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 and DIRECTION DE LA RECHERCHE SUR LA FAUNE

Serge Couturier ¹
Donald Jean ²
Robert Otto ³
and
Stéphane Rivard ²

¹ Faune Québec - Direction de la recherche sur la faune
² Faune Québec - Direction de l'aménagement de la faune du Nord-du-Québec
³ Government of Newfoundland and Labrador

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FOREWORD

Managing wildlife often requires knowing the size of the animal populations concerned. While it may seem simple, this key assumption can be difficult or even impossible to meet for certain wildlife populations. With migratory tundra caribou herds often numbering hundreds of thousands of animals ranging over hundreds of thousands of square kilometres, estimating the number of animals in a herd can seem impossible. Faced with this colossal task of counting the uncountable, a biologist had this to say over 60 years ago: "It is to be hoped that there will never be so few caribou that it will be possible to count them." (Clarke 1940, p. 101)

With the humility inspired by the pioneers of the study of migratory tundra caribou, this report presents the main results of two surveys conducted jointly and simultaneously in July 2001 by the governments of Québec and Newfoundland and Labrador. These two surveys probably represent one of the greatest logistical efforts of the kind in the world owing to the sheer number of caribou to be estimated, the difficult access and the vast survey area covering nearly 1 000 000 km².

LIST OF ACRONYMS AND ABBREVIATIONS

MRNFP = Ministère des Ressources naturelles, de la Faune et des Parcs – Faune Québec

RAFH = Rivière-aux-Feuilles Herd (Leaf River herd)

RGH = Rivière-George Herd (George River herd)

ABSTRACT

Historical records suggest that the migratory tundra caribou herds of Northern Québec and Labrador have undergone at least three cycles of scarcity and overabundance in the last 200 years. Prolonged periods of scarcity were followed by shorter periods of overabundance. This report discusses the recent demography of migratory tundra caribou herds and presents the results of photo-censuses of the Rivière-George (RGH) and Rivière-aux-Feuilles (RAFH) herds conducted in July 2001. The demographic trends for both herds, based on productivity, survival and physical condition, are discussed and previous censuses of the RAFH conducted between 1975 and 1991 are reviewed.

Two photographic surveys of post-calving aggregations were conducted in 2001 in order to estimate the size of caribou populations. Aggregations can be observed in July of most years, when caribou form large groups to avoid insect harassment during calm, hot days. Two statistical methods can be used to estimate herd size from post-calving survey data: this report compares the Lincoln-Petersen method used by Russell et al. (1996) and the model method proposed by Rivest et al. (1998). A comparison of results suggests that the two methods are relatively equivalent when smaller groups are excluded. However, since Rivest et al.'s method is less subjective, we recommend using the herd estimates obtained with their model in July 2001, namely, 296 000 ± 26.3% adults in the RGH and 931 000 ± 45.9% adults in the RAFH, although a review of previous census estimates and analysis of productivity, survival and physical condition data do not suggest that the RAFH herd reached such a record level. Rather, the high number is more likely an overestimate caused by inadequate herd sampling in July 2001 owing to logistical and weather problems. In a spirit of cautious management, we therefore recommend using the lower limit of the confidence interval for the RAFH estimate (504 000 adults in July). We suggest using the extrapolated population in October, or 385 000 ± 28.0% for the RGH and 628 000 caribou for the RAFH (including calves), as a basis for management. The growth in the RAFH is based on a finite rate of increase of 1.10 (10% annually) between 1975 and 1991, but also between 1975 and 2001. This is comparable to the rate of 1.12 reported for the RGH between 1976 and 1988, the period of dramatic growth when the population exceeded the record level of 600 000 animals.

RÉSUMÉ

Les données historiques suggèrent que les troupeaux de caribous migrateurs-toundriques au Nord-du-Québec et au Labrador ont enregistré au moins trois cycles de rareté et de sur-abondance au cours des deux derniers siècles. Les époques prolongées de rareté du caribou ont été suivies par des périodes de sur-abondance plus brèves. Le présent rapport fait le point sur la démographie récente du caribou migrateur-toundrique et décrit les résultats des inventaires effectués en juillet 2001 sur le troupeau de la Rivière-George (TRG) et le troupeau de la Rivière-aux-Feuilles (TRAF). Il discute, pour les deux troupeaux, des tendances démographiques suggérées par les données de productivité, de survie et de condition physique, et présente également une révision des inventaires antérieurs du TRAF réalisés entre 1975 et 1991.

Deux inventaires photographiques des groupes post mise-bas ont été réalisés en 2001 pour estimer la taille des populations de caribous. Ces grands rassemblements, formés sous l'effet du harcèlement par les insectes durant les journées chaudes et calmes, sont observés en juillet de la plupart des années. Pour analyser les données issues de cette technique d'inventaire, deux méthodes statistiques sont disponibles afin d'estimer la taille d'un troupeau. La méthode de Lincoln-Petersen utilisée par Russell et al. (1996) et celle par modélisation proposée par Rivest et al. (1998) sont comparées. Cette comparaison entre les résultats des deux méthodes suggère qu'elles sont relativement équivalentes lorsque l'on exclut les petits groupes. Par contre, la méthode de Rivest et al. (1998) est moins subjective. Il est donc recommandé de retenir les estimations du modèle de Rivest et al. (1998) pour les deux troupeaux en juillet 2001, soit 296 000 ± 26,3% adultes et 931 000 ± 45,9 % adultes pour le TRG et le TRAF respectivement. Cependant, dans le cas du TRAF, la révision des estimations des inventaires antérieurs et l'analyse des données de la productivité, de la survie et de la condition physique ne suggèrent pas que ce troupeau aurait atteint un tel niveau record. Ce résultat élevé serait plutôt une surestimation causée par le sous-échantillonnage en juillet 2001, à la suite de problèmes logistiques et météorologiques. Dans un esprit de gestion prudente, il est donc recommandé de choisir la limite inférieure de l'intervalle de confiance de l'estimation du TRAF, soit 504 000 adultes. Comme base de gestion, on propose de retenir l'extrapolation à la population d'octobre qui atteint 385 000 ± 28,0 % pour le TRG et 628 000 caribous pour le TRAF (incluant les faons). Les effectifs du TRAF auraient augmenté suivant un taux fini d'accroissement de 1,10 (ou 10 % par an) entre 1975 et 1991, mais aussi entre 1975 et 2001. Ce taux est également comparable à celui de 1,12 enregistré pour le TRG entre 1976 et 1988 durant la phase de croissance qui lui avait aussi permis de dépasser le seuil record de 600 000 individus.

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1. Introduction

Historical records suggest that the migratory tundra caribou herds of Northern Québec and Labrador have undergone at least three cycles of scarcity and overabundance in the last 200 years (Low 1896; Elton 1942). Prolonged periods of scarcity were followed by shorter periods of overabundance. Prior to the late 19th century, caribou could be observed in large numbers throughout Northern Québec and were successfully hunted for food by Aboriginal people from Ungava Bay to Hudson Bay. However, something happened between 1890 and 1910 to cause the caribou to disappear (Low 1896; Elton 1942; Rousseau 1951, Audet 1979). Although hunting by humans can now be eliminated as a possible cause, no one really knows what triggered the most recent decline and several Aboriginal groups have paid dearly for the resulting lack of food. It is possible that the overabundance of animals placed severe pressure on their habitat, causing the caribou to all but disappear (Messier et al. 1988). It is also possible that the decline was caused by climatic factors, as suggested by Crête and Payette (1990). Caribou populations remained extremely low during the first half of the 20th century, to the point that some people even suggested capturing and breeding a small number of animals in order to ensure the species' survival (Rousseau 1951). In the 1970s, the density of Northern Québec caribou began to increase again, for reasons that are again not clear. From a few thousand animals in 1958, the Rivière-George herd (RGH) rapidly rose to nearly 800 000 caribou in 1993, according to the census jointly conducted by the wildlife authorities of Québec and Newfoundland and Labrador (Couturier et al. 1996; Russell et al. 1996, Rivest et al. 1998). These scientific data were confirmed by Inuit elders, who as children knew about caribou only from their grandparents' hunting stories. Over the centuries, the life of the Naskapi, Inuit, Cree and Innu peoples has been closely associated with the Rivière-George caribou. This migratory tundra herd is most likely the world's largest caribou herd ever. In the early 1990s, its annual range covered more than 700 000 km², or nearly half of the territory of Québec. Today, the RGH's range has shrunk by roughly 45%.

In addition to the RGH, Québec biologists identified another large herd of migratory tundra caribou. In June 1975, Le Hénaff (1976) made the first scientific observations of the herd he named the Rivière-aux-Feuilles herd (RAFH) because the cows calved on both sides of the river. Since then, the range of the RAFH has expanded and the herd's calving grounds have rapidly moved northward: it is believed the herd was in search of more suitable

habitat. Le Hénaff (1983) estimated the number of female caribou present on the RAFH's calving ground in June 1983 at 33 000. The total number of animals in the RAFH, about which we still know very little, was later estimated to be 106 000 in 1986 (Crête *et al.* 1987), and 260 000 animals during the 1991 census (Couturier 1994). The RAFH occupies the western portion of Nunavik, between Hudson Strait to the north and the La Grande hydroelectric complex to the south. Although the herd's annual range partially overlaps that of the RGH (MRNFP, satellite monitoring, unpublished data), the two herds are considered separate populations because they have different calving grounds.

In addition to surveys, it is important to get a better understanding of the animal as such by characterizing the physical condition of caribou in the herds under study. These two parameters, i.e. physical condition and demography, are closely linked and previous studies already reported problems with the RGH (Couturier et al. 1988a; Couturier et al. 1990). Based on the initial observations reported by Couturier et al. (1988a, 1988b, 1989 and 1990), Huot (1989), Huot et al. (1985), and Vandal and Huot (1989), biologists acknowledged the poor physical condition of the Rivière-George caribou and the fact that some observations even indicated problems during summer. Partial data collected during the 1960s (Bergerud 1967) and 1970s (Drolet and Dauphiné 1976) as well as more complete data gathered during the 1980s (Parker 1980 and 1981; Couturier et al. 1988a, 1988b, 1989 and 1990; Huot 1989; Crête and Huot 1993) showed that the caribou's physical condition had deteriorated both in terms of skeletal stature and body fat and protein reserves. Crête and Huot (1993) and Crête et al. (1993a and b) also suggested that inadequate nutrition in summer causes slow calf growth. These observations suggest that migratory tundra caribou are limited by overuse of their habitat, especially summer habitat (Couturier et al. 1988a), and that predation is not a significant factor. However, this assumption still needs to be validated.

The major scientific work recently conducted on caribou management in Québec and Labrador comes at a crucial period in the herds' evolution. Indicators suggest a decline in the number of migratory tundra caribou in certain regions, and in the past few years both Aboriginal users and sport hunters have expressed concerns about the resource. To better support their management decisions, the governments of Québec and Newfoundland and Labrador studied various aspects of this culturally and economically important species. The first task was to determine herd size. To that end, a census of the two major migratory caribou herds was conducted in July 2001; this report presents the results of that survey.

Given the new information available, the report also includes a section revising the estimates from previous censuses of the RAFH, particularly the one conducted in June 1991 (Appendix 1). Lastly, some of the results of the study of the caribou's physical condition between 2001 and 2003 are presented for the purpose of situating the animals' state of health in relation to the demography and ecology of the herds.

2. Material and Methods

The study area was described by Couturier *et al.* (1990; 1996) and Russell *et al.* (1996). The post-calving survey technique was described in detail in Russell *et al.* (1996), and the method used to analyze the survey results was reviewed by Rivest *et al.* (1998), who proposed a new statistical method. Post-calving surveys essentially consist in fitting a large number of caribou with radio collars, letting them mix with the herd and then locating and photographing as many groups as possible during the period of post-calving aggregation in July, when caribou form large groups to avoid harassment from insects. That is why a census of migratory caribou takes nearly two years to prepare.

As soon as the insect season begins, the groups of caribou must be closely monitored and then photographed when aggregation conditions are adequate. The ideal conditions for photographic surveys are when groups are:

- dense (several hundred caribou per km²);
- well-delimited geographically;
- immobile in open habitats offering a certain degree of relief from insects: high, windy summits, residual snow cover, sand or other drier surfaces, etc.

Some groups may be photographed under less-than-optimal conditions, as it is not always possible to predict weather conditions, which can deteriorate. When caribou groups are sighted, they should be photographed even if it means photographing the same groups more than once: you never know if you will get another chance. Caribou herds range over a vast area in remote regions with difficult access. Post-calving surveys thus demand expedience.

Three parameters are used to estimate the size of the population under study: the total number of active collars, the number of collared animals in photographed groups, and the number of caribou counted in the photographed groups.

The following sections explain the stages in the July 2001 photographic survey of the Rivière-George and Rivière-aux-Feuilles caribou herds.

2.1 Post-calving surveys of the RGH and RAFH in July 2001

2.1.1 <u>Deployment of radio collars</u>

The post-calving photographic survey of caribou aggregations in July relies on the use of radio telemetry to locate the caribou. For large migratory caribou herds such as those of Québec and Labrador, dozens of radio collars are needed to locate most groups. The collars must be placed on the caribou long enough before the survey to enable adequate mixing of marked caribou throughout the herds' range.

Two technologies are available primarily to biologists wishing to monitor the migration of migratory tundra caribou. Available since the mid-1970s, VHF (Very High Frequency) radio collars are an effective means of monitoring caribou movement. However, these collars must subsequently be located by radio tracking from aircraft, with all of the vagaries that this entails: high cost of chartering aircraft, weather constraints, generally modest precision, etc. The other, and most common, technology used to monitor caribou migration is the Argos satellite tracking system. Established in the late 1980s under a French-US cooperation agreement, Argos has several advantages over the VHF technology, namely the possibility to frequently locate the animals without doing extra field work.

Table 1 presents an overview of the deployment of VHF radio collars during preparation for the July 2001 surveys. During each capture session, new collars were distributed as widely as possible throughout the herds' range on the basis of data received in real time from the Argos satellite collars and our knowledge of the herd's seasonal migration patterns (figure 1). During eight field expeditions between June 2000 and June 2001, 111 caribou from the RGH and 97 caribou from the RAFH were fitted with VHF radio collars (table 1). These collars were in addition to those deployed since June 1997, which were still working in July 2001.

2.1.2 Radio tracking

A twin-engine Piper Navajo flying at a speed of 280 km/h and an altitude of 3 300 m above ground level was used for radio tracking. The plane was equipped with two directional antennas mounted laterally. The herds' entire range was covered by flying transects approximately 50 km apart.

6

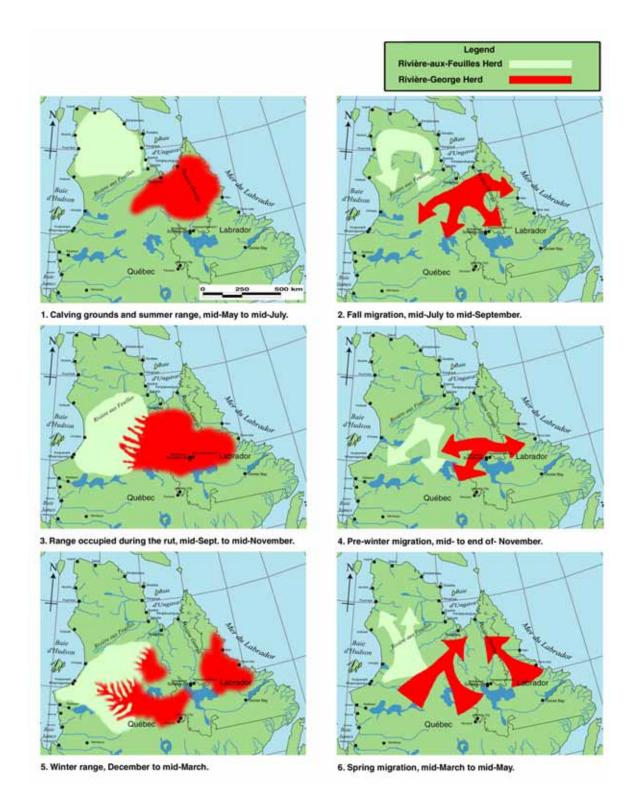


Figure 1. Seasonal movement patterns of migratory tundra caribou of Québec-Labrador, 1999-2001

Table 1. Recent deployment of VHF collars in preparation for the July 2001 caribou surveys

	June	Sept.	Nov.	March	5-8 March	21-23 March	June	
Sex/Age	2000	2000	2000	2001	2001	2001	2001	Total
	(Que)	(Que)	(Que)	(Que)	(Lab)	(Lab)	(Que)	
• Rivière-George her	d ^a							
Adult male	1	13	6	5	5			30
Adult female	14	27	8		7	4	1	61
Male calf		4	3		1	1		9
Female calf		7	2	1	1			11
Total	15	51	19	6	14	5	1	111
• Rivière-aux-Feuille	s herd ^a							
Adult male	3		7	19				29
Adult female	14		14	13			10	51
Male calf			5	2				7
Female calf			7	3				10
Total	17		33	37			10	97

^a The herd to which caribou belong was based on the capture location. See table 2.

There were four observers on board, each equipped with a VHF receiver. Their job was to record the frequencies heard, the strength (strong, medium or weak) and type (simple, double or triple) of signals, the number of pulses per minute and the direction (port or starboard) and GPS location of the plane when the signal was heard.

Telemetry data were also collected during extensive helicopter flights over the study area in July 2001.

2.1.3 <u>Locating and photographing groups</u>

From July 9 to 31, 2001, a second team of three or four observers flew over the study area by helicopter. Their main task was to locate and photograph groups of caribou deemed to be of adequate aggregation condition. They began by surveying the RGH, because the temperature is warmer in this herd's range than in that of the RAFH. Summer phenology often occur two or three weeks later in the RAFH's summer range.

The team used radio telemetry to locate the groups. The helicopter was equipped with three directional antennas: one mounted on the fuselage nose and the other two mounted laterally on the skids of the helicopter. Each observer had a VHF receiver programmed with all potentially active frequencies. The collars were located from an altitude of 800-1 000 m above ground level, a compromise enabling both good radio reception and a chance to see the groups of caribou on the ground.

Oblique aerial photographs of all caribou aggregations were taken using two Nikon 35 mm cameras: one with Fuji™ Professional 64 ASA colour slide film for photos taken in good lighting condition, the other with Fuji™ Professional 400 ASA colour film for photos taken late in the day. Both cameras had a 50 mm lens set at infinity. Exposure time varied from 1/250s to 1/1000s in automatic and shutter speed priority modes. Photos were taken from an altitude of 250-300 m above ground level.

More often than not, the groups of caribou were too large or too spread out to fit into one photograph. Where the group was spread out, several photographs were taken in a line along the helicopter's flight line. Two adjacent photographs were always overlapped such that the caribou appearing on the right side of one image also appeared on the left side of the following image. The same group could be photographed more than once, sometimes a few days apart. The best photographs (density of aggregation, maximum number of collars, optical quality) were used to count caribou.

2.1.4 <u>Image processing and counting of caribou on photographs</u>

Image processing and caribou counts were both done with the help of computers. Our slides were digitized using a Nikon™ Super Coolscan 4000ED film scanner with a resolution of 4000 dpi. Where necessary, we adjusted the contrast and colours of the photographs using the Photoshop™ image processing software to optimize image quality. To avoid double-counting caribou taken in two adjacent photographs, the overlapping area between the photographs was identified based on landmarks and individually recognizable caribou. The overlapping area was delimited directly on the digital file, which was then given to the counters.

Counting caribou required software capable of generating objects and recording them in a table. The ArcView[™] and MapInfo[™] geographic information systems (GIS) were used for this step. Generating an object for each adult caribou (1+ year old) present in the

photographs allowed us to count the number of caribou in each group. This step was repeated for calves, even though calf counts are generally considered to be underestimated because of their low visibility due to the calves' small body size (Russell *et al.* 1996).

2.1.5 <u>Modelling of the post-calving survey technique and statistical analysis</u>

Rivest *et al.* (1998) reviewed the analysis of post-calving survey data and proposed three different models for estimating the probability of detecting groups of caribou to account for missed groups. The homogeneity model assumes that each group has the same probability of being detected. The assumption is that groups are missed because of their location rather than because of their size or the number of collared animals in the group. With the independence model, the detection probability increases with the number of collared caribou in the group, where each collar is detected independently. The threshold model assumes a detection probability of 1 where the number of collars in the group is equal to or greater than a certain threshold (e.g. 2, 4 or 6 collars). This scenario assumes that groups with a higher number of collared animals should all be detected. The method proposed by Rivest *et al.* (1998) calculates the maximum likelihood estimate in order to determine which of the three models best describes the data.

Most statistical analyses were performed using the SPSSTM software. Unless otherwise indicated, a significance level of 0.05 (α =0.05) is used for statistical comparison purposes. Estimates are often presented with their confidence interval at α =0.10, expressed in percentage of the mean. Standard errors and deviations are also indicated for certain variables. The number of degrees of freedom was used to estimate the value of t in the calculation of confidence intervals. To calculate population estimates, the number of degrees of freedom was equal to the number of groups less 1.

2.2 <u>Physical condition, recruitment and demography</u>

A study was undertaken in 2001 to evaluate the physical condition of caribou in the Rivière-George and Rivière-aux-Feuilles herds (Couturier *et al.*, in preparation). One aspect of this study focused on the summer condition of adult females, for which a group of lactating females was harvested from each herd in July and August 2001 and 2002. The

standard measurements were used to describe body reserves and size (Huot and Goudreault 1985; Huot 1988 and 1989).

Every fall during the rutting period since 1973 (except in 1999), biologists from Québec and Labrador conduct a ground classification of hundreds of caribou to determine the age and sex structure of the RGH. Similar population classifications have been conducted since 1994 (except 1999) for the RAFH, following a previous one done in 1986 (Crête *et al.* 1987). These data can be used to calculate, among other things, the number of calves per 100 adult females (≥ 1.5 yr), which is in turn used to estimate productivity. However, this calf:cow ratio underestimates actual recruitment (number of calves becoming adults), as the mortality rate remains higher in calves than adults up until probably 12-16 months of age.

3. Results

3.1 <u>July 2001 post-calving surveys</u>

3.1.1 <u>Procedure for the two field surveys</u>

Two teams did the field work for the survey, one from a twin-engine plane and the other from a helicopter. The two teams were in contact every day by satellite phone.

The team in the plane was primarily responsible for the radio tracking (altitude of 2500-3000 m above ground). The aggregations were generally too far away to be located visually when flying at a low altitude. During the previous post-calving census in 1993 (Couturier *et al.* 1996; Russell *et al.* 1996), the groups of caribou were located much closer to an airport (Kuujjuaq), so greater use was made of fixed-wing aircraft. As well, the limited availability of aviation gas fuel for piston engines substantially restricts the use of small planes in the northern portion of the Ungava Peninsula, which is used by the RAFH.

The survey was completed between July 4 and 31. The temperature windows during which caribou form aggregations to escape insects were very brief. Poor weather conditions often prevented the aircraft from flying and major technical problems (change of helicopter in the middle of the period conducive to the RGH, breakdown of the helicopter engine during the RAFH survey) hindered the surveys (Appendix 2).

3.1.2 Active collars during the survey

From June 4-14 and July 3-23, 2001, two aerial tracking flights were conducted to locate as many radio collars as possible in most of the RGH's and RAFH's annual range, an area of 700 000 km² (figure 2 and figure 3).

All telemetry data were merged to determine the status of the collars and compile a list of active collars at the time of the photographic survey – a crucial element for calculating herd size under the survey method used. Given the large scale of the tracking flights conducted in June and July 2001, both by plane and helicopter, it was decided to use only the data from these two flights to compile the list of active collars. A total of 229 collars (Argos and VHF) in the RGH and RAFH were thus reported active during the surveys from July 9-31, 2001. This figure includes 19 and 15 Argos collars in the RGH and RAFH,

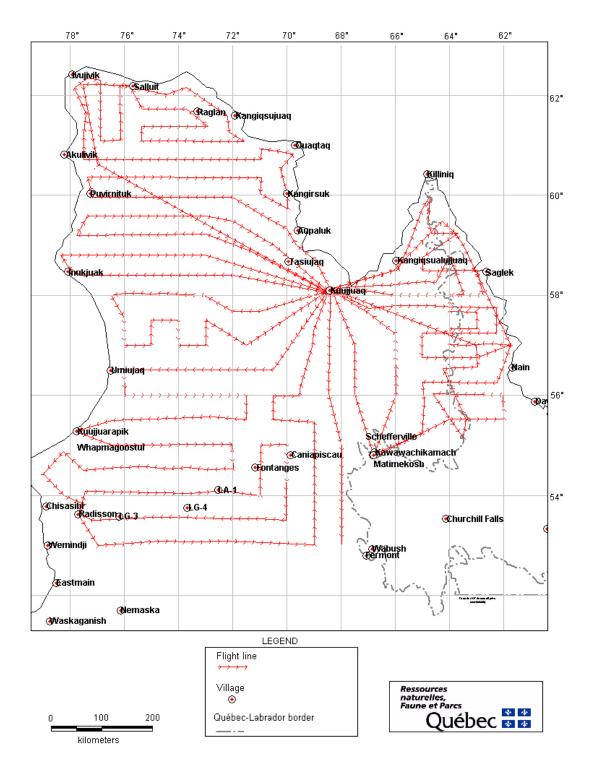


Figure 2. Radio-tracking flight lines, June and July 2001, Québec-Labrador

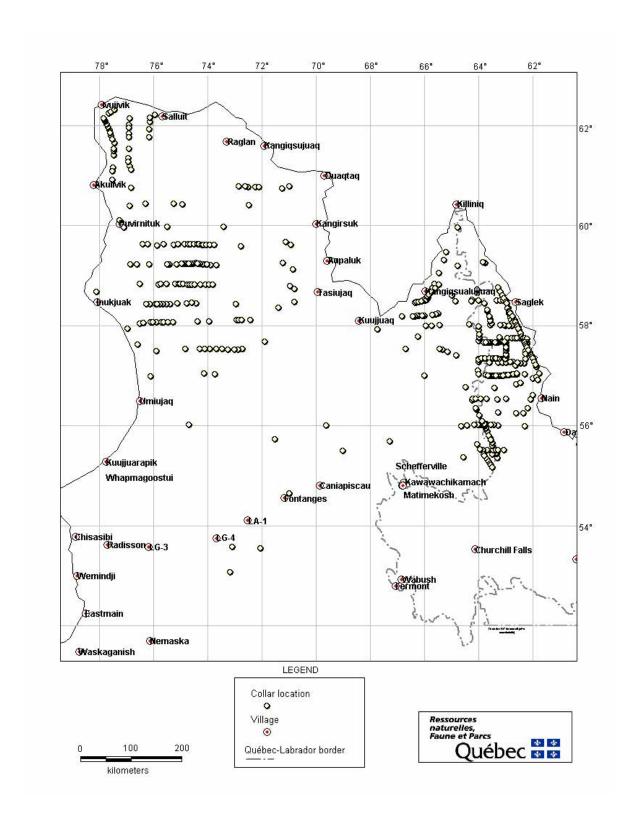


Figure 3. Location of collars detected during radio-tracking flights in June and July 2001

respectively. Most of the active collars were from among the 208 VHF collars deployed between June 2000 and June 2001 (table 1). However, apart from the Argos collars deployed continuously since 1991, a number of active VHF collars had been placed on caribou in June 1997 (n=2 collars), October 1997 (n=11 collars) and June 1999 (n=2 collars). Six very old collars deployed between October 1993 and June 1996 and heard only once between March and October 2001 were discarded from the analysis owing to their questionable status. Given the radio tracking effort in July, only one of the collars located in June was not heard in July, confirming that almost all of the active collars were heard by one or other of the teams when the caribou were photographed.

In previous surveys (Crête *et al.* 1989, 1991; Couturier *et al.* 1996), each collar was assigned to one of the migratory herd based in the range used at capture time. However, it quickly became apparent that this method was not suitable for the two July 2001 survey analyses. Several collars were shown to have changed herds in July 2001. Had the collars been assigned to a herd based on identification at capture time, the 229 active collars located would have broken down as follows: 129 in the RGH and 100 in the RAFH (table 2). Determining herd assignment of collars on the basis of the area used in July 2001 proved to be a better method, yielding 109 collars in the RGH and 120 in the RAFH. Twenty-two (22) collared animals formally assigned to the RGH emigrated to the RAFH's post-calving area, compared with the emigration of only two collared animals from the RAFH to the RGH.

Based on herd assignment in July 2001, table 3 presents a breakdown of the 229 active collars by collar type (Argos, VHF), sex of the caribou and according to whether or not the collar was found in the groups photographed during the survey. Of the 109 active collars in the RGH, 30 (28%) were carried by males. Of the 120 active collars in the RAFH, 43 (36%) were on males. The distribution of collars between sexes reflects the relative abundance of males in each herd. Based on the population classifications done each year during the rut (governments of Québec and Newfoundland and Labrador, unpublished data), the mean proportion of males in the adult population (≥ 1 yr) was 33% and 39% for the RGH and RAFH, respectively, between 1994 and 2001.

Table 2. Assigning of active collars to herds during the July 2001 caribou surveys

Active collars in 2001	RGH	RAFH	Total
Collars assigned to herds based on capture location	129	100	229
Collars assigned to herds based on range used in July 2001	109ª	120ª	229

^a Emigration/Immigration: 22 collared caribou from the RGH moved to the post-calving range of the RAFH. Two collared caribou from the RAFH moved to the post-calving range of the RGH.

Table 3. Distribution of active collars during the July 2001 survey

Herd ^a	Type of collar	Male	Female	Total
RGH (collars photographed)	• Argos	1	10	11
	• VHF	10	35	45
	Subtotal	11	45	56
RGH (collars not photographed)	• Argos	2	6	8
	• VHF	17	28	45
	Subtotal	19	34	53
TOTAL RGH		30	79	109
 RAFH (collars photographed) 	 Argos 		1	1
	• VHF	6	16	22
	Subtotal	6	17	23
RAFH (collars not photographed)	• Argos	4	10	14
(as a superior)	• VHF	33	50	83
	Subtotal	37	60	97
TOTAL RAFH		43	77	120

^a Collars were assigned to herds based on the range used in July 2001.

3.1.3 Photographing and counting caribou

The location of the caribou groups photographed during the survey are shown in figure 4. A total of 56 active collars were present in the groups photographed in the range of the

RGH between July 9 and 20, 2001. A total of 23 active collars were present in the groups photographed in the RAFH's summer range between July 23 and 30, 2001.

Only groups with at least one radio-collared caribou were considered in estimating herd size, although other groups observed by chance were still photographed to potentially serve in the minimal population size computation. Those results are not presented.

Approximately nine hundred 35 mm colour slides were taken of 41 and 30 groups of the RGH and RAFH respectively (figure 4). Some groups with collared animals were photographed twice, which meant selecting the session with the best conditions for photography and aggregation. Considering only those photographs without duplicates and that contained at least one active collar, 27 and 17 different groups were counted and used to calculate population estimates for the RGH and RAFH respectively. A total of 108 876 and 78 576 caribou for the RGH (table 4) and RAFH (table 5), respectively, were counted on the photographs of these groups.

Counting caribou on photographs requires considerable investment in terms of human resources. A total of 1 450 hours of work were required for the two herds, from the initial digitization to actually counting caribou on the photographs.

3.1.4 Comparison of caribou counts made from photographs by two observers

To validate the caribou counts made from the photographs, two observers each counted caribou on a sample of 139 photographs from 10 groups belonging to the RGH. They did their counts separately and without knowing the count obtained by each other.

The counts obtained by observers 1 and 2 differed, on average, by 1.9% and -3.0% per photograph for adults and calves respectively. On average, observers 1 and 2 respectively counted 288.1 (standard deviation=288.1) and 282.0 (standard deviation=274.4) adult caribou and 88.1 (standard deviation=94.9) and 87.1 (standard deviation=81.9) calves per photograph for the 139 photographs in the sample. A matched samples t-test showed no significant difference (p > 0.05) in the counts of adults or calves. The Pearson correlation coefficient between the observers' counts was 0.991 and 0.967 (p=0.001) for adults and calves respectively.

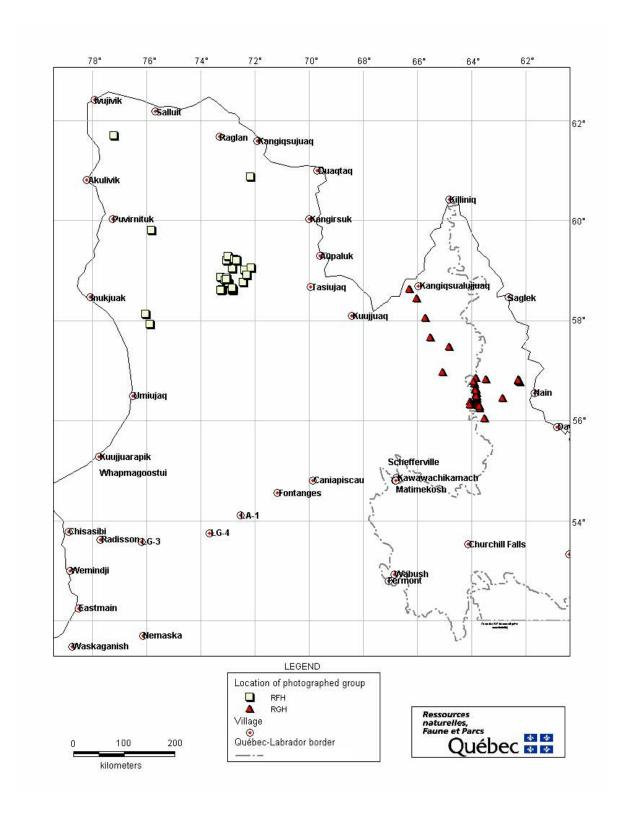


Figure 4. Location of caribou groups photographed in July 2001

Table 4. Raw results of the 2001 survey of the Rivière-George caribou herd (27 groups)

Session (No)	Date	Number of collars	Group size
1	July 9	2	1 600
2	July 13	4	2 698
3	July 13	2	775
4	July 13	1	218
5	July 14	1	337
6	July 14	1	2 636
7	July 14	2	3 166
8	July 14	1	622
10	July 14	2	6 629
11	July 15	1	992
12	July 15	1	1 113
14	July 15	1	2 128
15	July 15	1	2 399
16	July 15	1	2 154
19	July 15	2	15 866
20	July 15	2	2 533
23	July 16	1	1 896
29	July 16	7	18 711
30	July 16	10	16 285
32	July 17	1	2 963
33	July 17	4	9 140
34	July 18	2	1 238
35	July 18	2	6 836
37	July 18	1	1 874
39	July 19	1	953
40	July 19	1	2 137
41	July 20	1	977
TOTAL		56	108 876

Table 5. Raw results of the 2001 survey of the Rivière-aux-Feuilles herd (17 groups)

Session (No)	Date	Number of collars	Group size
1	July 23	1	3 326
2	July 27	1	500
4	July 27	1	2 321
8	July 27	1	7 104
10	July 28	2	2 310
11	July 29	1	3 403
12	July 29	1	871
18	July 29	1	1 553
20	July 29	1	3 360
21	July 29	2	17 770
22	July 29	2	9 885
23	July 29	2	12 514
25	July 29	2	5 682
29	July 30	1	5 695
30	July 30	2	2 172
32	July 30	1	98
33	July 30	1	12
TOTAL		23	78 576

Considering that the two observers partially counted the same groups, the total adult caribou count by observers 1 and 2 was 40 053 and 128 373 respectively. Where the same group was counted by both observers, the count obtained by observer 1 was used to calculate the population of the RGH.

Given the low deviation in the caribou counts made on the photographs of the RGH, it was decided not to do a double count of the photographs of the RAFH. The two observers therefore shared the counting. For the RAFH, observer 1 counted four groups totalling 23 845 caribou and observer 2 counted 13 groups totalling 54 731 caribou.

3.1.5 Herd size in 2001

During post-calving surveys, population size can be estimated using the Lincoln-Petersen method, also called the capture-recapture method for radio-collared animals (White and Garrott 1990). This method is described in Russell *et al.* (1996), which contains an estimate of the RGH in 1993. The number of active collars in a herd is an important

parameter in this method, and we used the values of 109 and 120 to calculate the size of the RGH and RAFH respectively in 2001.

Some authors consider that small groups observed during surveys should not be used for analysis purposes because the level of aggregation is inadequate. To solve this problem, Russell *et al.* (1996) decided to use only groups with more than 4 000 caribou. Rivest *et al.* (1998) raised the issue that arbitrarily selecting a threshold group size can significantly affect the population estimate. The very fact of defining what constitutes a large group could therefore impact the results. They also demonstrated that the Lincoln-Petersen estimate is negatively biased because groups with collared animals as well as groups without collared animals are missed during surveys.

To simulate the effects of defining a minimum group size, a Lincoln-Petersen population estimate was calculated using four different thresholds: no minimum size, 1 000, 2 000 and 4 000 caribou. Table 6 presents the results obtained using the data from the two 2001 surveys as well as from the 1993 RGH survey. The threshold size of groups used affects the estimate obtained, especially where the sample size is small and the number of collared animals photographed is low. For example, the population estimate of the RAFH in 2001 rises from 396 000 adults when all groups are considered to 645 000 when the minimum group size is set at 4 000 caribou, a 63% increase (table 6). The confidence interval also increases substantially from 31.3% (p=0.10) to 55.5% when the sample size of photographed collars decreases. The effect of a minimum group size on the population estimate and its confidence interval diminishes considerably with larger sample sizes. A case in point is the RGH in 1993: the estimate increases by only 20% depending on whether all groups or only those with at least 4 000 caribou are used (table 6).

A Chi² test for randomness of collar distribution in caribou groups suggests that this assumption is barely met and calls into question the mixing of collared animals in the herd. Merging groups of 4 000 caribou or less like Valkenburg *et al.* (1985) yields a Chi² value of 13.68 (p=0.04, degrees of freedom=6) for the RGH and 12.70 (p=0.05, DOF= 6) for the RAFH. For the RGH, group 19 alone accounts for most of the sum of deviations between the observed value of the number of collars (observed=2 collars) and the expected value (expected=8.31 collars) due to the size of the group (15 866 caribou). When this group is removed from the test, the Chi² value decreases to 10.76 (DOF=5) and probability

Table 6. Results of the 1993 and 2001 caribou surveys: number of adults in July and confidence interval (CI), and number of collars and groups photographed

	RGH 1993 ^a				RGH 2001 ^b				RAFH 2001 ^c			
Method/Authors	\hat{N} d	CI (90%)	Collars	Groups	\hat{N}	CI (90%)	Collars	Groups	Ñ	CI (90%)	Collars	Groups
Post calving: Lincoln-Petersen index												
All groups	451 000	8.9%	73	28	210 000	15.5%	56	27	396 000	31.3%	23	17
• Groups > 1000	502 000	11.4%	65	20	233 000	18.2%	48	20	466 000	35.5%	19	13
• Groups > 2000	525 000	12.8%	61	16	252 000	21.1%	41	15	481 000	36.9%	18	12
• Groups > 4000 (Russell et al. 1996)	540 000	13.9%	58	13	289 000	32.3%	27	6	645 000	55.5%	10	6
2. Post calving: Rivest et al. (1998)												
Model used: Homogeneity	587 000	15.5%	73	28	296 000	26.3%	56	27	931 000	45.9%	23	17
3. Calving grounds: Couturier et al. (1996)												
Photo-census in June	682 000 ^e	19.5%										

^a 92 collars were reported active during this survey.

^b 109 collars were reported active during this survey.

^c 120 collars were reported active during this survey.

^d Estimated population

^e Number of adults present in October, merging of results from Table 5 of Couturier *et al.* (1996).

exceeds the significance level. A linear regression of the number of collars (x) by group size (y) yields an r^2 value of 0.61 for 27 groups in the RGH. When group 19 is removed from the linear regression, the r^2 value increases to 0.79, again showing the exceptional nature of this group. A similar linear regression for the RAFH yields an r^2 value of 0.35 for 17 groups. Thus, it is possible that collared animals do not mix well with the herd, probably owing to the too-short time between the capture of some collared animals (e.g. March 2001 and June 2001) and the survey date.

To determine whether collar distribution in the herd was at random, Rivest *et al.* (1998) proposed a score test based on a Poisson regression model. The value of z for the homogeneity model was 0.49 and -1.1 for the RGH and RAFH, respectively, in 2001. The random distribution assumption must be rejected at a value α =0.05 if the value of z is greater than 1.645, which is not the case for the RGH and RAFH, indicating homogeneous collar distribution.

Analyses demonstrated that, for the RGH, the homogeneity model seemed to better fit to data and that the log-likelihood value of 7.16 was greater than that obtained for the four other models tested, i.e. 6.73, 4.70, 6.79 and 6.97 respectively for the independence and threshold models, at 2, 4 and 6 collars (see Rivest *et al.* 1998 for the calculation equations). The method used in 2001 with several observers in the aircraft suggests that the detection probability for groups did not vary with the number of collared caribou in the group and, consequently, that the homogeneity model is better suited for data analysis. There were always between 2 and 4 receivers scanning active frequencies, such that all frequencies in the group observed were heard within one or two minutes.

During the initial selection of models for the RAFH, we realized that the threshold model would not be suitable because the number of collared animals photographed per group was too low (only 1 or 2). The log-likelihood of the independence model for the RAFH was slightly higher than that of the homogeneity model, although the difference was minimal, or -6.58 compared with -6.81 respectively. To standardize analysis for the two herds and, especially, better reflect the observation conditions (more than one observer) during the July 2001 surveys, the estimate derived from the homogeneity model was also used for the RAFH (table 6), even though the log-likelihood value was slightly lower.

A comparison of results suggests that the two methods (Lincoln-Peterson's and Rivest *et al*'s) are pretty much equivalent when smaller groups are excluded. However, since Rivest

et al.'s (1998) method is less subjective, we recommend using the estimates derived from their homogeneity model in July 2001, namely, $296\ 000\ \pm\ 26.3\%$ adults in the RGH and 931 $000\ \pm\ 45.9\%$ adults in the RAFH. However, a review of previous census estimates and analysis of productivity, survival and physical condition data do not suggest that the RAFH herd reached such a record level. Rather, the high number is more likely an overestimate caused by inadequate sampling of this herd in July 2001. In a spirit of cautious management, we therefore recommend using the lower limit of the confidence interval for the RAFH estimate (504 000 adults).

Since the first studies of caribou in Québec-Labrador, herd size has always been described according to the size during the fall rut. Our July 2001 survey results expressed as the number of adults must therefore be extrapolated to account for adult mortality during summer and the number of calves present during the annual classification in October. Using the July to October survival rate of 0.99 (standard error=0.02) and adult ratio of 0.759 (standard error=0.01) from the October 2001 classification yields a herd size estimate of 385 000 \pm 28.0% caribou, including calves, for the RGH in fall 2001. The same calculation for the RAFH but using an adult ratio of 0.773 (standard error=0.01) yields a fall herd size estimate of 1 193 000 \pm 47.4% caribou, including calves present at the time of classification. As previously mentioned, we recommend using the lower limit of the confidence interval, or 628 000 caribou including calves in fall 2001, for the RAFH for management purposes.

3.2 Review of past RAFH surveys, 1975-1991

The early days of scientific monitoring of the RAFH were marked by Le Hénaff's (1976) first observations of a 19 740-km² calving area near the Rivière aux Feuilles. According to his reports, this calving ground was used by 21 019 adult caribou in June 1975. A number of observations have been collected since then and it would be useful to assess the main knowledge acquired on this major but lesser-known caribou herd than the RGH.

In June 1977, a second census of the RAFH was unsuccessful because the team was unable to find any caribou concentrations (Le Hénaff 1983). On June 6, 1980, several groups of female caribou and their calves were observed during a verification flight (Jean, M., pers. comm. in Le Hénaff 1983). In June 1981, another visual census by plane (DC-3) and helicopter estimated that 10 198 \pm 29.7% (conf. int. α =0.10) adult females used an

 870-km^2 calving area south of the Rivière aux Feuilles. Unfortunately, this estimate is incomplete, as the ground observers also reported that they had not surveyed another calving area north of the river, which also harboured a large concentration of adult females and their newborn calves. In June 1983, Le Hénaff (1983) conducted a visual census of two adjacent calving areas north of the river (Lac Tassialuk, 3 000 km², and Lac Dune, 3 700 km²). He estimated the number of adult females on the RAFH's two calving grounds in June 1983 to be 32 $812 \pm 19.9\%$.

When using the original calving ground survey technique, five correction factors were needed to estimate the total fall population, including males and calves:

- 1. Proportion of females on the calving ground;
- 2. Rate of sightability during the ground survey or photographic analysis;
- 3. Rate of presence of females on the calving ground;
- 4. Summer survival rate;
- 5. Proportion of females in the herd in October.

This method was used for the June 1984 (Goudreault *et al.* 1985), June 1986 (Crête *et al.* 1987) and June 1988 (Crête *et al.* 1991) surveys of the RGH. In 1993, Couturier *et al.* (1996) modified the technique slightly in order to survey the entire area potentially used by females rather than just the calving ground like before. This modification eliminates the need for the third correction factor (rate of presence of females on the calving ground). The modified technique was also used in 1991 for the RAFH (Appendix 1).

When scientific monitoring of the RAFH began, the tools and knowledge needed to estimate all of these correction factors were not always available. Thus, Crête $et\ al.$ (1987) estimated the size of the RAFH in fall 1986 at 106 000 \pm 17.8% caribou based on a June 1986 photo-census of calving grounds. Analyzing the same data again a few years later, and given the uncertainty regarding some of the correction factors, the same authors (Crête $et\ al.$ 1991) this time decided not to estimate herd size in the fall, but rather to simply express their results as the number of adult females present on the calving ground in June. The same problem arose in June 1991, when certain correction factors were not available at the time.

With the new knowledge we have today, it is possible to use satisfactory estimates of these correction factors to extrapolate the results of the June surveys to estimate the fall population. Table 7 presents the results of these new calculations for the RAFH surveys

conducted between 1975 and 1991. Note that some accuracy is lost during all these steps to convert the number of caribou in June into an estimate of the number of caribou in the herd in October. The new variance resulting from the multiplying or dividing of a correction factor was estimated using the method described by Crête *et al.* (1986). When calculating confidence intervals for the corrected estimates, the number of degrees of freedom used for the value of t was either that of the initial estimate or that of its correction factor, whichever was lower (Gasaway *et al.* 1986; Crête *et al.* 1991).

Where no correction factor was available for a given survey, the corresponding value for the RGH in June 1984 was used (Goudreault *et al.* 1985). This appears to be the best survey of the time and it was assumed that the condition of the RGH and RAFH was comparable. For visual censuses, a sightability rate of 0.80 was used to account for missed animals, as suggested by Le Hénaff (1983). The values in bold in table 7 represent original data that are proper to surveys; the other values were estimated using correction factors taken from the June 1984 survey of the RGH or suggested by other authors. These new calculations show that the size of the RAFH increases from 56 000 to 276 000 ± 27.5% caribou between 1975 and 1991 (table 7).

It is generally assumed that calving grounds are the most traditional habitat of migratory tundra caribou. It is therefore important to note that the calving grounds of the RAFH gradually moved around 400 or 500 km northward between the time they were identified by Le Hénaff (1975) and the mid-1990s (figure 5). They subsequently moved slightly northeast, such that they are now located near the highest parts of the Ungava Peninsula (MRNFP, unpublished data). The herd's calving grounds appear to be more stable since the late 1990s, a little like those of the RGH, which have moved very little in the past 20 years.

3.3 <u>Physical condition, recruitment and demography</u>

Based on the carcass mass of lactating adult females, the condition of caribou in the RAFH appears to have sharply declined since 1988 (Crête and Huot, 1993), while that of the RGH has improved (figure 6). In fact, between summer 1988 and summer 2001, the females of the RAFH lost 9.3 kg, whereas those of the RGH gained 8.1 kg. Summer 2002 appears to have been more difficult for both herds, although the RGH remains in better condition than the RAFH (figure 6). Other common indicators of the physical condition of lactating females (protein mass, percentage of fat reserves, body size, etc.) confirm the

Table 7. Revision of RAFH census results, 1975-1991

Calculation parameters and correction factors	1975ª	1981 ^b	1983 ^b	1986°	1991
No. of adult caribou on calving ground	21 019 ^d			50 624	232 614
X 1. Proportion of adult females	0.86 ^g			0.93	
= No. of adult females on calving ground	18 100	10198 south ^e	32 812	47 100	140 479
÷ 2. Sightability rate	0.80 ^f		0.80 ^f	0.96	0.97 ^g
= No. of adult females on calving ground (corrected)	22 600	-	41 000	49 000	144 800
÷ 3. Rate of presence of females on calving ground	0.77 ⁹		0.77 ^g	0.77 ⁹	1.00 ^h
= Total number of adult females in June	29 300	•	53 300	63 700	144 800
X 4. Summer survival rate (June- October)	0.99 ^g		0.99 ^g	0.99 ^g	0.99 ^g
= Total number of adult females in October	29 100	•	52 700	63 100	143 400
÷ 5. Proportion of females in herd in October	0.52 ⁹		0.52 ⁹	0.52 ⁹	0.52 ⁹
= Total number of caribou in October	56 000 ⁱ	-	101 000	121 000	276 000
(including males and calves)	50 000		± 43.0%	± 46.6%	± 27.5%

^a Visual census: Le Hénaff (1976)

^b Visual census: Le Hénaff (1983)

^c Photo-census: Crête et al. (1991)

^d Values in bold indicate unpublished data from the survey concerned; all other values were taken from other studies (e.g. RGH 1984).

^e Incomplete because a calving ground to the North was not surveyed in 1981 (Le Hénaff 1983).

^f Rate proposed by Le Hénaff (1983).

⁹ Estimate taken from the 1984 census of the RGH (Goudreault *et al.* 1985; Crête *et al.* 1991).

^h N/A in June 1991, as the entire area occupied by females was surveyed.

ⁱ The original data did not include an estimate of the variance.

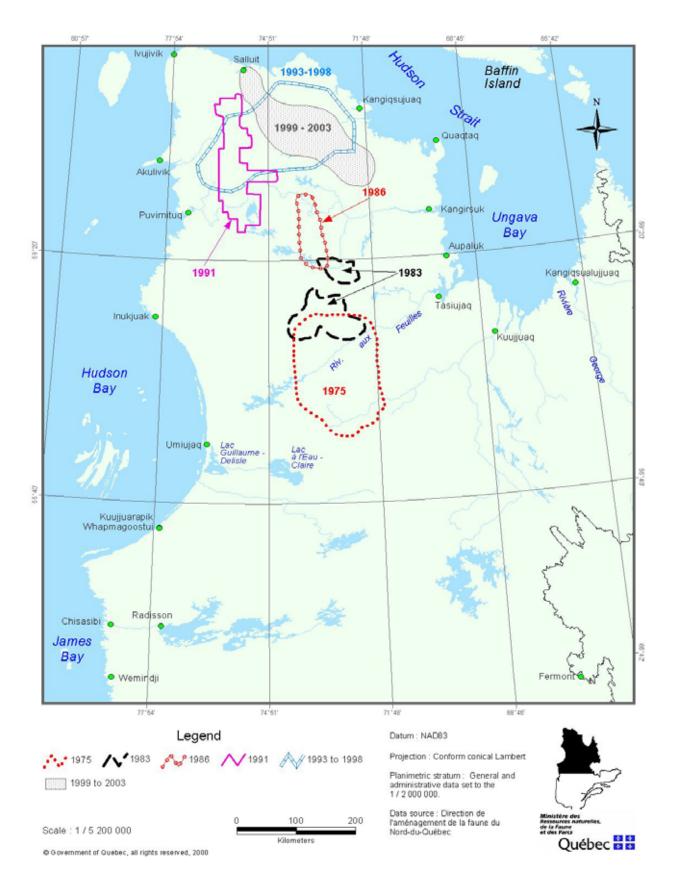


Figure 5. RAFH calving grounds, 1975-2003

observed trend in mass for the two herds. A herd's condition is also revealed by the mass and body size of calves. Between 1985 and 2002, the mass and body size of calves followed the same general trend as those in their mothers, i.e. the condition of the RGH improved and was generally better than that of the RAFH (Couturier *et al.*, in prep.).

Except for 1999, population classifications have been conducted every year since 1973 for the RGH and since 1994 for the RAFH in order to study the productivity of these herds. Figure 7 shows the changes in this population indicator for both herds. The productivity of the RGH appears to have gone through four phases. From 1973 to 1983, the average ratio was 51.9 (standard deviation=3.8) during a period of dramatic population growth and then fell to 39.3 (standard deviation=1.1) between 1984 and 1987. From 1988 to 1992, productivity further declined to a record low of 29.7 (standard deviation=4.3) on average. Between 1993 and 2003, the ratio remained low at 32.3 (standard deviation=9.6). Monitoring recruitment is more recent for the RAFH and average productivity was 37.5 (standard deviation=8.5) from 1994 to 2003 inclusively, compared with 41.4 in October 1986 (Crête *et al.* 1987).

Hearn *et al.* (1990) and Crête *et al.* (1996) estimated the caribou survival rates for the RGH using radio tracking and VHF collars. Table 8 presents the estimated female survival rates for the RGH. There are not enough data to estimate the survival rates for the RAFH.

Table 8. Annual female survival rate, RGH

Year	Adults ^a (≥ 2 yr)	Juveniles ^a (1 yr)
1983		0.95
1984	0.95	0.89
1985	0.92	
1986	0.91	0.66
1987	0.84	
1988	0.87	1.00
1989	0.93	0.84
1990	0.84	
1991	0.81	0.83
1992	0.83	0.88

^a Source: Crête et al. (1996)

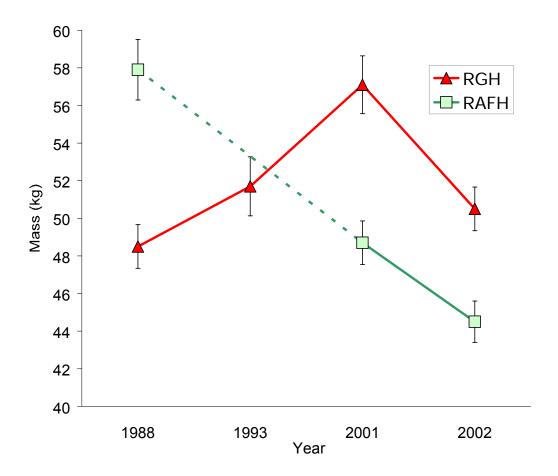


Figure 6. Carcass mass of lactating females of the RGH and RAFH

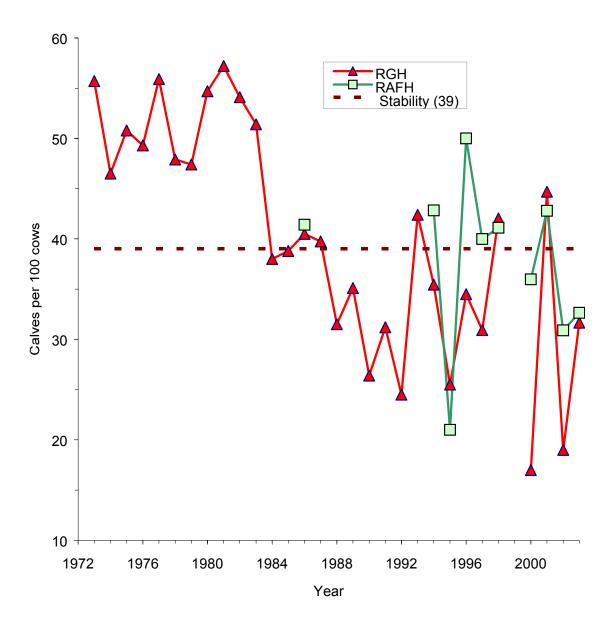


Figure 7. Productivity (calves/100 cows) in fall since 1973, RGH and RAFH

4. Discussion

4.1 <u>July 2001 post-calving surveys of the RGH and RAFH</u>

4.1.1 Survey method used

The oblique photography technique used for the 2001 surveys is based on the aggregation of migratory tundra caribou during the post-calving period in July. Vertical photography of calving grounds in June is the other technique used to count migratory tundra caribou and reindeer herds. It consists in taking vertical photographs (i.e. at a known scale) of caribou (especially females) on their calving grounds in June and then inferring the number of animals (especially males) not present in the areas photographed. This technique requires applying correction factors to account for, in particular, the absence of non-pregnant adult females on the calving grounds, the almost complete absence of adult males, the summer survival of adult females, and the abundance of calves in fall where juvenile recruitment is included in the population estimate (Crête et al. 1991). Each time a correction factor is applied, it results in a loss of accuracy and possible biases (Thomas 1998). In June 1984, 1986, 1988 and 1993, four photographic surveys of the RGH were conducted using the calving ground technique (Crête et al. 1991; Couturier et al. 1996). The same protocol was generally followed for the five surveys of the RAFH conducted between 1975 and 1991, except that photographs were taken only in 1986 and 1991. The calving ground survey technique can be affected by unusual migration. For example, in years where the RGH migrates later than usual, a portion of its calving ground is located below the tree line, thereby preventing the taking of photographs. One of the best examples of this situation was observed in June 2004, when the females did not reach their traditional calving grounds in time to give birth (MRNFP, satellite monitoring, unpublished data). In 2004, it would have been impossible to use the calving ground technique to survey either of the major herds.

In 1996, after a lengthy reflection by the Ministère de l'Environnement et de la Faune (now the MRNFP), it was decided to use the post-calving method for the coming caribou surveys in Northern Québec. In their report, Courtois *et al.* (1996) explained the reasons for choosing the post-calving survey technique over a calving ground survey:

(...) we recommend oblique photography of post-calving aggregations because there is less risk of being compromised by a possible change in migratory

behaviour. This method also costs less (...) and its validity was adequately demonstrated in a 1990 survey of the Rivière-George caribou herd conducted by National Defence (...) and in 1993 (....) [Translation]

Most other circumpolar jurisdictions also use the post-calving survey technique to conduct periodical herd counts (every 3-5 years). Biologists in Alaska routinely use this method to survey each herd every three years. In July 2001, they censused five herds this way, including the Mulchatna and Porcupine caribou herds, which number nearly 200 000 animals each (Valkenburg, P., pers. comm.¹). They use government aircraft, which remains available until weather conditions permit flying.

In July 2000, during an extremely hot summer that offered very good survey conditions, this technique was used to census wild reindeer in the Taimyr Peninsula of northern Siberia, which number an estimated 1 million animals (Kolpashchikov *et al.* 2003). However, we do not know whether this region has a single herd or a number of neighbouring herds such as in Québec-Labrador and elsewhere in North America.

In a critical review of survey methods, Thomas (1998) favours the use of the post-calving technique to count migratory caribou. However, he feels that managers should focus more on staying abreast of knowledge on the ecology of caribou than on spending considerable sums on surveys whose results are often inaccurate.

4.1.2 <u>Temperature, insects and quality of post-calving survey</u>

Post-calving surveys consist in monitoring caribou movements using telemetry to locate aggregations formed in response to insect harassment. This technique is therefore dependent on temperature. Harassment by insects is generally most intense during a two-to-four-week period between the beginning of July and the end of August. Temperature, wind, cloud cover, precipitation, humidity and atmospheric pressure are all influencing factors in insect harassment (Curatolo 1975; Roby 1978; Russell *et al.* 1993; Weladji *et al.* 2003). However, according to Russell *et al.* (1993) and Mörschel (1999), temperature and wind account for most of the variations observed in the activity of insects that harass caribou. Colman (2000) and Weladji *et al.* (2003) maintain that cloud cover is also a major

¹ Alaska Department of Fish and Game

influencing factor and suggest that insect harassment is more severe when the sky is clear (<40% cloud cover).

Despite the very brief summer, arctic and sub-arctic regions support a large insect biomass. Insects that are a source of disturbance to the caribou of Québec-Labrador include three groups of blood-sucking flies and a group of parasites (Toupin 1994). Mosquitoes (*Culicidae*), black flies (*Simuliidae*) and tabanidae (*Tabanidae*) and two species of parasitic warble fly (*Oestridae*, *Cephenemyia trompe* and *Oedemagena tarandi*) harass migratory tundra caribou, which have had to adopt tactics to mitigate the adverse effects on their physical condition (energy balance) and health (parasites). Russell *et al.* (1993) and Toupin (1994) reported that caribou spend less time eating and lying down to rest and expend more energy during the insect season. Some reindeer studies have shown that calf body mass is lower during summers of severe insect harassment (Helle and Tarvainen 1984; Helle and Kojola 1994; Colman 2000; Weladji *et al.* 2003).

According to our observations, mosquitoes and black flies become active when the temperature is over around 8°C. In her study of the RGH's summer range in 1992 and 1993, Toupin (1994) says that mosquitoes and black flies are absent when the temperature is below 6°C and that there are very few when the temperature is below 10°C. She also says that these two groups of insects stop being active when the wind speed is over 18 km/h. Syroechkovskii (1995) considers that the best conditions for mosquitoes are days with no wind and temperatures between 7° and 20°C. He suggests that mosquitoes can suck up to 2 kg of blood from a single reindeer in just one season. The period of high mosquito (Culicidae) abundance thus appears to coincide with the period of large postcalving aggregations of caribou (Curatolo 1975). Tabanidae are active only during the day when the temperature is over 14°C (Toupin 1994). The adverse effects of harassment by the two species of parasitic warble fly are mitigated by the relief tactics used by caribou. Thus, post-calving migration patterns appear to have evolved so that caribou avoid sites where they dropped larvae of these two parasites around mid-June (Folstad et al. 1991). Warble flies appear to be responsible for the caribou's scattering in August, when harassment by these insects lead to extreme behavioural reactions, causing the caribou to start racing over hundreds of metres (Curatolo 1975). These violent reactions to harassment break the cohesion of groups. Warble flies thus appear to be more of a nuisance in August and prefer the hottest periods of the day, or between 5:00 and 6:00 p.m. (Zhigunov 1968). Based on our experience, we suggest that in the tundra of Québec

and Labrador, insects do not become truly abundant until the temperature is over 18°C and the winds are calm.

The weather conditions were not favourable during the July 2001 survey, reducing the number of collared animals photographed. Long periods of bad weather marked by cold fronts from the ocean masses off the coasts frequented by caribou reduced insect harassment and prevented large aggregations of caribou. In fact, the weather conditions varied considerably throughout the study area and the caribou modified their behaviour and sought shelter in cooler areas, where there were fewer insects. Differences of nearly 10°C were observed from one part of a herd's summer range to another. The best example of this relief strategy was observed between July 3 and 12, 2001, when almost all of the Argos collars in the RGH were located in an unusually small area between Saglek and Nain, on a strip just a few dozen kilometres wide along the coast of the Labrador Sea. This was the first time with the RGH that we had observed such a large concentration of Argos collars in such a small area (unpublished data). The caribou stayed in this area until the weather got warmer and the marine fog lifted. As soon as the weather changed, huge groups of caribou quickly started moving south, probably in search of another relief area.

During the survey of the RGH, the team of photographers was in place and ready to start work as of July 7, 2001. In our opinion, the optimal survey conditions occurred between July 13 and 17, 2001. Unfortunately, part of the day on July 16 was spent moving the team, and the next morning (July 17) the helicopter had to leave to undergo a mechanical inspection (Appendix 2). During the previous survey of the RGH, Russell *et al.* (1996) took most of their photographs between July 5 and 20, 1993, a year when summer phenology was much earlier than usual (Couturier *et al.* 1996). As early as July 5, they were able to photograph a large concentration of approximately 50 000 caribou consisting mainly of adult males. They report that aggregations reached their peak between July 12 and 16 and that on July 23, the majority of caribou had scattered. Russel *et al.* (1996) also considered the 1993 summer to have been early. As well, they point out that a partial post-calving survey of the RGH had been attempted in 1990 and that the best aggregations were observed on July 27 and 28.

During the survey of the RAFH, where the summer phenology is later than in the RGH's range, the team of photographers was ready to start on July 22, 2001. The start of the RAFH survey was delayed because the team insisted on spending a few extra days on the

RGH survey in order to try and photograph more groups. Following several days of too-cold weather, conditions were optimal for the RAFH survey between July 27 and 29, 2001: July 29 may have been the best weather observed in 2001, with the temperature reaching 24°C in late afternoon and only a slight breeze (Appendix 2). A total of 16 groups were photographed that day between 10:32 a.m. (Group 11) and 9:00 p.m. (Group 28, table 5). Unfortunately, the helicopter suffered a major mechanical breakdown on July 31, bringing the survey of the RAFH to a sudden end. Had it not been for this technical problem, it would have been possible to continue photographing caribou for another few days. The last team member left the RAFH survey site on August 9, 2001, and the helicopter had still not been repaired.

When the weather is conducive to photography for only very short periods, most of the photos need to be taken during that time; however, that would require several experienced teams and several aircraft. This is the method used in Alaska in order to take advantage of the short window of optimal survey conditions, which sometimes last only two or three days. Between three and five aircraft belonging to the Alaska Wildlife Service are on standby for ideal weather conditions, and photos are taken as soon as it is possible (Valkenburg, P., pers. comm.²).

4.1.3 Counting caribou on photographs

Examining slides is a huge task and, for the first time, we used digital imagery to see if it would make counting easier and more accurate. High-definition digital images have several advantages, including better analysis of very dense groups photographed from a higher altitude. Software makes it possible to increase contrast between the animals and the surrounding terrain as well as enlarge images if necessary, which made it easier to distinguish between adults and calves – a possible source of error on certain photos – and made counting faster. The use of digital photos stored on compact disk facilitated the handling and exchange of photos between the people doing the recounting. More than one copy was circulated among the team, which was safer than using 35 mm slides. Digitization is a significant improvement over the standard technique for counting caribou on photographs.

² Alaska Department of Fish and Game

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A comparison of counts done by two different observers on the same photos shows that the method is both reliable and accurate. The same accuracy and consistency between counts were also observed during the counts of caribou from photographs from the July 1993 post-calving survey (Russell *et al.* 1996) as well as during the calving ground surveys conducted in June 1993 (Couturier *et al.* 1996) and June 1988 (Crête *et al.* 1991). Counting caribou on photographs is therefore not the source of inaccurate population estimates for either survey method (June and July).

4.1.4 Methodological assumptions

Russell *et al.* (1996) described four assumptions for validating the post-calving survey technique using telemetry. The first is a closed population. Like Russell *et al.* (1996) in their 1993 survey, it is reasonable to think that this assumption is realistic given the short survey period. This must not be confused with the previously mentioned cases of emigration, as once a collar has changed herds as a result of movements between capture time and the caribou's location in July 2001, the collar remains in the same herd for the duration of the survey.

The second assumption identified by Russell *et al.* (1996) is that all well-aggregated groups must contain at least one radio-collared animal in order to be located. With the relatively high number of active collars in 2001, it is reasonable to assume at the outset that this is an acceptable assumption. The probability of relocating a group with no collared animals if the herd is composed of equal-sized groups can be calculated as follows:

 $P = (1-N_g / N)^n$

where

n= Number of active collars

 N_q = Group size

N= Population size

With 109 active collars in the RGH and assuming a group size of 10 000 animals and a population of 300 000, the probability of having a group that is well-aggregated but has no collared animals is low, at 0.02. The probability quickly increases to 0.16 and 0.23 if the group size is set at 5 000 and 4 000 animals respectively. Thus, the probability rises from negligible to significant if the group size is 4 000 animals. However, aggregation conditions were not optimal for the RGH in July 2001 and groups numbered around 4 000 caribou (table 4). The average group size for the RAFH was approximately 4 600 animals (table 5).

Assuming a population of 500 000, 120 active collars and a group size of 5 000 caribou in the RAFH, the probability of having a group with no collared animals is 0.30. The probability falls to 0.09 if groups are assumed to reach 10 000 animals. This assumption was therefore not fully met in 2001 and it is possible that large groups with no collared animals were missed. On the other hand, because most of the RGH was concentrated in a relatively small area in mid-July 2001, we were able to locate groups during visual observation without the aid of telemetry. In fact, when the RGH started moving south, the majority of groups were forced to follow the Fraser Canyon, which is impassable over nearly 100 kilometres, so the groups were concentrated and could be located just through visual observation.

The third assumption identified by Russell *et al.* (1996) concerns the random distribution of collars in a herd. The virtual rejection of the random distribution assumption through the Chi² test or its acceptance through the score test proposed by Rivest *et al.* (1998) raises doubts as to the randomness of collar distribution in July 2001.

The fourth assumption (Russell *et al.* 1996) is that there be no exchange of animals between the photographed groups used to calculate the population estimate. Groups used to calculate this estimate cannot contain animals that might have been counted twice. To eliminate this bias, the number of caribou counted in groups 4 and 34 of the RGH was reduced in proportion to the number of collared animals that had already been photographed during another session. Since no collared animals in the RAFH were photographed more than once, this correction factor was not applied. It is assumed that this assumption was met.

4.1.5 Relative accuracy and possible bias in the calculation of population estimates

In the 1980s and early 1990s, the more limited knowledge of herd movements, especially those of the RAFH, precluded determining exchange/immigration among herds. Today, however, it is not only possible but mandatory to take emigration into account in the calculation of herd size. In 2001, there were occurrences where an animal assigned to one herd at the time of capture was subsequently photographed in another herd, which drastically changed the calculation of the number of active collars photographed in each herd (table 2). Determining the number of active collars in each herd can therefore bias population estimates, as emigration/immigration among migratory tundra caribou is still very poorly understood.

Bergerud and Luttich (2003) put forth the hypothesis that the June 1993 survey of the RGH was biased upward due to the emigration of caribou from the RAFH. However, this hypothesis was based on a small number of VHF collars that had apparently moved from the RAFH to the RGH. Moreover, the same hypothesis was made in previous papers by Bergerud (1996; 2000). Couturier *et al.* (1996) show that of the seven VHF collars deemed active in the RAFH, three were relocated near the calving grounds of the RGH. Not only is the number of VHF-collared animals having emigrated between groups low, but we also have to admit that knowledge of caribou emigration and movements was limited at the time. It is possible that the collars deemed to belong to the RAFH were actually carried by animals that originally belonged to the RGH. Nevertheless, recent data seem to show that emigration occurred and that this phenomenon could be an important consideration in planning future surveys of migratory tundra caribou herds.

The percentage of collared caribou photographed relative to the number of active collars was lower than predicted due primarily to poor weather conditions in July 2001. Cool periods significantly reduced insect harassment, with the result that there was less tendency for the caribou to form large aggregations after calving and aggregations were smaller and dispersed sooner. The percentage of collared animals photographed out of the number of collars reported active was 51% (56/109) and 19% (23/120) for the RGH and RAFH respectively. This is much lower than what we obtained in 1993, when 58 out of 92 active collars, or 63%, were photographed and used for calculation purposes (Russell *et al.* 1996; Rivest *et al.* 1998). However, in our opinion, this does not invalidate the 2001 population estimates, because even though the samples are smaller, they still appear to be representative of the overall range of each herd. Based on the field observations gathered over more than five weeks, the density of areas photographed appears to be the same as that of areas visited but not photographed owing to weather, logistics or technical difficulties.

These low rates of photographed collars have a direct upward effect on the confidence intervals of our estimates. Depending on the calculation method, the accuracy of the 2001 RGH estimates ranges from 15.5% to 32.3% and that of the RAFH estimates, from 31.3% to 55.5% (table 6). For comparison purposes, it must be remembered that the confidence interval of estimates of the total number of caribou including calves in fall 1984, 1986, 1988 and 1993 was 24.7%, 38.5%, 35.5% and 18.9% (α =0.10) respectively for the calving ground photographic surveys of the RGH (1984-1988: Crête *et al.* 1989; 1993: Couturier *et*

al. 1996). The confidence interval for the July 1993 survey was 15.5% (Russell *et al.* 1996 and table 6). These results compare favourably with the results obtained in other jurisdictions that also manage large migratory caribou herds. Table 9 presents the comparison with the Beverly and Qamanirjuaq caribou herds in the Northwest Territories, Nunavut, which respectively numbered between 87 000 and 277 000, and 221 000 and 496 000 animals during the period in question (Thomas 1998). The accuracy of the RGH surveys generally exceeded that obtained for the surveys of the Beverly and Qamanirjuaq herds during the same period.

Table 9. Confidence intervals for calving ground photographic surveys conducted in June in the Northwest Territories, Nunavut and Québec-Labrador

Herd/Year ^a	Confidence interval for surveys
	(α=0.10)
Beverly	
1982	72.4%
1984	50.3%
1988	61.5%
1993	33.9%
1994	63.5%
Qamanirjuaq	
1983	42.4%
1985	86.0%
1988	54.0%
1994	35.0%
Rivière-George	
1984	24.7%
1986	38.5%
1988	35.5%
1993	33.1%

^a Adapted from Thomas (1998)

4.1.6 <u>Herd size in 2001</u>

The estimate derived from the homogeneity model appears to best reflect the size of the RGH in July 2001. The alternative methods yield almost the same estimates for the RGH.

The herd had 296 000 adults \pm 26.3% in July 2001. Extrapolation yields a fall population including calves of 385 000 \pm 28.0%.

Table 10. Estimated size of caribou herds in October 2001

	No. of caribou in	No. of caribou in October,
	July 2001 (adults)	including calves ^a
RGH	296 000 ± 26.3%	385 000 ± 28.0%
RAFH		
Scenario 1: Mean estimate	931 000 ± 45.9%	1 193 000 ± 47.4%
 Scenario 2: Lower limit of confidence interval 	504 000	628 000

^a Assuming a survival rate of 0.99 between July and October and a proportion of adults of 0.759 (0.01) and 0.773 (0.01) in the RGH and RAFH respectively. The latter values were taken from the October 2001 classification.

A greater discrepancy between the results for the alternative estimation methods was obtained for the RAFH. In a spirit of cautious management, we therefore recommend using the lower limit of the confidence interval for the estimate derived from the homogeneity model, i.e. 504 000 adults in July 2001 and 628 000 in the fall including calves, as a basis for herd management. Using this conservative scenario for the RAFH, and by totalling the two herds, there were just over 1 million caribou in Northern Québec and Labrador in fall 2001.

4.2 Physical condition, recruitment and demography

A review of previous estimates of the RAFH between 1975 and 1991 confirm the herd's rapid and steady growth. Between 1975 and 1991, the finite growth rate (λ) of the population reached 1.10. The rate stayed the same from 1975 to 2001 and was 1.09 between 1991 and 2001 (lower limit of the homogeneity model=628 000 individuals, including calves). By comparison, the RGH had a similar finite growth rate of 1.12 between

1976 and 1988, when the herd's numbers also grew to over 600 000 individuals. Between 1988 and 1993, the rate was 1.03, when the size of the RGH peaked. Crête *et al.* (1996), based on an analysis of recruitment and survival rates, obtained a mean λ of 0.98 for the period 1988-1992. Considering the confidence intervals for population estimates, it is also possible that the RGH began declining between 1988 and 1993, as suggested by Boudreau *et al.* (2003). This dendrochronological study, and also the ones by Morneau and Payette (1998 and 2000), suggest that the RGH has rapidly increased in numbers in the 1980's, then stabilised and finally declined it's numbers during the 1990's.

It is important that the results of caribou surveys be related to the physical condition of caribou (Couturier, S. and R. Otto, unpublished data). Unfortunately, apart from the study by Manseau (1996), little data exist for estimating changes in the physical condition of herds during the 1990s. The preliminary results of the caribou physical condition study therefore shed light on the population trends revealed by the 2001 surveys. These results seem to suggest that physical condition is inversely correlated to herd size and declines when caribou numbers are high. The condition of the RAFH is currently the same or worse than that of the RGH in the late 1980s and early 1990s, when biologists feared a decline in the RGH. The decline actually occurred, probably in the early 1990s, and apparently enabled the caribou to partially replenish their body reserves. However, we do not know why the physical condition of the RGH improved while that of the RAFH declined, and analyses are ongoing in this area. Nevertheless, we can assume that the population regulation by forage exploitation set forth by Messier et al. (1988) continued having an effect during the 1990s. However, this hypothesis requires accepting that the quality of the RGH's summer habitat has improved since the mid-1980s, when Couturier et al. (1988a) and Crête and Huot (1993) identified summer habitat as a limiting factor for the herd. Although little data is available for estimating the quality of the RGH's summer habitat, it would appear that some vegetation regeneration can be observed (Boudreau, S., pers. comm.³). There are no recent data on the quality of the RAFH's habitat, but in the mid-1980s, Crête and Huot (1993) deemed the herd's summer habitat to be better than that of the RGH.

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³ Laval University

Based on VHF radio tracking between 1984 and 1992, Crête *et al.* (1996) estimated the average survival rate of adult females and juveniles of the RGH at 0.88 (range: 0.81-0.95) and 0.86 (range: 0.66-1.0) respectively (table 8). They also estimated that if the survival rate of adults was 0.85, the ratio of calves/100 cows in fall had to be at least 39 for numbers to remain stable. However, it seems that the RAFH exceeded this estimated level for demographic balance only five out of nine falls between 1994 and 2003 (no data for 1999) (figure 7). The RGH exceeded this level only twice during the same period, which may suggest that the observed improvement in physical condition is not yet sufficient to restore productivity to the optimal level observed in the 1970s.

The variability in annual productivity has been higher in recent years than in the initial years of scientific monitoring, as testified by the standard deviations for each of the periods compared. As demonstrated by Cameron (1994) for the caribou of Alaska, the significant year-to-year variability suggests the occurrence of reproductive pauses by female caribou that do not have sufficient body resources to successfully breed every year. Investigations of this assumption are ongoing.

Although not at the same time, the two herds have followed the same population and colonization trajectories, resulting in similar population peaks in recent history. However, we do not know whether the recent population explosion of both herds compares to the population peak observed between 1880 and 1900 (Low 1896; Elton, 1942; Rousseau, 1951; Audet, 1979). The rapid growth of the RAFH between 1975 and 2001 therefore does not appear to be unique to the migratory tundra caribou of Québec-Labrador. However, productivity on its own is not enough to explain the herd's growth during the 1990s. In fact, the average productivity of the RGH between 1973 and 1983, a period of population growth, was 51.8 (standard deviation=3.84) calves/100 cows, compared with only 39.1 (standard deviation=9.02) for the RAFH during a similar period of growth between 1994 and 2001. Either adult survival had to have been higher for the RAFH than for the RGH or immigration from the RGH had to have contributed to the increased numbers in the RAFH, as productivity alone cannot explain the rapid growth observed. It is also possible that the RAFH is levelling off, as suggested by the herd's poor physical condition, reflected in moderate productivity in the past few years. Preliminary analyses suggest that the RAFH has a higher survival rate than the RGH, judging by the results of satellite tracking of collared caribou using the Argos system (Couturier et al., in prep.). Our observations during VHF radio tracking (table 2) and satellite tracking (Couturier et al. in prep.) also

confirmed exchanges between the two herds, mainly from the RGH to the RAFH during the 1990s. Thus, the population growth of the RAFH could be the result of higher adult survival and immigration from the RGH, rather than of high productivity, as with the RGH between 1973 and 1983. However, this is a hypothesis that needs to be tested.

5. Conclusion

The 2001 surveys of the RGH and, in particular, the RAFH, were marked by logistical and weather problems that could not be foreseen. These problems directly affected the accuracy of herd size estimates. The 2001 estimates, especially those of the RAFH, are less accurate that the estimates calculated in 1993 using the same method (Russell *et al.* 1996; Rivest *et al.* 1998). The post-calving survey of July 1993 had the best relative accuracy of all surveys ever conducted in Québec-Labrador. Some logistical and administrative changes are required in order to improve the post-calving survey technique for future surveys.

Given the observed emigration in recent years, the two major herds will have to continue being counted simultaneously during the same year. Today, potential exchanges between the herds require managers to survey both herds at the same time in order to avoid possible biases caused by emigration.

With regard to the statistical assumptions, we noted two problems with the 2001 survey data. First, there is a certain probability that large groups had no collared animals and were missed. However, we believe that sightability was good, such that several groups were located without the aid of telemetry. Second, we question the randomness of collar distribution in groups, especially collars deployed shortly before the survey. Despite these concerns, however, we assume that enough data was collected to provide reliable information on the size of the RGH and RAFH in 2001. According to the data, there were $296\ 000\ \pm26.3\%$ adults in the RGH in July 2001. We propose using the extrapolated population estimate in October, or $385\ 000\ \pm28.0\%$ including calves (table 10), as the basis for management of this herd. Given the low accuracy of the survey results for the RAFH, and in a spirit of prudent management, we recommend using the lower limit of the confidence interval for the estimated population in October, or 628 000 caribou, as the basis for future management of this herd. These results concur with the recent trend in the physical condition and demography of the RGH and RAFH.

In 1991-1993, the two herds numbered just over approximately 1 million caribou. A decade later, the two herds still total slightly more than 1 million individuals, but the RAFH is challenging for the title of "world's largest caribou herd".

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APPENDIX 1. JUNE 1991
CENSUS OF THE RIVIÈRE-AUXFEUILLES CARIBOU HERD:
REVISED POPULATION
ESTIMATES

APPENDIX 1. June 1991 census of the Rivière-aux-Feuilles caribou herd: Revised population estimates

1. Introduction

When the photo-census of the Rivière-aux-Feuilles herd (RAFH) calving ground was conducted in June 1991, knowledge of the herd's ecology was limited (Couturier 1994). The new knowledge we have today allows us to revise the 1991 census results.

The main objective of the 1991 RAFH calving ground census was to estimate the number of females in the population in June. Three stages were conducted in the field. First, a reconnaissance flight was conducted by airplane to locate caribou concentrations (adults and neonates) and stratify the sampling area. A team then took vertical photographs from a helicopter. Lastly, the same team made visual counts, classifying the caribou by age and sex for the purpose of estimating the proportion of adult females in the area photographed in June.

In our revision of the June 1991 census results, we estimated the total herd size, including calves in October, taking into account the summer survival rate of adults and the proportion of age and sex classes during fall classifications. Where a correction factor was not available, the estimates of the Rivière-George herd (RGH) in 1984 (Goudreault *et al.* 1985; Crête *et al.* 1991) were used, as the values varied only slightly from one year or herd to the next.

2. Material and Methods

2.1 Reconnaissance flight and stratification of the area used by females

Delineation of the sampling area and its density strata was done using a twin-engine Aero Commander aircraft flying at a speed of 200 km/h and an average altitude of 200 m above ground level. The reconnaissance flight lines were generally 40 km apart (figure 1); however, when caribou concentrations were located, the team flew back over the same area to obtain flight lines 20 km apart.

A team of two observers (one on each side of the aircraft) and a navigator recorded the number of caribou observed and plotted their locations on a 1:250 000 topographical map. The observers tried to cover a 500-m strip on each side of the aircraft (10 line km flown =

10 km² on the ground). A fourth person on board the aircraft replaced the two observers when necessary. During the reconnaissance flight, this person surveyed the area with a scanning receiver.

The observers on board the aircraft divided caribou into three classes: 1+ year old females (almost white or no antlers), 1+ year old males (dark velvet antlers) and neonates. The latter class was used to cursorily evaluate the phenology of births on the calving ground. After the reconnaissance flight was completed, the data were quickly compiled in less than a day and were used to determine the density stratification of the observed caribou. The study area was divided into two density strata based on the number of adult females observed per 10 km²: the low-density stratum had between 1 and 5 females per km² and the high-density stratum had over 5 females per km². No density correction was made to account for caribou sightability.

2.2 Vertical photographs taken from a helicopter and classification in June

Once stratification was defined, the number of sample plots to be photographed in each stratum was determined using the optimal allocation method (Neyman allocation) for stratified sampling (Cochran 1977, p. 98). The location of the sample plots in each stratum was randomly selected on 1:250 000 topographical maps.

The Astar 350B helicopter used to take photographs had a 50 x 30 cm observation window in the floor to the right of the pilot. The camera operator sat in the right rear seat and could easily reach the observation window during the flight. Photographs were taken with an Olympus™ (OM-2S Program) 35 mm camera with aperture-priority automatic exposure control and an Olympus™ 50 mm f/1.8 lens. The camera was securely mounted in the observation window for vertical photographs of the ground. An intervalometer (Olympus™ Quartz M-1) and power winder (Olympus™ Winder 2) allowed pictures to be taken automatically every 10 seconds. All the operator had to do was change the film when the sample plot was finished being photographed. The majority of photographs were taken using Kodachrome™ 64 ASA colour slide film, although a number of locations were photographed using Kodachrome™ 200 ASA professional colour slide film. For the 64 ASA film, the aperture was set at f/4 and the exposure time was generally 1/500 or 1/1000s.

Thirty-six (36) colour slides in each sample plot were taken systematically along the helicopter flight line. With the helicopter flying at a speed of 200 km/h and photographs being taken every 10 seconds, a complete line of 36 photographs covered approximately 13 km on the ground. Before starting the flight line, the altitude above sea level was noted on the helicopter altimeter. The pilot was supposed to maintain an altitude of 200-300 m above ground level, depending on the surrounding topography, for the entire flight line along which photographs were taken. After photographs had been taken, the helicopter altimeter was periodically calibrated by landing on known-altitude geodesic points (mountains, airport runways, etc.).

Caribou were counted from the helicopter at low altitude (≤ 30 m) and speed (≤ 60 km/h) while flying between sample plots in order to evaluate the composition of the caribou population in the area photographed. The sampling areas used for classification purposes were uniformly distributed primarily taking into account the presence of caribou, fuel availability and the helicopter's flying time.

2.3 Counting caribou on slides and statistical analysis

A slide projector (Kodak™) was used to count caribou on the slides. The slides were projected on a white cardboard screen (surface of projection 90 x 60 cm) from a distance of approximately 2 m. The screen was divided into 10 equal squares. This grid served to standardize slide interpretation and facilitate counting. The number of caribou in each square was recorded and then the number of caribou in all 10 squares was totalled for statistical analysis purposes. All of the counts were done by the same observer. As a control measure, two secondary observers recounted a number of sample plots chosen at random.

The height above ground of photographs was calculated by plotting the location of the photograph on a 1:50 000 topographical map. This height was computed by the difference between the altitude according to the helicopter altimeter and the altitude on the ground according to the 1:50 000 maps. Knowing the height, the film format and the focal distance of the lens used (0.05 m) made it possible to calculate the surface area (in km²) photographed (Couturier *et al.* 1996).

The size of the RAFH in June 1991 was estimated using the "separate ratio estimator" method where the numerator is the total caribou count (adults or calves) for the 36

photographs of a sample plot and the denominator is the total surface area covered by the 36 photographs (Cochran 1977). The statistical methods used to analyze data in this type of calving ground survey are detailed in Couturier *et al.* (1996). The new variance resulting from the multiplying or dividing of a correction factor was estimated using the method described in Crête *et al.* (1986). When calculating the confidence intervals of the revised estimates, the number of degrees of freedom used for the value of t was the lower of the initial estimate and its correction factor (Gasaway *et al.* 1986; Crête *et al.* 1991).

3. Results and Discussion

The main results of the June 1991 census of the RAFH, and the process of revision leading to an estimate of the total population in fall 1991, are presented below.

3.1 Delimitation and stratification of the area used by females in June 1991

The airplane reconnaissance flight over the study area took seven days from May 27 to June 2, 1991. A total of 44.3 hours of flying time (including 7.9 hours of installation and removal) was required to cover 436 000 km² (figure 1). The reconnaissance flight allowed us to delineate the area used by females of the RAFH. Two density strata were identified: a high-density stratum composed mostly of females with calves, which actually consisted of the calving ground, and a low-density stratum consisting mostly of non-breeding females dispersed on the edge of the calving ground. Areas with a high density of adult females also had a higher number of calves. The high and low-density strata were respectively 13 934 km² and 21 918 km² in size. The second stratum defined in June 1991 was a change from the method used thus far, since the purpose was to conduct a census of the total range used by females rather than just the calving ground. The total number of females therefore no longer had to be extrapolated from the rate of presence on calving grounds, thereby eliminating one correction factor. The same method was used in the 1993 census of the RGH (Couturier *et al.* 1996).

3.2 Vertical photographs taken from a helicopter in June 1991

Photographs were taken from a helicopter between June 14 and June 18, 1991, starting at the northern limit of the study area, and required a total of 51.4 hours of flying time (not including installation and removal). Although inclement weather and a fuel supply problem in the northern portion of the study area delayed the start of photography by two days,

once the operation was started, it was completed with no interruptions. However, before actual photographs could be taken, nearly 45 helicopter hours were required just to prepare for the operation.

A total of 5 437 photographic slides were taken of the study area. Of this total, 394 slides (7.2%) had to be discarded, mainly because of problems with the image (blurred, poor exposure, etc.) or a location error in the strata or outside the study area.

Figure 2 shows the location of the study area, the two density strata and the 140 sample plots for the June 1991 census. The high-density stratum consisted of 86 sample plots and the low-density stratum, 54. In the 140 sample plots photographed, we were able to analyze between 4 and 37 slides on site. The size of the photo sample varied slightly from one plot to the next due to the fact that some slides were discarded. Except for four plots where 4, 13, 20 and 25 photographs were taken, the number of photographs taken per plot varied from 29 to 38, for 136 plots. In all, 5 043 slides were kept and used to calculate caribou densities in the study area in June 1991.

The primary observer subjectively qualified the degree of difficulty in reading the slides. Of the 5 043 slides analyzed in the two density strata, 4 450 (88.2%) were deemed easy to read, 576 (11.4%), hard to read, and 17 (0.3%), very hard to read.

It took the primary observer 420 hours to read all of the slides and plot each one on a 1:50 000 topographical map so as to estimate the height at which the photographs were taken.

To evaluate the quality of the caribou counts made from slides, 56 sample plots were randomly selected from among the total 140 plots. Of this sample, 34 plots were from the high-density stratum and 22, from the low-density stratum. Thus, 2 080 photographs were separately analyzed by two secondary observers as well as by the primary observer. Photographs served as the unit of comparison and no significant difference (ANOVA, F=0.72, p=0.49) was noted between the number of adult caribou counted per photograph in the random sample by the three observers.

3.3 Estimated number of adult females in June 1991

Some results of the June 1991 photo-census of the RAFH are shown in table 1. The number of adult caribou observed per plot in the high and low-density strata was 13.2

(standard error=2.0) and 5.3 (standard error=1.9) respectively, which corroborates the stratification used (p=0.005, t-test). The number of calves per plot was 4.0 (standard error=1.0) and 0.7 (standard error=0.2), which confirms that the high-density stratum corresponded to the calving ground. The mean area of a cluster of 36 photographs was 1.21 km² (standard error=0.03). Table 2 presents the estimated number of adult caribou on the calving ground in June 1991. The total number of adult caribou in the two strata in June 1991 is estimated at 232 614.

Based on the classifications conducted from helicopter in the 46 sites distributed throughout the two density strata, the proportion of females in the adult population is estimated to be 0.771 (standard error=0.024, n=24) and 0.409 (standard error=0.036, n=22) in the high and low-density strata respectively. The proportion of females in the two strata combined is 0.532 (standard error=0.048, n=46). The estimated number of females in the study area in June 1991 can be derived by using the "separate ratio estimator" method (table 3) and relating the proportion of females to the estimated number of adult caribou in each stratum (table 2). Thus, in June 1991, there were 140 479 \pm 24.5% adult females in the RAFH.

3.4 Estimated size of the RAFH in October 1991

When using the original calving ground survey technique, five correction factors were needed to estimate the total fall population, including males and calves:

- 1. Proportion of females on the calving ground;
- 2. Rate of sightability during the ground survey or photographic analysis;
- 3. Rate of presence of females on the calving ground;
- 4. Summer survival rate;
- 5. Proportion of females in the herd in October.

This method was used for the June 1984 (Goudreault *et al.* 1985), 1986 (Crête *et al.* 1987) and 1988 (Crête *et al.* 1991) surveys of the RGH. In 1993, Couturier *et al.* (1996) modified the technique slightly in order to survey the entire area potentially used by females rather than just the calving ground like before. This modification eliminates the need for the third correction factor (rate of presence of females on the calving ground). The modified technique was also used in 1991 for the RAFH.

When scientific monitoring of the RAFH began, the tools and knowledge needed to estimate all of these correction factors were not always available. At the time of the June 1991 census, estimates of the fourth and fifth correction factors were not available because radio-telemetry tracking and population classification during the rut did not exist. With the new knowledge we have today, it is possible to use satisfactory estimates of these correction factors to extrapolate the results of the June surveys to estimate the fall population. Table 4 presents the results of these new calculations for the June 1991 census of the RAFH. We used the values of the correction factors from the June 1984 RGH census (Goudreault *et al.* 1985; Crête *et al.* 1991). This appears to be the best survey of the time and it is assumed that the condition of the RGH and RAFH was relatively the same.

Based on the new calculations, applying the July to October survival rate of 0.99 (standard error=0.02) and a proportion of adult females in the herd of 0.52 (standard error=0.01), we estimate the size of the RAFH in October 1991 at 276 000 \pm 27.5% caribou, including calves (table 4).

Table 1. Some results of the June 1991 photo-census of the RAFH and Student ttest

Parameter	Stratum ^a	Mean	Standard error	n	t	Р
Number of adu	lts per plot					
	High ^b	13.2	2.0	86		
	Low	5.3	1.9	54		
	Total	10.1	1.5	140	2.87	0.005
Number of calv	es per plot					
	High	4.0	1.0	86		
	Low	0.7	0.2	54		
	Total	2.8	0.6	140	3.33	0.001
Snow cover on	ground (%)					
	High	27.18	1.96	84		
	Low	22.06	3.22	50		
	Total	25.27	1.73	134	1.36	0.178
Area (total for t	the 36 photo	s; km²)				
	High	1.22	0.03	86		
	Low	1.19	0.06	54		
	Total	1.21	0.03	140	0.38	0.709

^a The high and low-density strata are respectively 13 934 km² and 21 918 km² in size.

^b Based on the census technique used in 1991, the high-density stratum corresponds to the calving ground.

Table 2. Estimated number of adult caribou from the RAFH present in the area surveyed in June 1991

Density stratum	km²	n	Number of adult caribou	Confidence interval $(\alpha = 0.10)$
High	13 934	86	125 175	93 815; 156 535 (± 25.1%)
Low	21 918	54	107 439	51 036; 163 842 (± 52.5%)
Total	35 852	140	232 614	168 079; 297 149 (± 27.7%)

Table 3. Estimated number of female caribou from the RAFH present in June 1991

Density stratum	km²	n	Number of adult females	Confidence interval $(\alpha = 0.10)$
High	13 934	86	96 522	71 808; 121 236 (± 25.6%)
Low	21 918	54	43 957	19 931; 67 983 (± 54.7%)
Total	35 852	140	140 479	106 011; 174 947 (± 24.5%)

Table 4. Estimated total size of the RAFH in October 1991, calculated using the correction factors from the June 1984 RGH census

RAFH 1991	RGH 1984
232 614	293 600
	0.86
140 479	252 500
0.97	0.97
144 800	260 300
1.00 b	0.77
144 800	338 100
0.99	0.99
143 400	334 700
0.52	0.52
276 000	644 000
± 27.5%	± 25.1%
	232 614 140 479 0.97 144 800 1.00 144 800 0.99 143 400 0.52 276 000

^a Values in **bold** indicate original data from the June 1991 census of the RAFH; all other values were taken from the June 1984 census of the RGH (Goudreault *et al.* 1985; Crête *et al.* 1991).

^b Does not apply to the June 1991 census of the RAFH, as the entire area occupied by females was surveyed. Calculation of the third correction factor is skipped.

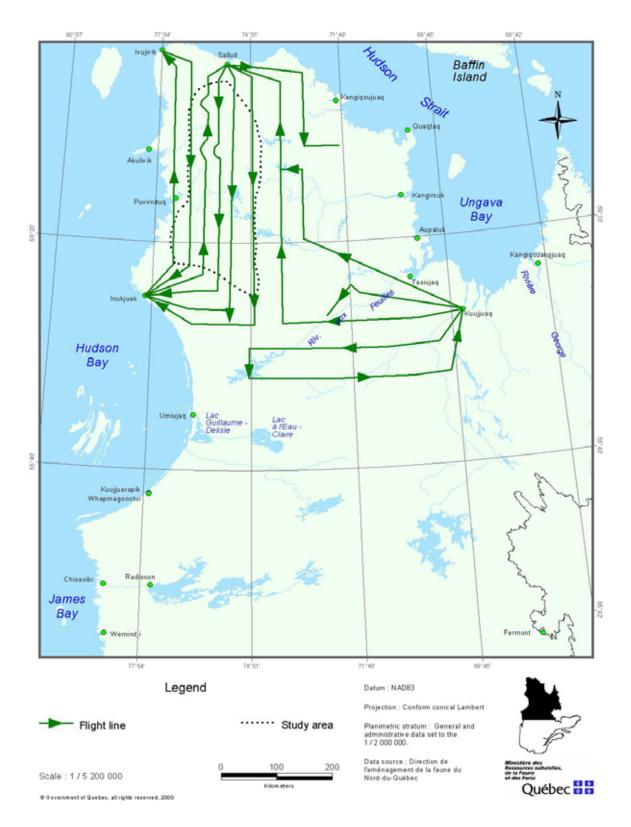


Figure 1. Visual reconnaissance flight prior to the June 1991 RAFH photo-census

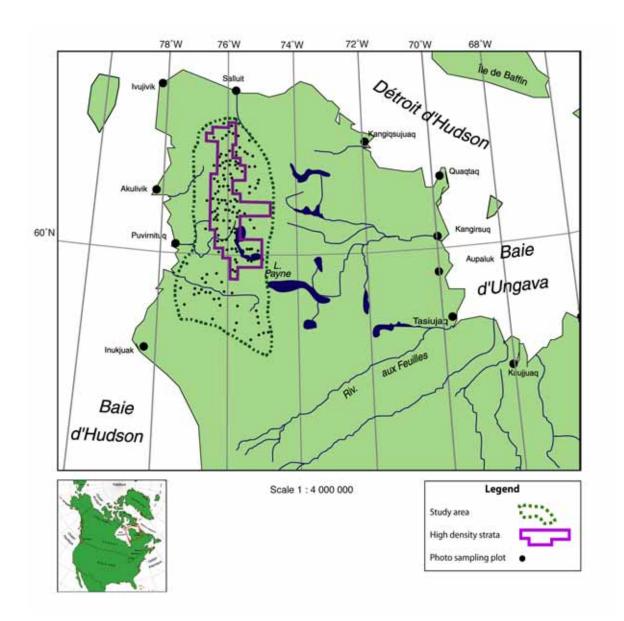


Figure 2. Location of high density strata and sample plots photographed on the range of the RAFH in June 1991

APPENDIX 2. CARIBOU SURVEY FIELD NOTES, SUMMER 2001

Appendix 2. Caribou survey field notes, summer 2001

DateAirplane teamHelicopter team07/03Qc-Kuujjuaq: LB SR AT QvG.07/04Radio tracking07/05Radio tracking07/06Radio trackingFlew from Québec City to Kuujjuaq on regular flight: SC, DJ07/07Rad. track.: LB, DJ, SR, AT, QvGPoor weather on the coast (Hebron Fjord): chopper still in Goose Bay.07/08Radio trackingPoor weather on the coast (Hebron Fjord): chopper still in Goose Bay.07/09Radio trackingFlew to Hebron Fjord. Team: SC, JF, RO, IS and pilot07/10Radio trackingHebron Fjord: chopper grounded because of bad weather (fog, 4-7°C).07/11Plane back to Québec City due to photo delay because of weatherHebron Fjord: chopper grounded because of bad weather (fog, 4-7°C).07/12Fog, 5°C. Finally able to leave Torngat Mt. Arrived at Pyramide, Riv. General Company (Fog)07/14Photo west of Kangiqsualujjuaq, 17°C07/15Photo near Lac Dihourse, 16°C07/16Photo near George and Falcoz riv. and Nain. 1:10 pm: 16°C, sunny, no wind	No flies.
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07/17 Chopper had to leave for 2 days for inspection. JF and IS left for Goo stayed. Used other chopper on site. Photo near Esker L.	se Bay, SC and RO
07/18 Photo near Esker Lake, 16°C and cloudy, with replacement chopper	
O7/19 Only a few photos from replacement chopper, cloudy 14°C. Chop delayed because of bad weather.	
07/20 Québec City to Kuujjuaq. rad. RO left for Goose Bay, SC tried to take photos from replacement c track. of priority photo area, LB, (12°C, cloudy, light winds). Changed chopper and 3rd pilot used. Nev SR, AT, QvG pilot.	hopper but too cold w team: SC, DJ and
07/21 Rad. track. and visual survey near Photos impossible, 5:08 pm: 8°C and rainy. RGH survey completed back later weather permitting.	for now. Will come
07/22 Radio tracking +DJ RAFH begins near Lac Minto. 10°C, new team: SC, SR and pilot	
07/23 Radio tracking Few photos southeast of Inukjuak, late in the day, 7:20 pm: 14°C, cloud flies	dy, no wind, very few
07/24 Rad. track. and visual sur.: Salluit 9:46 am: 8°C, overcast, ceiling at <1000'. No collars located. No photos and Kovik Bay	3 .
07/25 Rad. track: Kuujjuaq 11:30 am: 3°C, strong winds, rain. No flies or photos.	
07/26 Rad. track: Kuujjuaq 3:54 pm: 12°C, sunny, moderate winds, groups not yet formed. No photo	tos.
07/27 Rad. track: Kuujjuaq- Kangirsuk 8:11 am: 11°C, cloudy, light winds. Change of team members in Kang and return to Qc, LB, SR, QvG left, DJ and AT arrived. Took some photos late in the day. 8:21 pm: 16° clouds	
07/28 Photos possible only late in the day	
07/29 4:26 pm: Lac Payne: 24°C, sunny, light winds, lot of flies. Ideal cond groups photographed.	ditions for photo. 18
07/30 Moved closer to groups near Salluit, took a few photos	
07/31 Salluit 8:53 am: 17°C, strong winds, no flies. Between 40-60000 caribo	
Bay. No dense group, no photos possible. Recovered collars from de	ead caribou. Engine
broke down upon arrival in Salluit.	
08/01 Turbine damaged: grounded in Salluit. Waiting for company to fix tomorrow. 10:30 am: 16°C, a few clouds, winds 15-25 knots.	
08/02 3:15 pm: 15°C, sunny, 12 knots, a few flies. Photo conditions probably	
08/03 Ceiling at 500', Air Inuit flying, but chartered plane couldn't get in with arrived on Air Inuit after forced landing in Iqaluit.	the parts. Mechanic
08/04 12:15 pm: chartered plane arrived with parts	
08/05 O-ring broke while assembling turbine: had to start from scratch. No re to be flown in from Montréal.	
08/06 DJ left on chartered plane (one seat available), SC and AT to leave on chopper, whichever leaves first. Air Inuit can't land due to fog.	regular flight or with
08/07 Heavy rain, fog, 6°C, nothing flying: planes or flies	
08/08 3:00 pm, heavy rain, thick fog, 7°C, nothing flying: planes or flies	-
08/09 Chopper still not repaired, SC and AT left on Air Inuit for Kuujjuaq an Photo census of RAFH ended.	d then Québec City: