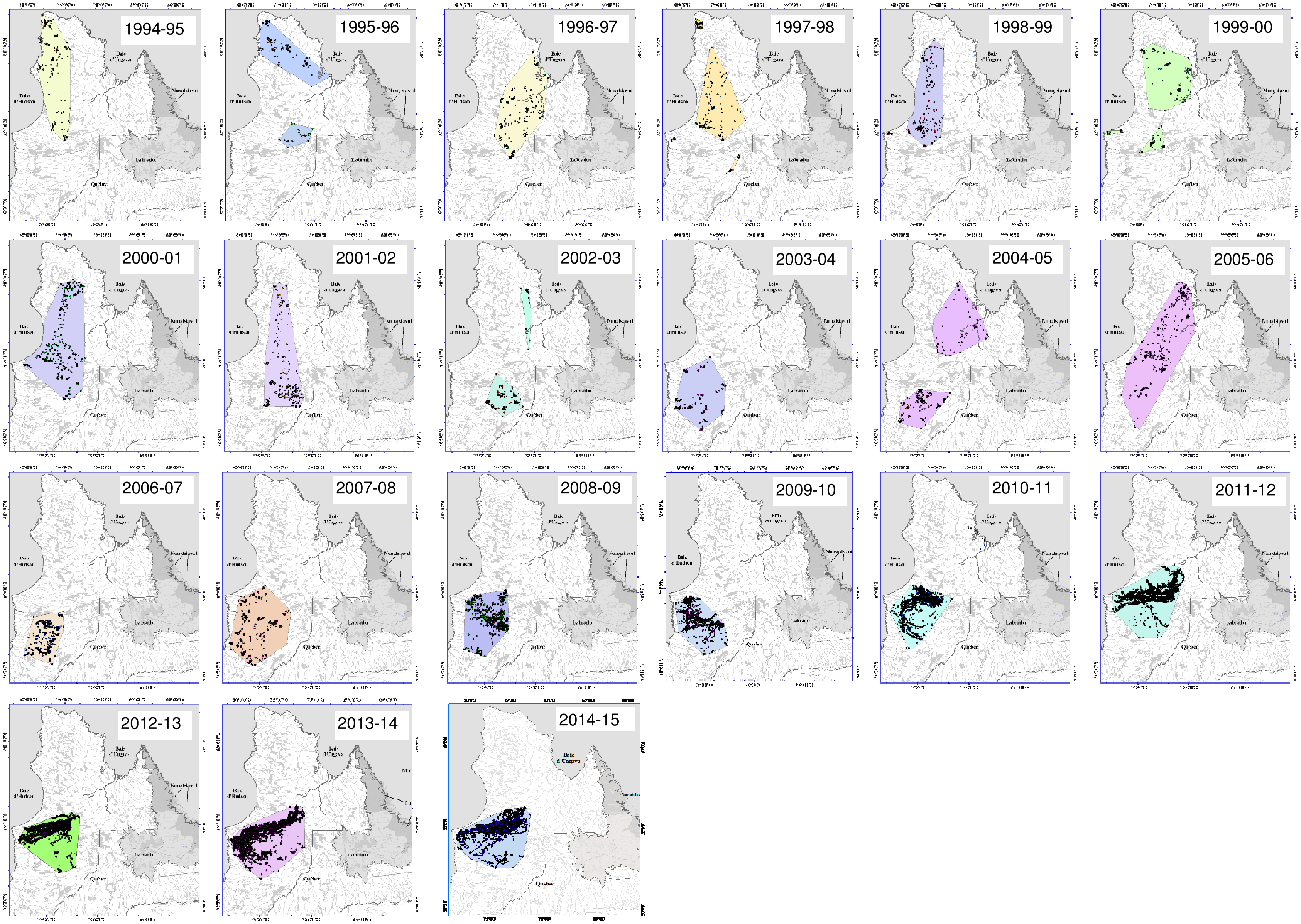


Figure A1. Annual variations in the size of the annual range of the LRH, 1994-2015.

Appendix 3 – Delineation of the winter ranges of the Leaf River herd, 1994-2014

The period corresponding to the use of the winter ranges begins on December 15th (year 1) and ends on April 1st (year 2) (inclusively). The delineation is based on data from all radio-collared individuals, males and females, of all ages. The cloud of points does not represent the number of caribou in the herd, but the number of locations of radio-collared individuals. The number of caribou fitted with a radio-collar and the frequency of the locations' transmission have increased gradually over the years (Table 3). For each winter, all selected locations are represented by a cloud of points and the winter ranges are delineated by a minimum convex polygon (100%).



Appendix 3 (cont'd) – Delineation of the winter ranges of the Leaf River herd, 1994-2014

Table A2. Number of radio-collared individuals used to delineate and calculate the size of LRH winter ranges, winter 1994-95 to winter 2014-2015.

Winter	Number of collars	Size (km^2)
1994-95	11	142,667
1995-96	10	120,533
1996-97	13	163,006
1997-98	13	128,992
1998-99	13	129,629
1999-00	12	142,489
2000-01	18	226,326
2001-02	15	165,180
2002-03	12	59,413
2003-04	13	124,904
2004-05	18	184,088
2005-06	22	251,180
2006-07	31	70,844
2007-08	41	166,713
2008-09	68	116,050
2009-10	61	102,167
2010-11	76	114,607
2011-12	80	164,425
2012-13	78	119,656
2013-14	125	174,637
2014-15	115	142,357

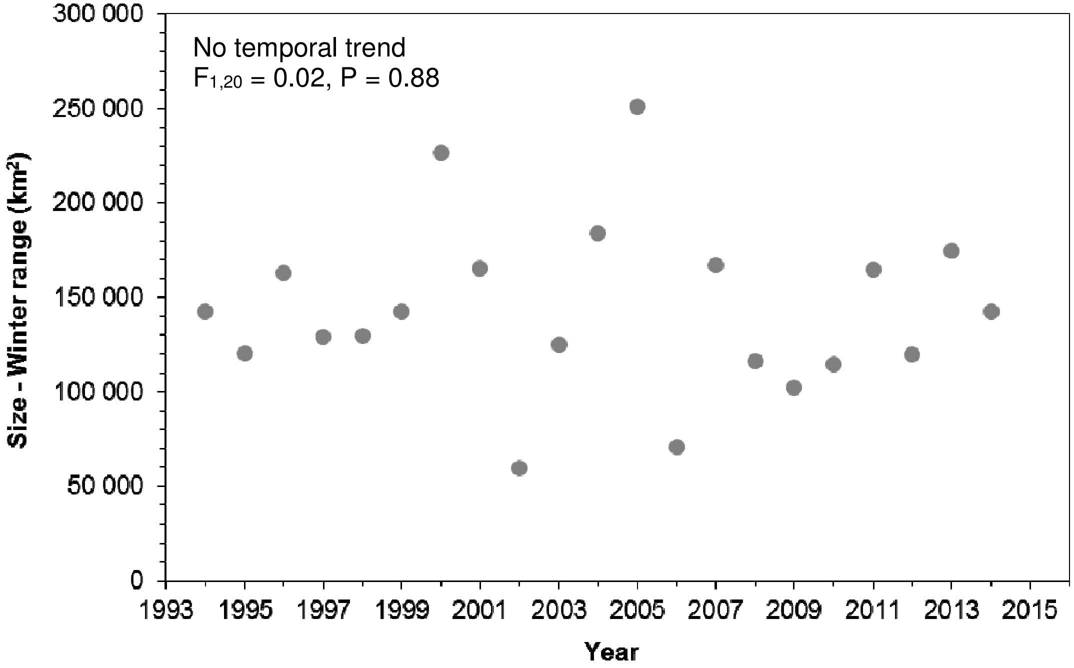
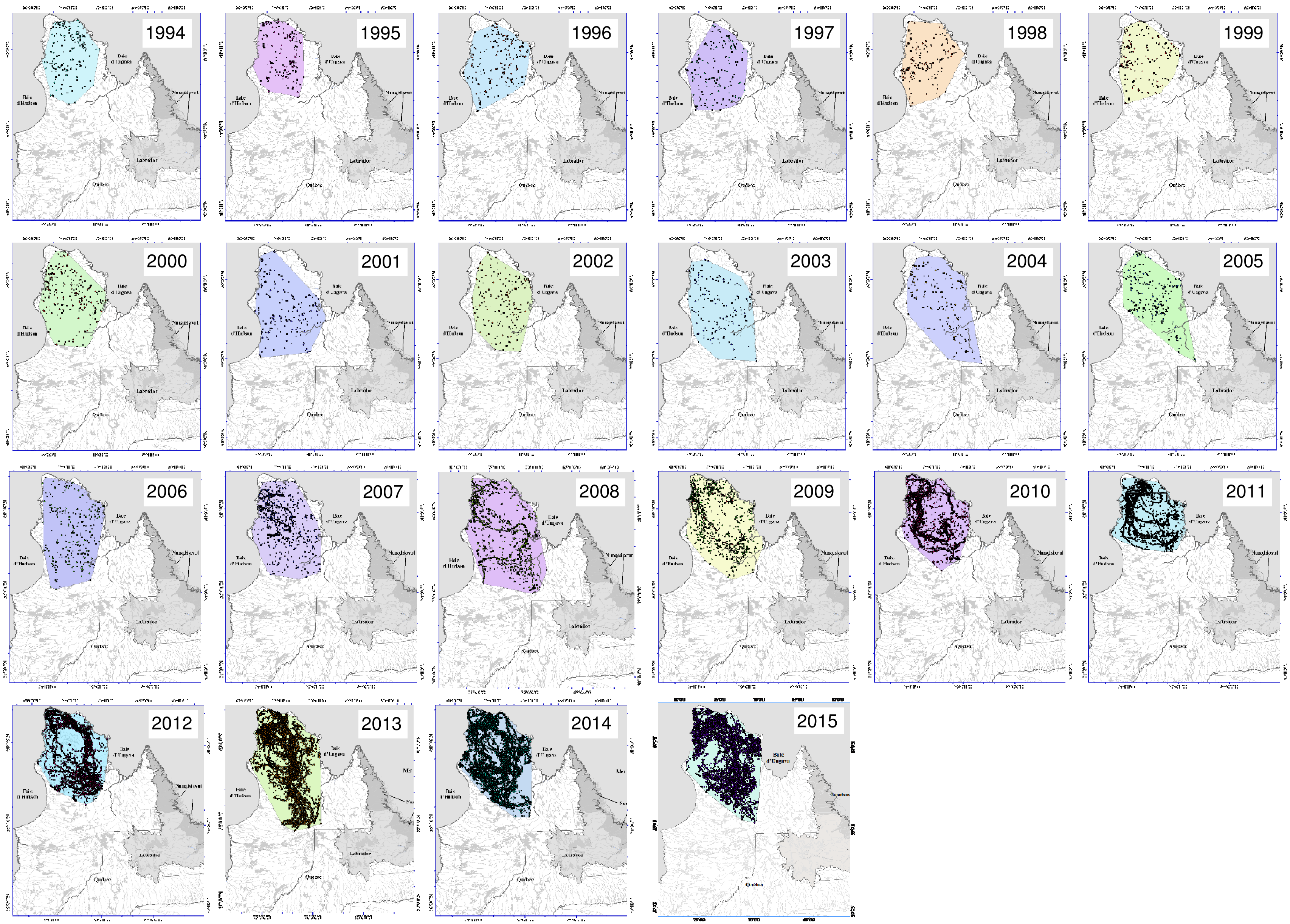


Figure A2. Annual variations in the size of the winter ranges of the LRH, winter 1994-95 to winter 2014-2015.

Appendix 4 – Delineation of the summer range of the Leaf River herd, 1994-2015

The period corresponding to the use of the summer range begins on July 1st and ends on September 15th (inclusively). The delineation is based on data from all radio-collared individuals, males and females, of all ages. The cloud of points does not represent the number of caribou in the herd, but the number of locations of radio-collared individuals. The number of caribou fitted with a radio-collar and the frequency of the locations' transmission have increased gradually over the years (Table 3). For each summer, all selected locations are represented by a cloud of points and the summer range is delineated by a minimum convex polygon (100%).



Appendix 4 (cont'd) – Delineation of the summer range of the Leaf River herd, 1994-2015

Table A3. Number of radio-collared individuals used to delineate and calculate the size of LRH summer ranges, 1994-2015.

Summer	Number of individuals	Size (km^2)
1994	13	177,770
1995	12	157,095
1996	13	198,055
1997	13	196,584
1998	12	190,178
1999	14	178,854
2000	17	228,150
2001	15	262,357
2002	17	222,734
2003	13	273,797
2004	13	267,421
2005	23	221,134
2006	21	263,379
2007	42	259,252
2008	59	316,031
2009	68	271,581
2010	71	223,266
2011	57	199,127
2012	75	235,725
2013	120	317,238
2014	121	270,533
2015	99	266,159

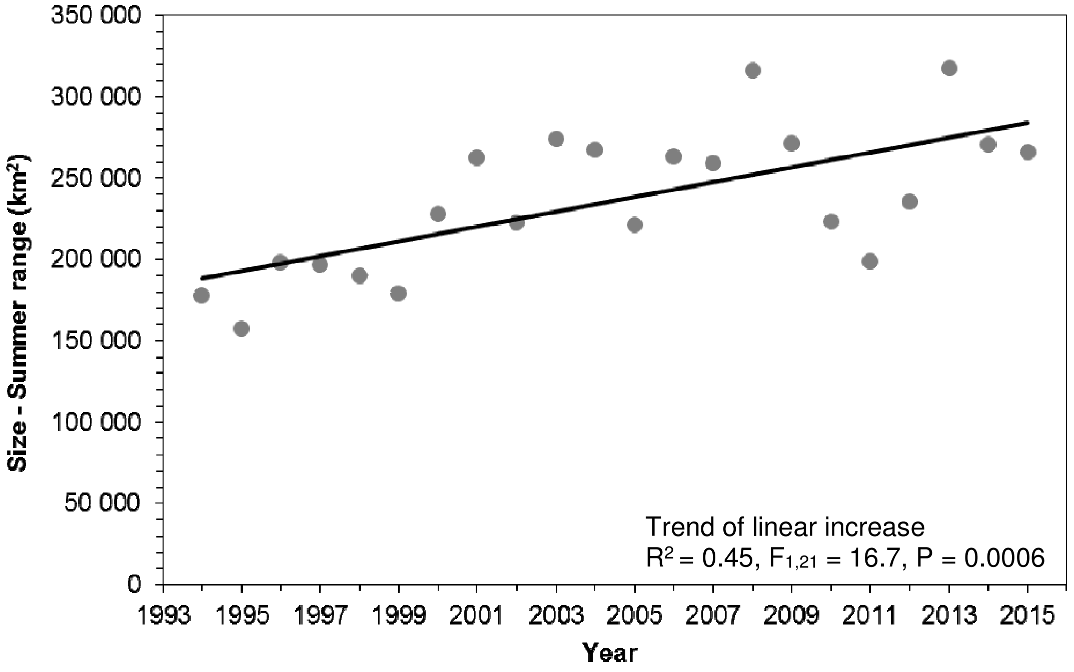


Figure A3. Annual variations in the size of the summer range of the LRH, 1994-2015.

Forêts, Faune
et Parcs
Québec