Chapter 9. Caribou herd dynamics: impacts of climate change on traditional and sport harvesting

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Abstract

Caribou (*Rangifer tarandus*) are a key species in Arctic ecosystems including northern Québec and Labrador. They play a central role in the ecology of predators and the structure of Arctic plant communities. In addition, caribou provide socioeconomic and cultural benefits from subsistence and sport hunting activities. Changes in the distribution and abundance of caribou due to global climate change would have serious biological, societal, and economic implications. Direct and indirect consequences of climate change on migratory caribou herds may include alteration in habitat use, migration patterns, foraging behaviour and demography. For example, caribou may experience a further northerly shift in distribution due to several factors including longer ice-free periods, increases in snowfall and extreme weather events, alterations in the fire regime, and changes in the distribution of insects and predators. Future research by Caribou Ungava, a research group interested in the ecology of migratory caribou in the context of climate change, will address the factors outlining variations in the population dynamics of caribou, implications for survival and reproduction, as well as the response of caribou habitat to different climate change scenarios. Management efforts focusing on mitigating greenhouse gases to reduce the potential effects of climate change, preserving high quality habitat, limiting anthropogenic landscape disturbances, and managing hunting in a sustainable manner, could alleviate stressors on migratory caribou of the Québec-Labrador peninsula.

9.1 Introduction and importance of caribou for traditional and sport harvesting

Caribou (*Rangifer tarandus*) are a key species in Arctic ecosystems including northern Québec and Labrador. They play a central role in the ecology of predators and the structure of Arctic plant communities (Crête 1999, Bergerud et al. 2008). In addition, caribou provide socio-economic and cultural benefits from subsistence and sport hunting activities. Thus, changes in the distribution and abundance of caribou due to global climate change would have serious biological, societal, and economic implications (Festa-Bianchet et al. 2011).

9.1.1 Traditional harvesting

In the Arctic and Subarctic, caribou are the most important terrestrial subsistence resource for Aboriginal people. Traditional Aboriginal communities and individuals have a strong cultural connection to caribou and economic reliance on caribou for food (Miller 2003). For example, for 24 rural communities in interior Alaska, median caribou harvest was 3.5 kilograms per person per year, reaching as high as 22 kilograms per person per year (Nelson et al. 2008). In northern Québec and Labrador, subsistence hunters are thought to harvest about 15,000 caribou each year (MRNF 2009, unpubl. data), providing 347 tonnes of meat (AMAP 1998). The actual Aboriginal harvest, however, is unknown as there are no quota or registration requirements.

The health and cultural survival of indigenous peoples are directly affected by any potential impacts of climate change on caribou harvests. Most migratory caribou herds are declining or have recently declined (Vors and Boyce 2009). Current caribou numbers in northern Québec and Labrador are not known precisely because the last survey was conducted 10 years ago, but biological indicators of population size as well as observations by Aboriginal harvesters and outfitters suggest caribou are declining or have declined substantially in the last decade. In addition, weather conditions are critical in the caribou's selection of seasonal migratory routes and winter grounds, affecting hunter success. Long-term climate changes may affect access to hunting grounds, for example by changing the timing of freeze-up and break-up of large bodies of water. If climate change alters the distribution of caribou away from northern villages, hunting may become increasingly difficult.

9.1.2 Outfitting industry and sport hunting

In northern Québec, there are 90 to 100 outfitting businesses and approximately 11,000 sport hunters who head north to hunt caribou. The sport hunt includes two seasons: 5,000 to 10,000 animals are harvested in the fall (August 1st to October 31st), mainly trophy males through outpost camps (MRNF 2009, unpubl. data); and the winter hunt (November 15 to February 15) which mainly involves Québec residents in the James Bay area with an average annual harvest of 12,000 caribou. Caribou sport hunting generates nearly $20 million in annual revenues, for a total economic impact exceeding $30 million, excluding tax returns to governments.

9.2 Caribou herd dynamics

9.2.1 Caribou herds in northern Québec and Labrador

Two migratory caribou populations are found on the Québec-Labrador peninsula: the Rivière-George herd (RG) and the Rivière-aux-Feuilles herd (RAF) (Boulet et al. 2007). These caribou travel up to 6,000 km per year (Bergerud et al. 2008). They occupy the peninsula north of 53°N although they have been seen as far south as 50° 30'N in recent winters. Although not genetically different (Boulet et al. 2007), these two herds differ in body size and condition, as well as in movement rates and demography (Couturier et al. 2010). The small (ca. 5000) Torngat herd which belongs to the mountain ecotype, migrates up the Torngat Mountains in Labrador (Bélanger and Le Hénaff 1985). This herd is often confused with the RG herd, whose range it overlaps during part of the year (Schaefer and Luttich 1998).

9.2.2 Historical variation in population abundance

The RG and RAF herds exhibited dramatic population fluctuations in recent decades (Messier et al. 1988, Boudreau et al. 2003). After a population peak in the 1890s (Low 1896, Elton 1942), the RG herd remained extremely low until the 1950s when it included only about 5,000 animals (Banfield and Tener 1958). By 1993, the population had increased to more than 775,000 (Couturier et al. 1996). It then decreased to about 385,000 by 2001 (Couturier et al. 2004) and 74,000 by 2010. The RAF herd was first described in June 1975 when Le Hénaff (1976) saw a group of about 20,000 calving females near the Leaf River (58 ºN, 73 ºW). The RAF herd increased from 56,000 animals estimated in 1975 to 276,000 in 1991, and to at least 628,000 in 2001 (Couturier et al. 2004). The RAF herd has declined since 2001. An aerial survey is planned for July 2010.

9.2.3 Distribution, seasonal migrations and seasonal ranges

Migratory caribou of northern Québec and Labrador range over more than 1 million km² (Figure 1). The mi-

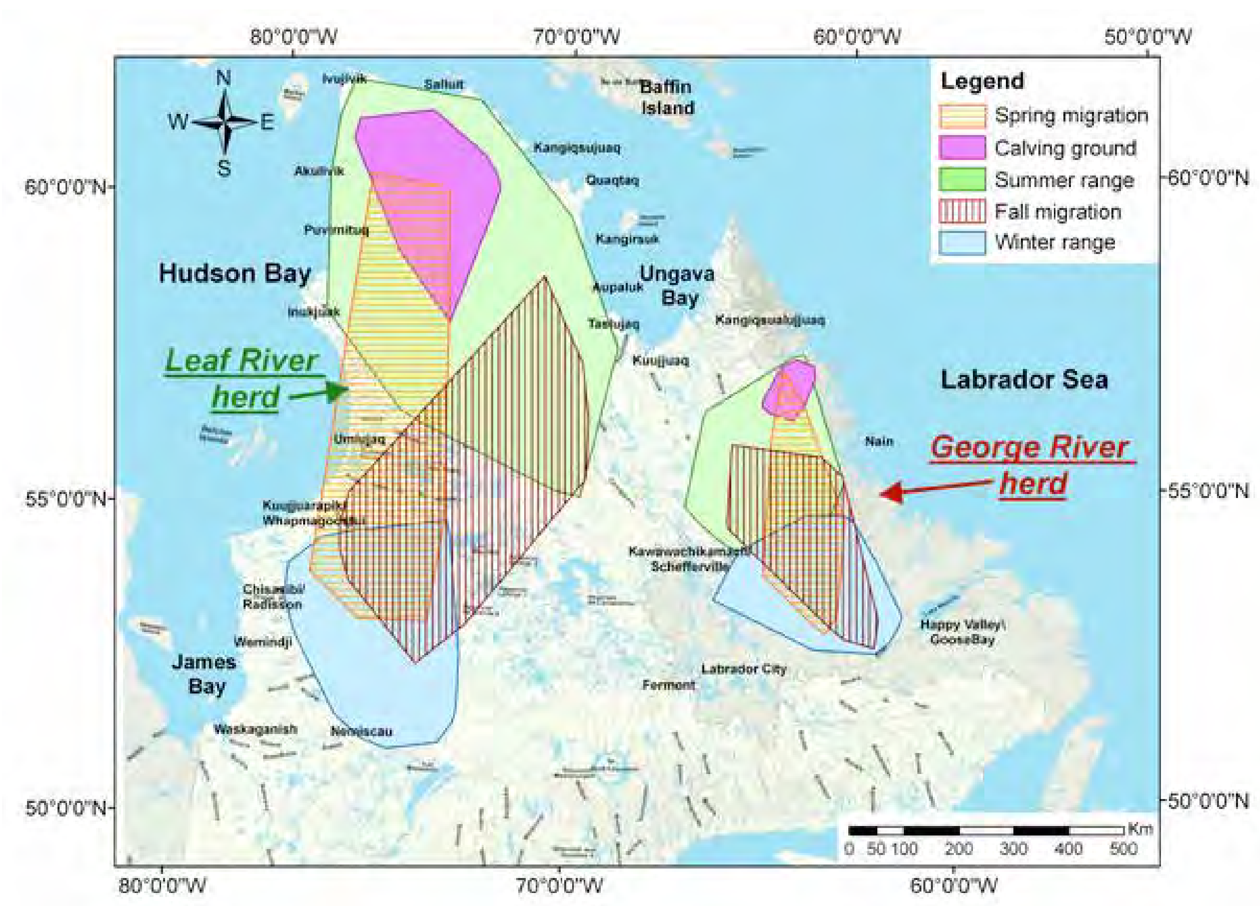

Figure 1. *Seasonal ranges of the Rivière-George and Rivière-aux-Feuilles caribou herds, Québec-Labrador peninsula.*

gration routes and seasonal ranges of caribou from the RG and RAF herds have been monitored during the last 25 years using radio and satellite telemetry. Between 1986 and 2010, more than 300 animals were fitted with satellite transmitters.

Migratory caribou undertake large seasonal migrations to use specific habitats, exploit seasonal resources and avoid predators. Seasonal migrations involve directional movements of 15 to 30 km per day. In early spring, caribou leave their winter ranges in the taiga and migrate over hundreds of kilometres (RG: 280 ± 20 km; RAF: 630 ± 15 km) to reach calving grounds in the tundra. Adult females usually initiate spring migration first, followed by adult males and non-reproductive sub adults. Initiation of spring migration by females of the RAF herd is earlier and more variable (mean: 3 April ± 30 days) than for females of the RG herd (mean: 25 April ± 10 days). Preliminary results suggest that a delay in the initiation of spring migration may lower calf birth mass and reduce fall recruitment rates.

Females of the RG herd calve on the high tundra plateaus on the eastern Québec/Labrador peninsula (57°N, 65°W), whereas females of the RAF herd calve on the Ungava Peninsula (61°N, 74°W, Figure 2). These calving grounds are more than 800 km apart (Boulet et al. 2007) and are used from early June (RG: 1 June ± 6 days; RAF: 4 June ± 6 days) to early July (RG: 1 July ± 4 days; RAF: 2 July ± 3 days). The size of the RAF calving ground has remained relatively stable since the 1990s (mean: 53,700 ± 9,700 km^2), whereas the RG calving ground declined drastically from 46,500 ± 8,800 km^2 in the early 1990s to 5,300 ± 1,100 km^2 in the last three years. Although females generally show strong fidelity to their calving ground (Boulet et al. 2007), the locations of the calving grounds have changed over time for both herds. The RAF calving ground has shifted northward, whereas the RG calving ground has moved east to the Labrador coast (Figure 2).

Summer ranges are larger than calving grounds and are used from early July to mid-September. The size of the summer range of the RAF herd has remained relatively stable since the 1990s (mean: 178,900 ± 5,300 km^2), whereas that of the RG herd has declined from 234,600 ± 12,800 km^2 in the early 1990s to 88,800 ± 2,700 km^2 in the last three years. Caribou can travel hundreds to thousands of kilometres while on summer ranges (RG: 970 ± 35km; RAF: 1000 ± 41km). There is substantial annual variability in the period of use of summer ranges (for both herds: from 50 to 90 days). Preliminary analyses suggest that a longer period of use of the summer range is positively correlated with fall recruitment.

In mid-September, caribou leave their summer range and migrate south. Initiation of the fall migration is less variable than for the spring migration and is similar between herds (RAF: mean=10 September ± 6 days; RG: mean=11 September ± 9 days). During the fall migration, reproductive females and males form large aggregations. The peak of the rut is estimated to occur around October 23rd and the majority of adult females breed over a period of 2 weeks.

From November to April, caribou winter in the taiga and concentrate their activities in spruce stands with thick terrestrial lichen cover. During winter, the RAF herd is located mostly between Chibougamau and La Grande Rivière reservoirs, whereas the RG herd winters mostly in Labrador. During this period, caribou move about 5 km per day (RG: 3.2 ± 0.1 km/day; RAF: 5.7 ± 0.4 km/day). The use of winter range, however, is currently poorly understood.

9.2.4 Past and current variation in demography

The population dynamics of long-lived vertebrates, including caribou, are complex because they can be driven by many ecological factors that can affect multiple vital rates (such as natality, calf survival, adult survival and age of first reproduction) in different ways, often with substantial interactive effects. Both the importance of different limiting factors and the relative roles of different vital rates can vary over time (Coulson et al. 2005).

Over the past two decades, long-term studies of ungulates have elucidated the relative roles of different vital rates

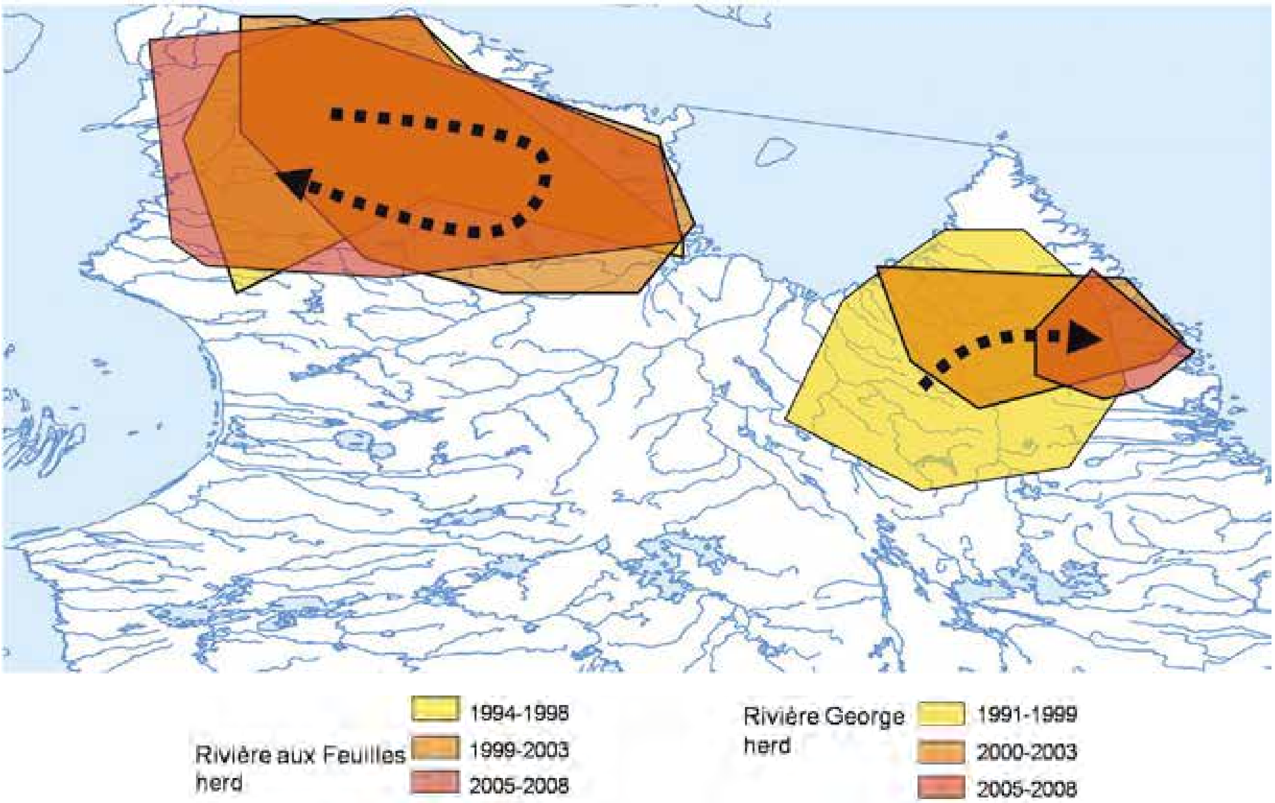

Figure 2. *Calving grounds of the Rivière-George and Rivière-aux-Feuilles caribou herds, 1991-2008, Québec-Labrador peninsula.*

in contributing to population growth, and the possible effects of various intrinsic and extrinsic factors in driving changes in population size. In general, variation in both adult survival and in survival over the first year of life can be important in determining changes in population growth rates, while variability in productivity is often less important, with the exception of possible changes in age of first reproduction (Gaillard et al. 2000). Ecological factors that affect ungulate populations include density-dependence, climate, disease, hunting and predation. These factors often interact. For example, predation rate can be affected by snow cover (Hebblewhite 2005), the effects of parasites and diseases can be exacerbated by density (Gulland 1992), and inclement weather typically is more pronounced at high population density (Jacobson et al. 2004).

Although it is likely that the population dynamics of migratory caribou, including those in northern Québec and Labrador, would be similar to those of other ungulates, they may show substantial differences for a number of reasons. First, long-distance migrations change the relationship between caribou and their predators. Migratory ungulates can reduce the impact of predators because they are a seasonal resource (Fryxell et al. 1988). Most caribou predators are unable to follow their migration because they must stop to raise their young, or because of intra-specific territoriality (Frame et al. 2008). Second, long-distance movements coupled with limited fidelity to some seasonal ranges mean that caribou population size does not necessarily correlate with density, because the areas used can change from year to year (Messier et al. 1988; Couturier et al. 2010).

Information on age-specific survival and reproduction of migratory caribou is limited, because few studies have monitored known-age animals. Consequently, although both scientific and Aboriginal Traditional knowledge suggest that caribou populations fluctuate widely over decades, the demographic changes underlying those changes are mostly unknown.

Survival and mortality

Studies of known-age ungulates generally report that survival of adult females is high and varies little from year to year, with notable exceptions due to predation, disease and, rarely, extreme weather (Gaillard et al. 2000). Survival of adults declines strongly with advanced age, so that while the survival of females age three to six years is usually 90-95%, the survival of females a decade older is typically less than 60%. Consequently, the age structure of a population strongly affects its expected survival (Festa-Bianchet et al. 2003).

Available estimates of adult female survival for RG caribou include an analysis of age distribution of 875 females that drowned in the Caniapiscau River in 1984. That analysis of cross-sectional data is based on several assumptions (equal sampling probability for all age classes, no difference in initial size of cohorts, stationary population size) that were unlikely supported. Nevertheless, it suggests age-specific survival rates that are typical of most studies of ungulates: average survival is approximately 94-95% for females age 2-7 years; this decreases for older females (Messier et al. 1988). Monitoring of radio-collared females age 2 years and older suggests a decline in survival from an average of 93% in 1984-1986 to 83% in 1990-1992 in the RG herd (Crête et al. 1996). Those estimates, however, do not account for age structure. Given that recruitment declined over this time period, it is likely the average age of radio-collared females also increased. For example, the average age of females harvested during a commercial hunt near Nain, Labrador increased from 4 to 5 years from the 1970s to the 1980s (Bergerud et al. 2008).

A preliminary analysis of survival of radio-collared caribou in the RG and RAF herds from 1996 to 2009 suggests that yearling female survival was only 69% (N=65), much lower than, for example, the 93% estimated by Fancy et al. (1994) for yearling females in the Porcupine herd in Yukon. Survival of adult females was 82%, increasing to 87% if known hunting mortality was excluded.

There are no age-specific estimates of adult male survival, although it is likely lower than for females of the same age, as is typical of ungulates (Toïgo and Gaillard 2003). Comparisons of sex ratio from fetuses to adults reveal a declining proportion of males (Bergerud et al. 2008). Data on radio-collared adult males in the two migratory herds in Québec-Labrador since 1996 suggest a low survival of 51%, based on 61 caribou-years of monitoring 39 adult males. If hunting mortality was excluded, adult male survival was 65%. In the Porcupine herd of migratory caribou (Fancy et al. 1994), adult survival was similar for females and males (84.2% and 82.6% respectively) but exact age was not accounted for.

Reproduction

In ungulates, reproductive rates are strongly affected by age (Gaillard et al. 2000). The age at first reproduction often increases with increasing population density, and pregnancy rates are lower for very young females than for prime-aged females. In most species, females age 3 to 4 to about 10 to12 years have very high pregnancy rates, typically over 90% (Gaillard et al. 2000). Reproductive senescence begins later than survival senescence, and few females reach the age of 13 to14 years when reproductive rates decline. Maternal age usually does not have an important effect on juvenile survival, with the exception of primiparous mothers, whose offspring tend to have lower survival rates than those of mothers who have given birth two or more times.

Productivity in northern Québec-Labrador appears to be generally high, although it was greater (average 91%) during years of population increase than during years of population decline, when it was about 69% (Couturier et al. 2009a). Female age plays an important role in determining how population dynamics may affect pregnancy rates. Comparing the increase and decline phases of the RG herd, pregnancy rates of females age four and older declined from 96% to 82%, but for females age two or three the decline was from 77% to 24% (Bergerud et al. 2008).

Recruitment rate

In caribou, recruitment is best measured as the number of calves that survive to one year of age, because mortality of calves can be substantial and highly variable both pre- and post-weaned (Bergerud et al. 2008). Yearling survival is usually high and stable, although in most ungulates it remains lower and more variable than adult survival (Gaillard et al. 2000).

There is little information on calf survival from weaning (October) to the following June. Comparisons of calf to female ratios in fall and spring cumulate the errors and biases of two ratios. Nevertheless, looking at the time period between 1974 to 1992 suggests overwinter survival likely declined from years when the RG herd was increasing (1973 to 1983, average of 67.4% winter calf survival) to when it was declining (1985 to 1992, average 47% survival). The yearling to female ratio over these periods dropped from 33% to 16% (Bergerud et al. 2008). Calf survival is strongly affected by body condition, as revealed by the positive relationship between birth mass and recruitment rate measured as calf to female ratio in the fall (Couturier et al. 2009b). Although population statistics are often used to calculate the 'minimum' recruitment at either weaning or one year required to maintain a stable population, it is not a very good predictor of population growth because changes in age structure or in adult survival can have strong effects on population dynamics. Nevertheless, a series of years with poor recruitment will inevitably lead to population declines. Couturier et al. (2009b) estimated that when average calf birth mass is less than 6.0 kg, calf recruitment may be insufficient to maintain a stable population. A time series of classified counts conducted in the fall suggests that calf to female ratios have been lower in recent years in both herds, compared to ratios observed in the RG herd during the increase phase in the 1980s (Figure 3).

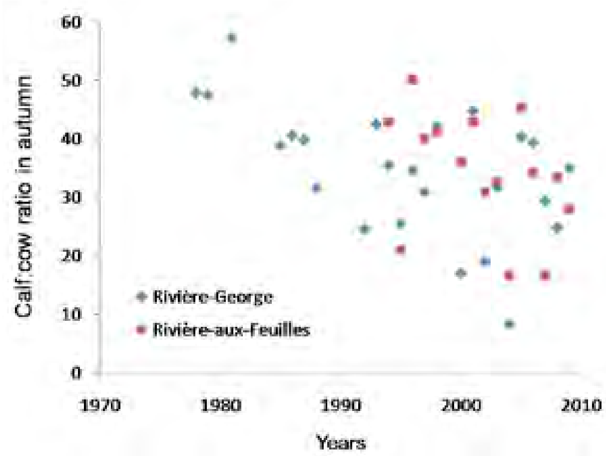

Figure 3. *Cow:calf ratios in October for the Rivière-George and Rivière-aux-Feuilles caribou herds in northern Québec and Labrador.*

9.3 Expected impacts of climate change on herd dynamics

9.3.1 Impacts on migration routes

Migration is important habitat selection behaviour for large herbivores. These large-scale movements may allow animals to follow plant phenology (see section 9.3.2), adapt to seasonal changes in food availability, or limit predation risk during critical periods such as calving (Bolger et al. 2008). In spring, caribou migrate north to calving grounds where predation risk is low (Fancy and Whitten 1991) and high quality forage is available. Caribou arrival on calving grounds usually corresponds to a peak in vegetation productivity (Post et al. 2003). Migration, however, also involves high energy expenditures (Wikelski et al. 2003) and is a critical period of the year. Environmental variations related to climate change could have a dramatic impact on migratory species such as caribou.

Timing of migration and freshwater ice formation: Increasing risk of massive mortality associated with crossing rivers and reservoirs

The spring migration typically occurs just before ice cover breaks up on lakes and hydro-electric reservoirs, while the fall migration occurs at about the time lakes and reservoirs are freezing up. Migrating caribou use frozen lakes and rivers to facilitate movements. However, with climate change, the ice-free period is predicted to lengthen (see chapter 2, Magnuson et al. 2000) with earlier thaws and later freezing. Caribou will then be more likely to encounter partially frozen or ice-free lakes and rivers along their migration routes. Large bodies of water, once beneficial to caribou, could become obstacles, forcing caribou to go around them as observed in recent years. It is likely incidental mortality associated with crossing over thin ice will increase.

In the Northwest Territories, Miller and Gunn (1986) observed that migrating barren-ground caribou that encountered lake ice too thin to bear their weight hesitated to cross ice that had no snow cover and some, mostly bulls, broke through the thin ice. Although some caribou escaped, risk of death by drowning, hypothermia or exhaustion were high. Dead animals had severe injuries in their forelegs, obtained as they tried to extract themselves from broken ice (Miller and Gunn 1986; S. Côté, pers. obs.). Injured and exhausted caribou are vulnerable to predation. Caribou can swim across ice-free water, but the increase in precipitation expected under global warming (see chapter 2, Maxwell 1992) could increase water discharge in large rivers, thereby increasing the risk of massive drowning. For example, the death of 10,000 caribou that attempted to cross the Caniapiscau River (northern Québec) in 1984 was mainly attributed to the abnormally high water flow (Nault and Le Hénaff 1988). A delay in migration to avoid ice-free bodies of water could reduce reproductive success, as females might not be able to reach calving grounds in time and be forced to calve in suboptimal sites (Fancy and Whitten 1991). Unless caribou populations move to higher latitudes (Sharma et al. 2009), they may have to initiate spring migration earlier and fall migration later (Brotton and Wall 1997) in order to safely cross large bodies of water.

Snow depth and energy expenditures

Temperatures and snowfall are expected to increase with global climate change (Maxwell 1992), which will modify snow quality. According to the Canadian Regional Climate Model, snowfall in Nunavik may increase by 30 to 50% in the 2041-2070 period compared to the 1960 to 1990 average (CCCSN 2009). Snow depth and frequency of thaws could also increase, resulting in a denser and wetter snow layer. In addition to reducing forage accessibility (Miller and Gunn 2003; section 9.3.3.1), these changes will increase the energetic costs of movements during critical periods.

Higher temperatures in spring could induce an earlier onset of snowmelt. Snow cover may last longer because of greater accumulations. Caribou could then be forced to migrate over deep snow, increasing the energy cost of migration. Parker et al. (1984) showed that the energy costs of movements in cervids increase exponentially with sinking depth. Heavy and wet snow might further impede locomotion. Increased energy expenditures combined with lower resource availability could lower body condition and ultimately affect population dynamics because most life history traits are closely related to body condition. Couturier et al. (2009b) showed that winter snowfall experienced by caribou mothers has a negative impact on the mass of their offspring.

Changes in the snowfall regime in the fall, unlike spring, might be beneficial to caribou during migration. Delayed snowfall up to 16 days in Nunavik and Nunatsiavut (see chapter 2) in fall will facilitate access to resources and movements, thereby limiting energy expenditures (Brotton and Wall 1997). Energy savings, however, could be reduced by the costs of increased distance traveled if caribou must avoid ice-free water bodies.

9.3.2 Mismatch in the timing of calving and timing of forage availability influence recruitment rate

Caribou track variation in day length through complex hormonal processes to prepare for seasonal changes in foraging conditions (Bronson 2009). Normally, this adaptation guarantees synchrony between calving and the onset of the plant growing season. The nutritional content and digestibility of plants peak soon after their emergence and decline rapidly thereafter (Klein 1990; Albon and Langvatn 1992). Synchronizing calving with the peak in forage quality is crucial for reproduction since energy requirements for females increase 65-215% during the first month post-partum (Robbins 1993).

Climate change is likely to affect the relationship between the timing of calving and forage availability by changing the timing of green-up and the length of the growing season (Bradshaw and Holzapfel 2006). The timing of plant development and growth is mainly driven by changes in temperature, with warmer springs leading to earlier onset of plant growth (Parmesan and Yohe 2003). The annual timing of calving is much less variable than that of plant growth since it is partly driven by photoperiod (Post and Forchhammer 2008), generating a mismatch between the timing of spring green-up and of caribou calving. A two-week advance in the onset of plant growth in West Greenland has been related to a fourfold decline in calf production (Post and Forchhammer 2008; Post et al. 2008).

9.3.3 Impact of climate change on forage availability

Winter forage

Lichens growing on the ground (terricolous) and in trees (arboreal) form the staple of caribou diet in winter (Crête et al. 1990a). They contain a high amount of digestible energy (Côté 1998), providing the fuel needed by caribou to travel, forage in deep snow and maintain body temperature. Winter forage ensures caribou do not use the fat and protein reserves accumulated during the snow-free period which are required by pregnant females to grow their fetuses. Lichen cover is globally decreasing in the Arctic in response to climate change. In Alaska, higher occurrence of wildfires and competition from grasses and shrubs induced by climate change has lead to a widespread decline in lichens over the last decades (Joly et al. 2009).

Extreme weather events associated with climate change can drive the dynamics of caribou herds through their effect on winter forage. Freezing rains on snow have led to massive die-offs of Peary caribou in the Canadian High Arctic (Miller and Gunn 2003) and on Svalbard (Solberg et al. 2001, but see Tyler 2010). Frozen layers of snow affect the ability of ungulates to travel and forage. Some climate scenarios suggest an increase in the prevalence of rain or snow in the winter ranges of the RG and RAF herds (Rennert et al. 2009). Alternatively, the occurrence of wet and heavy snow in the winter habitat of migratory caribou may increase the litter fall of arboreal lichens and provide an additional source of food (Tremblay et al. 2005).

Spring and summer forage

Caribou depend on high-quality forage during spring and summer for reproduction, growth and replenishment of body reserves. Because their winter diet is based largely on low-protein lichens, caribou have a negative protein balance for 7 months of the year (Gerhart et al. 1996). Protein requirement increases steeply in late winter when up to 80% of the fetal mass is deposited (Robbins 1993), using up protein stored during the previous summer. After calving, females use protein obtained from growing plants to produce milk. A summer diet rich in protein is also essential for males that must regain body mass lost in winter and reach prime condition for the autumn rut.

Deciduous shrubs such as dwarf birch (*Betula nana*) and willows (*Salix* spp.) account for 70% of the rumen content in caribou from the RAF herd in July (Crête et al. 1990b). Shrubs respond dramatically to warming in arctic ecosystems. In Alaska, Tape et al. (2006) reported a 33 to 160% increase in the relative abundance of deciduous shrubs from 1945 to 2002. A similar study near Kangiqsualujjuaq revealed a relative increase of 29% in the cover of erect shrubs from 1964 to 2003 (Tremblay and Lévesque, unpubl. data). Increasing cover of shrubs (further discussed in chapter 8) could increase summer forage for caribou, but earlier onset of the growing season (as projected in chapter 2) may reduce digestibility of leaves through the accumulation of lignin, tannins and phenols (Herfindal et al. 2006). The response of plants to warming varies among species (see chapter 8), soil nutrients and the level of temperature increase. In nutrient-poor soils such as those found in Nunavik, a decrease in protein is expected (Turunen et al. 2009).

9.3.4 Changes in abundance and distribution of competitors, predators, parasites, and diseases

In Nunavik, musk ox (*Ovibos moschatus*) are caribou's only potential competitors (Wilkinson et al. 1976). The introduced population of musk ox occupies a small portion of the caribou range at moderate densities. They are mostly located along the coast northwest of Kuujjuaq and number only a few thousand individuals (Jean et al. 2004). Climate change is unlikely to impact their abundance to a point that would be detrimental to caribou. The main predators of caribou in northern Québec and Labrador are wolves (*Canis lupus*) and black bears (*Ursus americanus*). Almost no information exists on these predators on the northern Québec-Labrador peninsula, and the potential impact of climate change on their population dynamics is unknown.

Caribou diseases in RG and RAF herds are not regularly monitored, but the possible impacts of climate change on caribou disease are well documented elsewhere in Canada (Bradley et al. 2005; Hoberg et al. 2008). Direct changes such as an increase of insect harassment may cause secondary infections and a loss of body condition (Weladji et al. 2002). A study on the RG showed that pregnant females reduced feeding time and moved towards snow patches during the period of insect harassment (Toupin et al. 1996). An increase of biting flies that are carriers of parasites may increase infection rates. For example, Besnoitia tarandi can cause severe skin and reproductive organ infections in caribou and is suspected to be transmitted by biting insects (Wobeser 1976; Glover et al. 1990). The number of *B. tarandi* cysts is higher in the RAF than in the RG herd and other sampled western herds (e.g. Bathurst, Bluenose West, Porcupine, Southampton) (J. Ducrocq, pers. comm.). Higher temperatures shorten the development time of larval nematodes (from the Strongyle group) in slugs and snails, hence increasing parasite abundance in caribou that accidentally ingest them while feeding (Kutz et al. 2001; Kutz et al. 2005; Jenkins et al. 2006; Ball et al. 2001). Snails are also hosts to the giant liver fluke (*Fascioloides magna*), present in caribou of both the RG and RAF herds, especially the RG (Choquette et al. 1971; Lankester and Luttich 1988).

The transmission of the parasitic protozoa *Toxoplasma gondii* is dependent on environmental factors such as warmer weather which is optimal for oocyst (egg) development. Abundant rainfalls increase run-offs and parasite transportation and thus increase infection risk while drinking or feeding (Meerburg and Kijlstra 2009). In eastern Canada, Canada lynx (*Lynx canadensis*) are the only felids that caribou may encounter. Lynx are the only animal in which *Toxoplasma gondii* can reproduce and produce oocysts that can be deposited into the environment. Lynx are present as far north as Kuujjuaraapik and Kuujjuaq (Anderson and Lovallo 2003). With a change in habitat, lynx may expand their range northward and infect new Arctic wildlife species or increase the parasite's abundance in the environment. The last survey reported that 0.8% of Nunavik caribou have been exposed to*Toxoplasma gondii* (Leclair and Doidge 2001). Abundance of *Giardia* sp. and the protozoan parasite *Cryptosporidium* sp. may also be influenced by extreme rainfall events, and changes in stream runoff patterns. Bacteria, such as *Leptospira sp*. and Q-fever (*Coxiella burnetti*), may persist in the environment when water surfaces are warmer,

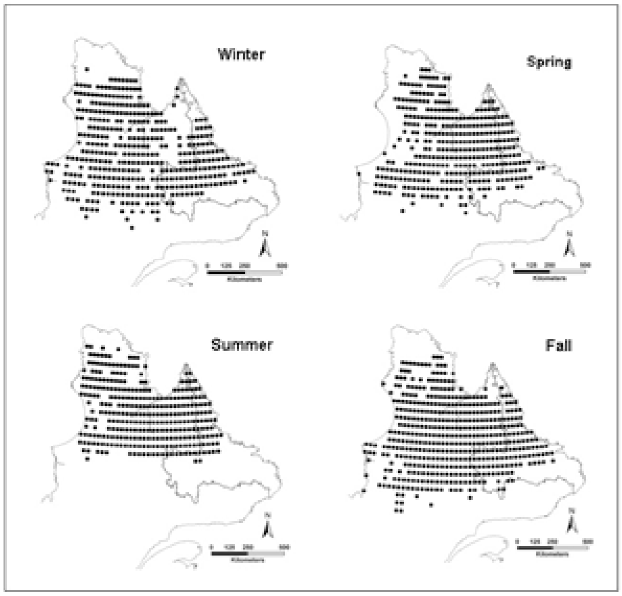

Figure 4. *Rivière-George migratory caribou occurrence for 1988-2003, Québec-Labrador peninsula (from Sharma et al. 2009). Points represent at least one occurrence of satellite-tagged caribou between 1988-2003.*

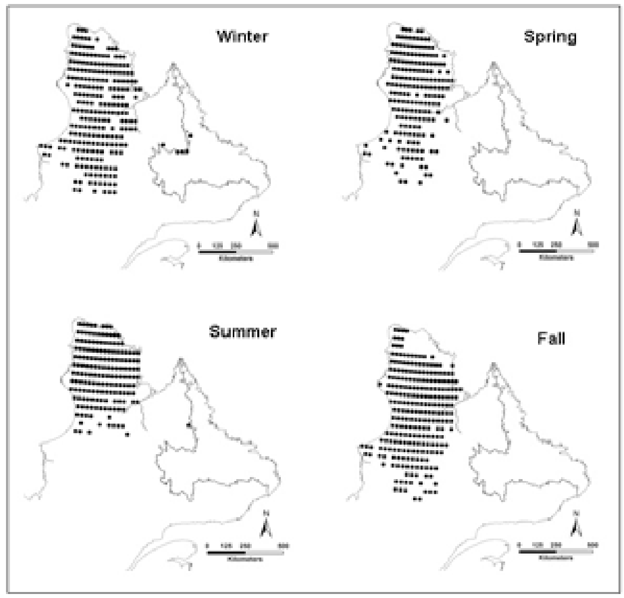

Figure 5. *Rivière-aux-Feuilles migratory caribou occurrence for 1994-2003, Québec-Labrador peninsula (from Sharma et al. 2009). Points represent at least one occurrence of satellite-tagged caribou between 1988-2003.*

or during desiccation and drought (Hoberg et al. 2008). Evidence of infection by these bacteria has been found in Nunavik musk ox (M. Simard, pers. comm.). As well, these last five pathogens are a concern for Inuit health in Eastern Canada (Messier et al. 2008).

9.4 Modeling of population dynamics and spatial distribution

9.4.1 Predicted occurrence of the Rivière-George and Rivière-aux-Feuilles herds

Global change is predicted to impact many ecosystems by altering species distributions (Walther et al. 2002, Parmesan and Yohe 2003). Arctic ecosystems are especially vulnerable to changes in temperature and precipitation regimes. We compared the current and potential future occurrence of the RG and RAF caribou herds under a Canadian General Circulation Model climate change scenario on the Québec-Labrador peninsula, using climatic and habitat predictor variables (Sharma et al. 2009). Our models were based on Argos satellite-tracking collars on >200 caribou between 1988 and 2003. We assembled a database of climate (temperature, precipitation, snowfall, timing and length of growing season) and habitat data obtained from the SPOT VEGETATION satellite sensor.

Migratory caribou demonstrate spatial and temporal variation in habitat use (Figures 4 and 5). In particular, high quality habitat is a reliable predictor of caribou distribution (O'Brien et al. 2006). Migratory caribou appear to prefer regions with higher snowfall and lichen availability in the fall and winter (Sharma et al. 2009). In the summer, caribou prefer cooler areas likely corresponding to a lower prevalence of insects, and avoid disturbed and recently burnt areas. Using projections from a Canadian General Circulation Model climate change scenario for

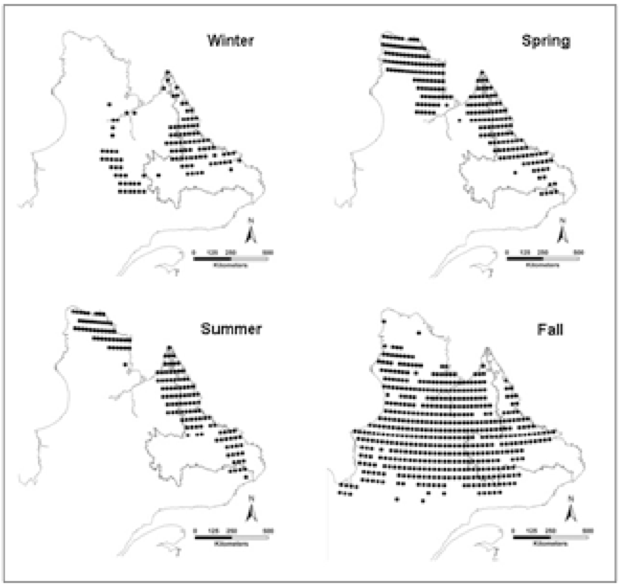

Figure 6. *Predicted Rivière-George caribou distribution for 2040-2069 under a climate-change scenario for the Québec-Labrador peninsula (from Sharma et al. 2009).*

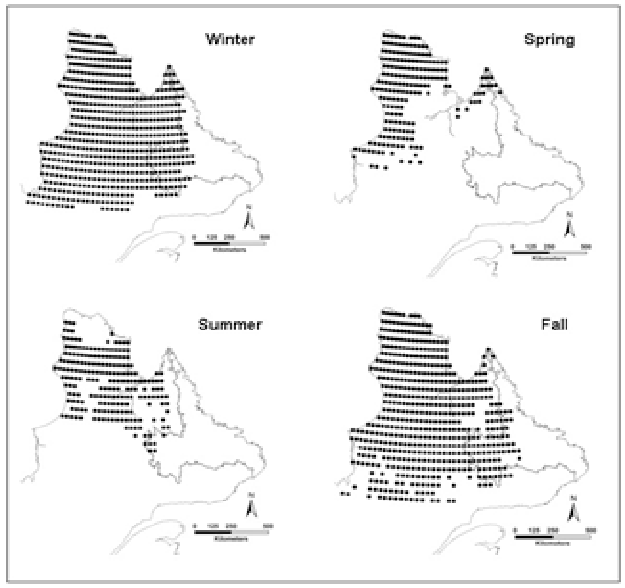

Figure 7. *Predicted Rivière-aux-Feuilles caribou distribution for 2040-2069 under a climate-change scenario for the Québec-Labrador peninsula (from Sharma et al. 2009).*

2040-2069, we predicted that winter, spring and summer RG caribou occurrences will be restricted to the north-eastern portion of Northern Québec and Labrador (Figure 6). In the fall, climatic conditions are likely to be suitable for caribou from the RG herd throughout most of its range. Spring and summer RAF caribou occurrences should remain the same (Figure 7). In the winter and fall, however, climatic conditions should be suitable for caribou from the RAF herd throughout most of the study region. The RAF migratory caribou herd is predicted to expand its range across all seasons, by as much as 47.4% in the winter. Furthermore, the spatial overlap between the two migratory caribou herds is predicted to increase in spring and fall, and decrease in winter and summer. Greater overlap may increase competition on the calving grounds but may also affect their location. In the last two to three decades, the calving grounds of the RG and RAF herds have been separated by about 800 km and the vast majority of females have shown fidelity to very specific calving grounds (Boulet et al. 2007).

9.4.2 Consequences of changes in occurrence

Direct and indirect consequences of climate change on migratory caribou herds may include alteration in habitat use, migration patterns, foraging behaviour and demography, as well as social and economic stress for Aboriginal populations. In addition to the direct effects of climate change on caribou occurrence modelled in this study (Sharma et al. 2009), caribou may experience a further northerly shift in distribution due to several factors including longer ice-free periods, increases in snowfall and extreme weather events, alterations in the fire regime, and changes in the distribution of insects and predators. Reductions in the predicted distributions of these two migratory caribou herds could result in changes in population sizes, further affecting caribou distribution (Bergerud et al. 2008; Couturier et al. 2010). It should be noted, however, that these projections were based on current climate and habitat use during a period when both herds were abundant. If migratory caribou population numbers decrease, there may be range constrictions independent

of climate change (Messier et al. 1988; Bergerud et al. 2008), underlining the difficulty of modelling range use and population dynamics of large migratory herds in a context of changes.

9.5 Adaptability to change in caribou populations

9.5.1 Population monitoring and assessment

Conservation and harvest of caribou require knowledge of population size and structure. The rapid changes in population trends and annual variability in recruitment and survival of caribou require constant monitoring. Satellite telemetry guides field operations and provides valuable information on behavioural and demographic parameters. Known-age individuals are needed to monitor the survival rates of different age classes (Festa-Bianchet et al. 2003). The main purpose of telemetry is to monitor the spatial components of caribou ecology, such as habitat selection, migration patterns and distribution. Maintaining a sample of radio-collared animals representative of the population requires sustained investment and effort, especially to satisfy the requirements for aerial censuses (Rettie 2008).

Conducting an aerial photographic census is widely used to estimate caribou population abundance in North America (Fisher et al. 2009), based on the seasonal aggregation of animals in open areas. Populations can be estimated from the number of females that aggregate on the calving grounds, or on the post-calving ranges, where the entire population aggregates during the fly harassment period (Couturier et al. 2004). Over the past twenty years, two population censuses have been conducted during the post-calving aggregations in Québec and Labrador (Couturier et al. 2004). The most recent census in 2010 documented the rapid decline of the RG herd. Population censuses are often limited by budget and frequency varies from five to ten years.

Monitoring caribou population structure is essential to assessing population trends between censuses. The annual classification conducted in fall provides information on

BOX 1. The Caribou Ungava website.

An efficient tool for knowledge transfer

(www.caribou-ungava.ulaval.ca)

Caribou Ungava is a large research program focussing on the ecology and population dynamics of migratory caribou of the Québec-Labrador peninsula in the context of climate change and industrial development. The program is supervised by scientists at Laval University (QC), University of Sherbrooke (QC) and the Ministère des Resources naturelles et de la Faune du Québec. It was initiated in 2009 to increase knowledge on the ecology of caribou and to respond to various concerns of industry, outfitters and Aboriginals. To quickly communicate new knowledge, the team uses a highly efficient and accessible tool, its website. The site is the most important means of communication between the research team, partners, managers and users of the resource. Anyone can track the progress of the research program by visiting the News section where all field activities, conferences, photos, publications and upcoming events are frequently updated. Information vignettes presenting various components of the research program and publicizing new results are also available. These vignettes summarize results in plain language. The website is dynamic, accessible and continuously updated according to the needs of each stakeholder. Anyone interested in migratory caribou can obtain information and find the answers to many questions for personal, scientific and management needs.

the proportion of males, females, yearlings, and calves in the population. The fall female to calf ratio is an indicator of annual recruitment (Couturier et al. 2009b). Close observation of caribou during the classification (in fall) allows biologists to distinguish males of different age categories based on antler size. These results are combined with harvest registration reports and population estimates to calculate harvest rates.

Changes in population abundance influence the body condition of caribou (Couturier et al. 2010). Body condition indices provide information on recent and past environmental conditions. Indicators such as seasonal fat reserves, protein ratios, body size and parasite load are useful to better understand population dynamics (Morellet et al. 2007). Caribou body condition varies with habitat quality and environmental conditions (Couturier et al. 2009a).

9.5.2 Management and conservation of migratory caribou under climate change

In Québec, migratory caribou are subject to a specific management plan developed following consultation with all stakeholders to allow for sustainable subsistence, and sport and commercial harvests (Jean and Lamontagne 2004). The Québec government developed the Management plan in close cooperation with the Hunting, Fishing and Trapping Coordinating Committee (HFTCC), who's mandate is to integrate the rights of the signatory Aboriginal peoples into the management of wildlife species in the Territory covered by the James Bay and Northern Québec Agreement and the Northeastern Québec Agreement.

The RG herd ranges over Québec and Newfoundland/Labrador. They are managed by different jurisdictions and hunting modalities depending on location and time of year. The spatial organization of hunting management is based on known seasonal ranges. Climate change could modify the seasonal distribution of caribou and changes in their conservation and management could be required (Sharma et al. 2009).

The current management plan for migratory caribou in Québec was not developed in collaboration with Newfoundland and Labrador. It was planned to be revised in late 2011 based on the population estimates obtained through the aerial survey of July 2010 for the Rivière-George herd and the one planned for the Rivière-aux-Feuilles herd. Collaboration between the two provinces, the HFTCC, the Labrador and Québec Innu, and the Inuit of Nunatsiavut is essential for the sustainable management of caribou. Communication is fundamental to adapting management guidelines to the changing environment and caribou populations.

9.5.3 Conservation and protection of caribou habitat

The protection of caribou habitat can contribute to the conservation of the species by limiting habitat loss and exposure to human-induced stresses. Calving grounds are critical areas where caribou are most vulnerable. The RAF and RG calving grounds are currently the only areas protected by Québec law as habitat for migratory caribou (Loi sur la conservation et la mise en valeur de la faune, L.R.Q., c. C-61.1, r.18). These calving grounds are protected only from 15 May to 1 July, when most activities are prohibited or have to be authorized by the Ministry.

It is difficult to legally define the habitat of migratory caribou because the area concerned is extremely large and changes over time. Variations in migration patterns and in the distribution of the two herds require a flexible approach. For example, the location of the calving grounds of the RG herd has changed substantially over time (Figure 9.2), and its protection must be adaptable over time as well. This difficult task will require large buffers around current calving grounds to allow for future movements.

Our increasing knowledge of caribou ecology and the potential effects of climate change on vegetation will contribute to better protect caribou habitat from industrial activities.

9.5.4 Hunting caribou in the future

Preliminary analyses of hunting mortality of radio-collared caribou over the last few years suggest that harvest levels may be substantial. In particular, hunting-related yearly mortality of males may exceed 20%, and harvest of radio-collared females in the RG herd is over 10%. We offer several recommendations to improve the consumptive management of migratory caribou. Our recommendations are driven by two fundamental considerations: harvests should be sustainable (both ecologically and evolutionarily); and based on science. As well, the collection of information from harvested caribou should be improved.

Sustainable harvests require information on population size and composition, or as a minimum, on harvest rates. Continued monitoring of harvest rates of marked caribou will provide managers with essential information on herd, gender and to some extent age-specific harvest rates. In this regard, efforts to discourage harvest of radio-collared caribou may be counterproductive, as they will negatively bias the estimation of harvest rate.

There is currently much emphasis on the size of antlers of harvested males, and in recent years the proportion of large males appeared to have declined precipitously. As managers realize the evolutionary and ecological importance of large mature males, it is to be hoped that the future harvest will no longer be based principally on the size of antlers. Sociocultural changes in the attitude of caribou hunters may be as effective as changes in regulations to improve the sustainability of caribou harvesting.

The continued sustainable harvest of migratory caribou, whether as subsistence or sport hunting, requires information on what is available and what is being harvested. The large yearly harvest of caribou of all gender and age classes during the winter hunt may not be sustainable, and the autumn trophy hunt may remove a very large proportion of mature males before the rut. Information on the numbers and gender and age composition of caribou harvested in the autumn, winter, and Aboriginal hunt would allow managers to assess the impact of these different harvests, particularly if collected over several years.

9.6 Conclusion

The RG and RAF herds are two of the largest migratory caribou populations in the world (Vors and Boyce 2009), and declines in their numbers could have negative social and economical implications, particularly for northern arctic and subarctic First Nation and Inuit cultures that rely on caribou for subsistence (Miller 2003). Changes in the distribution of caribou, for example a shift to Labrador for the RG herd (Sharma et al. 2009), as well as decreases in abundance, are expected in the near future. We anticipate the negative effects of changes in the distribution of animals and reduced abundance of caribou will be stronger than the positive effects of an earlier and longer

period of vegetation growth. Available evidence suggests that caribou abundance and distribution will change in the near future. Managers, stakeholders and communities should be prepared for a lower abundance of animals and perhaps a less predictable distribution, further away from communities. Future research by Caribou Ungava (Box 1), a research group interested in the ecology of migratory caribou in the context of climate change, will address the factors outlining variations in the population dynamics of caribou, implications for survival and reproduction, as well as the response of caribou habitat to different climate change scenarios. Management efforts focusing on mitigating greenhouse gases to reduce the potential effects of climate change, preserving high quality habitat, limiting anthropogenic landscape disturbances, and managing hunting in a sustainable manner, could alleviate stressors on migratory caribou of the Québec-Labrador peninsula.

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