

Post-calving photo-census of the Rivière George caribou herd in July 1993

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Abstract: A photographic census of the Rivière George caribou herd in Quebec and Labrador was conducted between 4-23 July 1993 during the post-calving period. The primary objective of the study was to obtain an accurate estimate of the current size of the herd to permit the monitoring of population trends and effective management of the herd. The census procedure consisted of (1) use of satellite and conventional radio-telemetry to locate and photograph post-calving aggregations during the period of optimal aggregation, (2) determination of the minimum population size by direct counts from photographs, and (3) estimation of the total population size using the Petersen Index method. This method allowed extrapolation of the data to caribou that were either not photographed or that were not aggregated at the time of the census. The minimum count indicates that the Rivière George caribou herd consisted of at least 358 460 adults (older than calves) at the time of the census. This count underestimates the total population size but is useful because it is virtually free of error. The total size of the Rivière George herd in July 1993 was estimated to be 540 040 adults within 90% confidence limits of $\pm 12.8\%$. Comparisons with previous estimates indicate that the size of the herd continues to be large, but that its growth has probably ceased. This study demonstrates that a photographic survey of post-calving aggregations is an effective method to census the Rivière George herd and possibly other large migratory caribou herds that are monitored by telemetry.

Key words: *Rangifer tarandus*, population estimate, minimum count, radio-telemetry, aggregation, Quebec, Labrador

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Introduction

The Rivière George herd of migratory caribou (*Rangifer tarandus*) occupies a vast annual range extending from the Labrador coast to Hudson's Bay and between 52° and 60° N latitude. The herd constitutes the most important sustainable wildlife resource in Northern Quebec and Labrador. The herd is a vital economic and cultural resource for aboriginal people in northern communities, who rely on caribou for a large part of their diet. It also supports a multi-million dollar sport-hunting industry and a developing commercial hunt.

The Rivière George herd has undergone at least three cycles of scarcity and abundance over the past 200 years, and the numbers have fluctuated from a few thousand to several hundred thousand caribou. Historical records suggest that the numbers peaked in the early and late 1800s (Elton, 1942), and recent data suggest that another peak may have occurred in the

mid- to late 1980s (Messier *et al.*, 1988; Hearn *et al.*, 1990).

The Rivière George herd underwent a period of rapid population growth from the mid-1950s to the mid-1980s to become one of the largest caribou herds in the world (Williams & Heard, 1986; Messier *et al.*, 1988). Fall population estimates (including calves) ranged from 644 000 in 1984 to 283 000 in 1986 and to 682 000 caribou in 1988 (Crête *et al.*, 1991). However, the 1986 and 1988 censuses were relatively imprecise, with 90% confidence intervals of 36% and 39%, respectively.

Recent studies on productivity, body condition and survival rates suggest that the growth of the herd has ceased (Couturier *et al.*, 1988a,b; 1989; 1990; Hearn *et al.*, 1990; Messier *et al.*, 1988; Camps & Linders, 1989). Unfortunately, recent population estimates, determined by photographing caribou on the calving grounds, have suffered from technical problems and lack of precision (Messier *et*

al., 1988; Crête *et al.*, 1991). Due to historic fluctuations in population size and recent evidence of a decline in growth rate, it is important to obtain reliable population estimates at regular intervals to establish population trends. Such information, in turn, is essential for effective management of the herd.

We present the results and evaluate the methodology of a photographic census of the Rivière George herd conducted in July 1993. The method takes advantage of a brief phenomenon that occurs in July of most years as a part of the annual life cycle of large migratory herds of caribou (Valkenburg *et al.*, 1985). On calm, warm days most of the population aggregates in large groups, thus allowing photography of almost the entire herd in a cost-effective manner.

The technique relies on the presence of a large number of radio-collared caribou that disperse randomly within the population, thus facilitating the location of the aggregations. The majority of caribou can then be photographed and directly counted. An estimate of the total herd size is obtained by extrapolation to the (small) proportion of the population that could not be photographed. This method provides a high degree of accuracy and precision, and potentially allows frequent monitoring of herd size.

In the past, photography of post-calving or rutting aggregations has been used to successfully estimate the size of caribou herds in Alaska and Yukon (e.g. Whitten *et al.*, 1980; Whitten, 1985; Valkenburg *et al.*, 1985; Taylor, 1993), as well as in the Northwest Territories (McLean & Russell, 1988; Russell, 1990). A partial photographic census of the Rivière George caribou herd was carried out during the 1990 post-calving period (Russell & Jakimchuk, 1991). This census resulted in an imprecise population estimate, because less than 50% of the caribou were photographed during opportunistic surveys. The 1993 post-calving census represents a refinement of the 1990 census methodology.

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Study area

The study was conducted within the summer range of the Rivière George caribou herd in northern

Labrador and northeastern Quebec (Fig. 1). The study area, about 120,000 km² in size, consisted of habitat used by caribou for post-calving aggregations as documented since 1990 (RRCS, 1990, 1992, 1993) and extended eastward from about 70° W longitude to the Labrador coast and northward from about 55°30' N latitude.

Pleistocene glaciations have shaped much of the geomorphology of the study area, which is underlain by the Canadian Shield (Sutton, 1972). Glacial and alluvial land-formations, including eskers and glacial drift plains, occur throughout the area, and deeply scarified bedrocks are a characteristic feature of the interior plateaus. Topography of the area is varied, ranging from the rugged Torngat Mountains (elevations up to about 1,500 m) and deep coastal fiords and valleys in the east to low coastal areas in the north. The vast Labrador Plateau, south of the Torngats, extends from the Rivière George eastward to the Labrador coast. The area west of the Rivière George is relatively flat and characterized by many large lakes and rivers, draining into Ungava Bay.

The terrain over most of the study area, excluding the Torngat Mountains, consists of rolling tundra plains, dominated by barren rock, lichens, mosses and grasses. Black spruce (*Picea mariana*) forest grows in the sheltered valleys along larger rivers. Scrub-forest associations, dominated by willows (*Salix* spp.) and alders (*Alnus* spp.), are found higher along valley slopes and along smaller rivers (Rowe, 1972; Meades, 1990; Sogeam Inc., 1992a,b). Open spruce-lichen woodland is present along the southern rim of the study area and westward from Rivière à la Baleine (Whale River).

The topography of most of the range provides terrain features, such as barren windy ridges, that are used by the caribou as insect-relief habitat during the post-calving period. Their movements within the traditionally-used summer range are governed largely by a response to harassment by blood-sucking and parasitic insects at this time. Suitable insect-relief habitats appear to be abundant on the Rivière George Plateau and in the barren tundra in the east (Juniper, 1982).

Methods

Location and photography of post-calving aggregations

The census began on 4 July, when monitoring by satellite telemetry indicated that the caribou were forming post-calving aggregations just east of Kuujuaq. Two biologists, using either a twin-engine Partenavia aircraft or an amphibious float-equipped Cessna 206, conducted radio-telemetry surveys and took oblique photographs of caribou aggregations from the side windows of the aircraft. On July

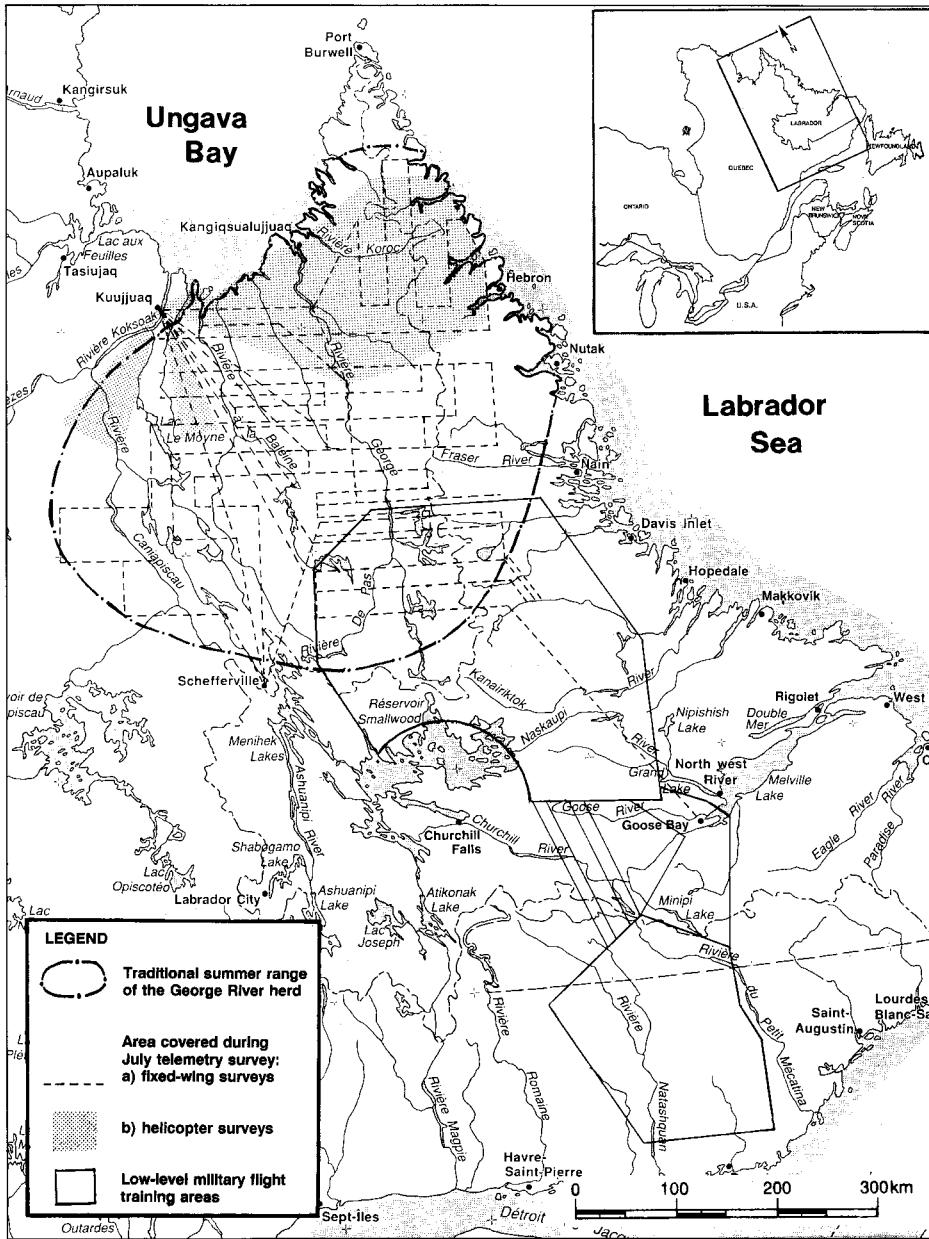


Fig. 1. Areas surveyed during the post-calving census of the Rivière George caribou herd between 4 - 23 July 1993, in relation to seasonal range use by the herd. Low-level training areas used by military flights originating from Goose Bay, Labrador, are also shown.

13, a second crew of two biologists in an A-Star helicopter joined the effort to ensure that as many aggregations as possible were located and photographed.

Each aircraft was equipped with two scanner receivers (either from Telonics Inc. or Lotek Inc.), which were used to locate VHF signals emitted by radio-collars. The receivers were connected to two H-shaped antennae, mounted on the wing-struts or

fuselage of each aircraft. Both crews scanned at least 125 VHF frequencies, which were split between the two scanners of each aircraft.

Photographs of caribou aggregations were taken at oblique angles with motor-driven 35 mm single lens reflex cameras, equipped with a 50 mm (focal length) lens, on Kodachrome ASA 64 slide film. Minimum shutter speed was 1/500 second, but the speed of 1/1000 second was used whenever light

conditions permitted. The lens was focused at infinity, and most photography was done at 250–300 meters above ground to minimize disturbance to caribou. Each exposed roll of film and each caribou aggregation was assigned a unique sequential number. To avoid confusion between the two survey crews, the crew using the fixed-wing aircraft began their number sequences from 1, whereas the helicopter crew began their sequences from 101.

Aggregations containing satellite collared caribou (i.e. collars equipped with Telonics Inc. platform transmitter terminals, PTT's) and conventional VHF radio-collars were monitored to determine the optimal time for photography. Systematic telemetry surveys over the entire summer range were conducted (Fig. 1). An attempt was made to photograph only highly aggregated groups, as indicated by their large size, high density and well-defined borders.

Under ideal conditions, a highly aggregated group of caribou is photographed during only one pass of the aircraft. This results in the least amount of time between overlapping frames and thus in the most precise counts. However, in cases when a very dense aggregation was not likely to develop, groups were photographed during more than one pass. If these aggregations were later observed under more suitable conditions, they were photographed again. Surveys and monitoring of the herd continued until all known groups were photographed or until caribou became too dispersed to warrant continued effort.

Counting caribou images on photographs and determining minimum population size

Caribou images were counted from slides projected onto a sheet of white paper taped to a sloping board. The projector (Leitz Pradovit R150) was aimed downward over the shoulder of the counter/interpreter onto the paper from a slanted stand. This arrangement allowed the greatest comfort for the counter to reduce fatigue over the extended counting period of several weeks. Each caribou image projected on the paper was marked with pencil, and a hand-held tally machine recorded each counted image. Images obtained in July could easily be assigned into two classes: calves and caribou older than one year (adults). A separate tally was kept for adults and calves. To determine the amount of overlap between two adjoining slides, at least two landmarks common to both slides were located. A straight line was drawn between these landmarks to eliminate counting images of the same caribou twice.

All counts were performed by the senior author, who has extensive experience in counting caribou

images from slides (over a million images counted). To obtain an estimate of counting error, a second person recounted images on portions of slides, and the independent counts by the two persons were then compared.

The minimum number of adult caribou in the Rivière George herd was calculated by adding together the counts of photographed groups that did not contain repeated observations of individual radio-collared caribou. An exception was made in one case to account for caribou in a group that contained mostly new observations of radio-collared individuals (see "Results").

Unlike adult counts, calf counts in oblique photographs are biased and lower than the actual values, because some calves are likely to be eclipsed by the larger adults. Therefore, these counts are not presented.

Determination of population estimate and confidence interval Calculations

An estimate of the total population size, including caribou associated with radio-collars that were either missed or not highly aggregated at the time of photography, was calculated using the Petersen Index procedure, as applied to radio-telemetry data (White & Garrot, 1990):

$$(1) \hat{N} = \frac{(M+1)(C+1)}{R+1} - 1$$

where \hat{N} = estimate of population size at time of census

M = total number of radio-tagged animals present in the herd

C = total number of caribou observed in highly aggregated groups during the survey

R = number of radio-tagged caribou observed in highly aggregated groups

The 90% Confidence Interval for the estimate was determined as follows (White & Garrot, 1990):

$$(2) \hat{N} \pm 1.645 \text{Var}(\hat{N})^{0.5}$$

where

$$(3) \text{Var}(\hat{N}) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}$$

Assumptions

An accurate estimate of population size using the above methodology is dependent on the following assumptions:

1. The population is closed.

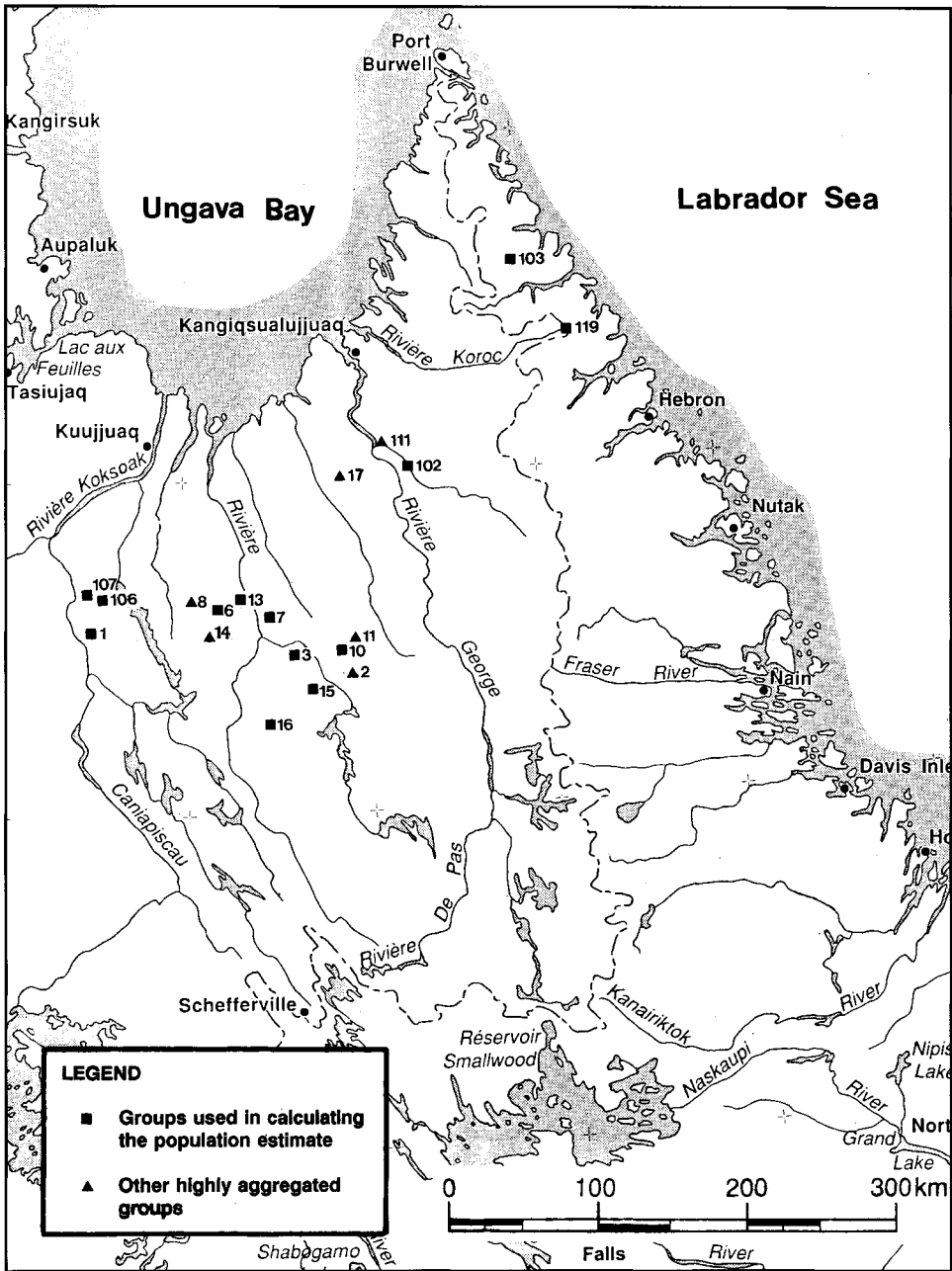


Fig. 2. Location of highly aggregated post-calving groups of the Rivière George herd, each containing more than 4 000 adult caribou, at the time of photography in July 1993.

2. All highly aggregated groups contain at least one radio-collar, and thus they can potentially be located.
3. The collared animals are randomly distributed throughout the herd during the time of census.
4. No significant movements of caribou between photographed groups used in the estimate occur during the time of census.

Results

Number and movements of photographed groups

A total of 50 groups in various stages of aggregation were photographed between 4–23 July 1993. Details of groups not used in the calculation of the minimum count and population estimate are presented elsewhere (RRCS, 1994). At the start of the census, several large aggregations, consisting of at

least 300 000 adults, in total, were drifting around both east and west shores of Lac la Moinerie. These caribou moved southeast, reaching latitude 57°00' N and longitude 66°00' W on 11 July, and then turned westerly. Most of these caribou were highly aggregated between 12–18 July when they were photographed (Groups 3, 6–8, 14–16, 106, 107 in Fig. 2).

On 5 July, a group of about 50 000 adult caribou, consisting mainly of mature males, was photographed near Chute Calcaire (Limestone Falls) and the Rivière Caniapiscou, southwest of Kuujuaq. This large aggregation (Group 1 in Table 1 and Fig. 2) had already started moving west toward the periphery of the traditional summer range and continued in this direction throughout the census period.

The remainder of the herd was located in an area that extended from just west of the lower Rivière George valley east to the Labrador coast and from the Collines Pyramid (Pyramid Hills) north to Abloviak Fiord. Within this large area there were several aggregations that appeared to be moving independently of each other. Caribou in the Torngat Mountains north of the Rivière Koroc were on the Quebec side of the border on 2 July, but by 10 July they were mostly on the Labrador coast. Caribou in this movement that were used in

the estimate include Groups 102, 103 and 119 (Table 1 and Fig. 2). Near the end of the census, many of the animals on the Labrador coast had started moving back into Quebec in a southwesterly direction and were dispersing into many smaller groups. Most caribou had dispersed by 23 July, when the census was terminated.

Total number of functioning radio-collars in the herd

A total of 92 functioning radio-collars (31 PTT and 61 VHF) were determined to be present in the herd and on the summer range at the time of the post-calving census. These caribou consisted of 16 adult males and 76 adult females captured and collared between June 1987 and May 1993.

During the census, 84 individual radio-collared caribou were located. Five additional collars were located during surveys conducted by Couturier *et al.*, (1994) over the calving and summer range of the herd in June 1993. An additional three collars were estimated to be functional based on battery life of transmitters and survival probabilities of adults and calves.

Number of radio-collars in photographed groups

Most photographed groups (38 of 50) contained at least one radio-collar. The majority of unmarked

Table 1. Post-calving aggregations of the Rivière George herd photographed between 4 – 23 July 1993 and used in the calculation of population estimate.

Date	Group	No. of radio-collars	Adults	Calves	Total	Percent calves	Adults per radio-collar
July 5	1	9 (7) ^a	49 310	2 745	52 055	5.3	5 479
July 12	3	5 (1)	11 789	2 231	14 020	15.9	2 358
July 13	6	2	8 543	2 374	10 917	21.7	4 272
July 13	7 ^b	4 (2)	8 779	1 551	10 330	15.0	2 195
July 14	10	2	16 585	5 576	22 161	25.2	8 293
July 16	13	10 (2)	66 448	11 032	77 480	14.4	6 645
July 16	15	5 (1)	16 278	3 897	20 175	19.3	3 256
July 18	16	6	55 773	11 576	67 349	17.2	9 296
July 14	102	4	14 082	4 950	19 032	26.0	3 521
July 14	103	2	4 678	1 835	6 513	28.2	2 339
July 16	106	2	11 498	1 088	12 586	8.2	5 749
July 16	107	4	51 187	9 401	60 588	15.5	12 797
July 20	119	3 (1)	27 656	11 132	38 788	28.6	9 219
Totals	13	58 (14)	342 606	69 388	411 994		

^a value in parentheses shows the number of radio-collared males included in the total. Groups without parentheses contained collared females only.

^b Group 7 contained 6 radio-collared caribou when it was photographed. However, two collared females were photographed also in Group 13. To avoid duplication, we reduced the count of Group 7 to two thirds of the original value (i.e. the original count was 13 168 adults and 2 327 calves).

Table 2. Image interpretation of a sample of census photographs by two observers, differing in experience. All photographs counted were taken from 250–300 m above ground.

	Observer 1 (experienced)			Observer 2 (inexperienced)			Difference in counts (%)	
	Adult	Calf	Total	Adult	Calf	Total	% Difference Adult Count	% Difference Total Count
Day 1	1 944	538	2 482	1 709	641	2 350	-12.1	-5.3
Day 2	47	— ^a	47	41	—	41	-12.7	—
	68	—	68	61	—	61	-10.3	—
	74	—	74	56	—	56	-24.3	—
	135	43	178	115	67	182	-14.8	+ 2.2
Day 3	114	40	154	118	50	168	+3.8	+ 8.3
	109	33	142	108	37	145	-0.9	+ 2.1
	82	26	108	81	36	117	-1.2	+ 8.3
Total	2 573	680	3 253	2 289	831	3 120	-11.0	-4.1

^a calves were not counted in these samples.

groups (10 of 12) were relatively small, ranging in size from 389 to 1 859 adult caribou, and were most likely not photographed at the optimal state of aggregation. However, two large groups (Group 5: 23 615 adults, and Group 108: 7 175 adults) contained no radio-collars. These groups were probably photographed at another time during the census as a part of other larger groups containing radio-collars.

The size of groups containing only one radio-collar ranged from 59 to 2 770 adults (\bar{x} = 967.5, SD = 895.5, n = 19). All 19 highly aggregated groups, as defined by their well-defined borders and large size (>4 000 adults), contained at least two radio-collared caribou. These groups ranged in size from 4 137 to 66 448 adults. Fig. 2 shows the location of these groups at the time of photography.

Accuracy of counting

The error associated with counting images from slides by the senior author, who performed all counts, was very small. Therefore, no correction was made to the actual counts. Portions of 8 slides (about 3 000 caribou) were selected to be counted independently by two observers. The counts obtained by the second person, inexperienced in counting caribou in oblique photographs, were lower in all but one case than the counts by the senior author, an experienced interpreter (Table 2). Because each person marked on paper the exact position of each image counted, it was possible to compare and verify these counts. By the end of the session, the counts and the classification of adults and calves by both observers agreed closely.

Minimum population size

A minimum count is useful, because it provides a measure of the population size that is relatively free of error. A total of 342 606 adult caribou were counted in 13 highly aggregated groups (Table 1). These groups, with the exception of Group 7, did not contain repeated observations of individual collared caribou. Group 7 contained six collared caribou, two of which were also photographed in another group. To avoid duplication, we reduced the count of Group 7 to two thirds of its original value.

An additional 15 854 adult caribou (corresponding to caribou associated with 14 radio-collars) were added to the above value, resulting in a minimum count of 358 460 adults. These caribou were associated with 72 of the total of 92 radio-collared animals. The remaining collars were found in groups that contained repeated observations of individual collared caribou and thus were not included in the minimum count.

Estimation of total population size

Groups used in estimating population size

Of the total of 19 highly aggregated groups, 13 were selected to be used in the calculations of population size (Table 1). Six groups were deleted (2, 8, 11, 14, 17 and 111 in Fig. 2), because one or more collared caribou in these groups were the same individuals photographed as part of another group. Counts of groups that were photographed under more suitable conditions (e.g. fewer animals obscured by trees, clearer images) were used in the calculation of population size in cases of repeated observations.

Population estimate

The total size of the herd is larger than the minimum count because not all caribou were photographed under optimal conditions of aggregation, and not all radio-collared caribou were photographed. Therefore, the total population size at the time of the census was estimated using the Petersen Index method (White & Garrot, 1990).

The Rivière George herd was estimated to consist of $540\ 040 \pm 69\ 339$ adult caribou (older than calves) in July 1993. The 90% confidence limits deviate by 12.8% from the mean.

Discussion

Evaluation of assumptions for the population estimate

Accurate estimation of herd size based on the Petersen Index method requires that the underlying assumptions are met. The analyses presented below indicate that all the assumptions outlined in "Methods" were satisfied with reasonable accuracy, although several potential sources of violation were identified.

Assumption 1: The population is closed

Due to the short period of the census (21 days), no significant adult mortality, immigration or emigration was likely to occur. Thus, the assumption is valid.

Assumption 2: All highly aggregated groups contain at least one radio-collar and can thus be located

Caribou aggregations were located primarily through radio-telemetry, and groups containing no radio-collars could potentially have been missed, thus resulting in an under-estimate of the total population size. The probability of a group containing at least one radio-collar decreases with group size, and thus an unknown number of smaller aggregations could have gone undetected during the census. However, the number of undetected groups was probably small for the following reasons:

(a) Migratory caribou, including the Rivière George herd, tend to aggregate in a few large groups during the post-calving period, rather than in numerous small groups, when environmental conditions are suitable (Western Arctic herd: Valkenburg *et al.*, 1985; Porcupine herd: Whitten *et al.*, 1980; Whitten, 1985; Bluenose herd: McLean & Russell, 1988; Qamanirjuaq herd: Russell, 1990; Rivière George herd: RRCS, 1990; 1992). Post-calving aggregations of the Rivière George herd can consist of more than 100 000 caribou (RRCS, 1990; 1992). Large groups are likely to contain at least one radio-collar, thus resulting in their location.

If the entire herd was composed of groups of equal size, then the probability of groups with no radio-collars (p) can be calculated as follows:

$$p = (1 - N_g/N)^n,$$

where n = number of radio-collars
 N_g = group size
 N = population size

For example, if the entire herd (about 550 000 caribou) was composed of groups of 5 000 caribou at the time of the census, then the probability of groups with no radio-collars would be 0.43. If, however, the herd was composed of groups of 15 000 caribou, then the probability of groups with no radio-collars would be very small (0.08). Because suitable conditions for aggregation were present during July 1993 (warm, calm weather, abundance of mosquitoes), most aggregations were likely to be very large and thus have a low probability of being unmarked. Caribou in the Torngat Mountains may be an exception, because lower temperatures may have resulted in a relatively dispersed distribution during the census period.

- (b) Visual surveys conducted during telemetry monitoring resulted in the location of two highly aggregated groups with no radio-collars. However, these groups were believed to be a part of larger aggregations, containing radio-collars, that were photographed on a different day during the census.
- (c) Previous surveys, involving both visual and telemetry surveys and conducted as a part of the Wildlife Avoidance Monitoring Program sponsored by DND to protect caribou from aircraft disturbance, indicated that radio-telemetry was a very effective method for locating all or most post-calving aggregations of caribou (RRCS, 1992).
- (d) Studies in Alaska, which combined intensive visual and telemetry surveys, showed that most caribou of several herds (87% to 90%) would have been located during the post-calving period based solely on telemetry (Valkenburg *et al.*, 1985).

Assumption 3: Radio-collared animals are randomly distributed throughout the herd

Several possible sources of violation of this assumption exist. The first source of violation may arise from the fact that caribou equipped with radio-collars do not represent a random sample of the population. However, given sufficient time, random

mixing of radio-collared caribou in the herd is likely based on:

- (a) random distribution of the collared caribou in highly aggregated groups (see below), and;
- (b) evidence of random mixing of similarly collared animals in other migratory caribou herds (Valkenburg *et al.*, 1985; McLean & Russell, 1988; Russell, 1990).

We used the χ^2 -test to compare the observed number of radio-collars per highly aggregated group in Table 1 to the expected number, assuming random distribution of radio-collared caribou among groups. Smaller groups were combined to achieve expected values of at least 3, and the entire Group 7, which at the time of photography contained duplicate observations of some collared caribou, was deleted from the analysis. The distribution of radio-collared caribou among the highly aggregated groups did not deviate from random ($\chi^2 = 9.78$, $df = 7$, $P = 0.2$), thus supporting the validity of the assumption.

A second source of violation of the assumption may arise from independent movement of males and females during the post-calving period. The sexes were mixed unevenly throughout the various groups, as evidenced by the observation of two aggregations consisting predominantly of adult males and few calves. However, the ratio of adults/collar in Group 1, containing 7 collared males and 2 collared females, was very similar to the ratio in groups containing only collared females (5 479 adults/collar in Group 1 versus a mean of 6 610 adults/collar in 7 groups with two or more collared females and no males; data from Table 1). This suggests that the aggregation behaviour of each sex was similar. Furthermore, the data on collared caribou indicate that mixing of the sexes occurred in large aggregations: all nine groups with two or more radio-collars and with at least one collared male also contained one or more collared females. Thus, any possible differences in behaviour of the sexes was not likely to affect our estimate.

A third potential source of violation of the assumption may arise from non-random dispersion of the 13 caribou collared in 1993 (12 in March and 1 in May). All five caribou collared just north of the Fraser River travelled northward, but their relocation sites show a dispersed pattern within the northern portion of the post-calving range of the herd. The remaining seven caribou, collared at different locations in 1993, had moved considerable distances from their original capture sites and were relocated within a central area for post-calving aggregations.

Some non-randomness was possible based on the distribution pattern of the caribou collared in 1993. However, the collars deployed in 1993 represent a

relatively small proportion of the total number of radio-collars functional in the herd during the census. Furthermore, the group of five caribou captured north of the Fraser River that showed unidirectional movement had dispersed within the area they occupied during the census.

Assumption 4: No significant movements of caribou between photographed groups used in calculating the estimate occur during the census

Independence of observations was achieved by excluding those groups that contained repeated observations of individual collared caribou from the analyses (except Group 7, the size of which was reduced in proportion to the number of repeated observations of collars; Table 1).

Because of the low proportion of collared individuals in the herd, groups of unmarked caribou could potentially have broken off from an already photographed group and joined another group yet to be photographed. Large scale movements (involving groups of several thousand individuals) would most likely have been accompanied by collared caribou and therefore should have been detected by telemetry.

Comparisons with the June 1993 calving ground census

Since 1984, population estimates of the Rivière George caribou herd have been derived by photographing caribou in calving areas (Crête *et al.*, 1991). To obtain a more robust estimate of the size of the herd, two independent photographic censuses were carried out in 1993: a calving ground census in June (Couturier *et al.*, 1994) and a post-calving census in July (this study).

Both the June calving ground census and the July post-calving census resulted in similar estimates of the size of the Rivière George caribou herd (566,800 versus 540,040 adults in the June and July censuses, respectively). The post-calving census provided a more precise estimate, with 90% confidence limits of $\pm 12.8\%$ versus $\pm 34\%$ in the calving ground census. However, the error associated with the post-calving census may be greater than indicated due to uncertainty surrounding the exact number of functional radio-collars in the herd and the possibility that some highly aggregated groups did not contain radio-collars and hence were not included in the estimate.

Advantages and disadvantages of the post-calving photo-census methodology

The main advantages of a photographic census of post-calving aggregations are that;

- (a) few assumptions regarding population structure are necessary, and;
- (b) most caribou are counted directly from photographs, requiring extrapolation to only a relatively small segment of the population.

Radio-telemetry was used to locate post-calving aggregations during this census, and the presence of an adequate number of radio-collars in the herd is essential for a successful use of this method. The timing of photography is also critical, and caribou must be photographed when aggregated in well-defined, high-density groups.

The Petersen Index method, used to estimate population size, circumvents the two main drawbacks of photographic censuses of caribou aggregations:

- (1) uncertainty regarding whether all caribou in the herd are located, and;
- (2) problems associated with caribou that are not aggregated sufficiently for photography (Heard, 1985).

The Petersen Index method has been previously used to estimate the size of the Qamanirjuaq herd (Russell, 1990) and the Rivière George herd (Russell & Jakimchuk, 1991). Unlike these studies, we provide a measure of the error that is associated with the population estimate.

Potential problems associated with the application of the post-calving census methodology to the Rivière George herd result from the large population size and large summer range of the herd, necessitating extensive survey and photographic interpretati-

on effort. In addition, forested terrain in parts of the range decreases the visibility of caribou on photographs. The caribou may also not aggregate sufficiently each year to enable efficient photography. Uncertainty regarding the number of functional radio-collars in the herd at any one time may also bias the estimate. However, the 1993 post-calving census shows that this method is a viable census method for the Rivière George herd, and that these potential problems are outweighed by the advantages of the method.

The precision of the population estimate derived from future post-calving censuses can be improved by two measures: First, caribou movements should be monitored closely throughout the month of July to ensure that all photographs are taken during the period of optimal aggregation. For example, post-calving aggregations began to form unusually early in 1993 because of an early spring, whereas the best photographs in 1990 were taken on 27–28 July (Russell & Jakimchuk, 1991).

A second measure to improve the accuracy of future post-calving censuses is to deploy more radio-collars in the herd. In 1993, we monitored 125 frequencies, but 33 of these were found to be inactive. The above measures should result in the photography of a high proportion of the herd under optimal conditions, thus reducing the error associated with the estimate.

Implications for herd management

Recent population estimates suggest that the size of the Rivière George herd has been stable within the past decade (Table 3). However, various other para-

Table 3. Recent population estimates for the Rivière George herd, 1984–1993.

Year (month or season) ^a	Census type	Adults ^b	90% Confidence limits			Source
			Lower limit	Upper limit	Percentage	
1984 (fall)	calving	517 454 ^d	388 091	646 818	±25%	Crête <i>et al.</i> , 1991
1986 (fall) ^c	calving	225 038 ^d	137 273	312 803	±39%	Crête <i>et al.</i> , 1991
1988 (fall)	calving	564 895 ^d	361 533	768 257	±36%	Crête <i>et al.</i> , 1991
1990 (July) ^c	post-calving	465 000	–	–	–	Russell & Jakimchuk, 1991
1993 (fall)	calving	566 800	374 655	758 945	±34%	Couturier <i>et al.</i> , 1994
1993 (July)	post-calving	540 040	470 701	609 379	±13%	This study

^a time of year for which estimate was calculated.

^b animals older than calves.

^c these censuses were not complete.

^d Crête *et al.* (1991) do not present directly the number of adults in the population. We computed the adult numbers from their data (total population size) and from the proportion of calves observed in the fall (see Table 12 in Crête *et al.*, 1989).

meters (e.g. physical condition, productivity) indicate a decline in the growth rate of the herd. Due to these uncertainties, caution should be exercised when developing management programs.

Because the 1993 post-calving census provides an accurate and precise estimate of the size of the adult population, herd size over the next several years can now be monitored with greater confidence by measuring the gross recruitment rate of juveniles in spring and the annual mortality rate of adult caribou. This requires that the annual harvest of caribou from the herd and the overall mortality rate of adults be accurately monitored.

We recommend that the total adult population be censused every 3-4 years, because the error associated with estimating population size solely from recruitment and mortality data is likely to increase over time. The results of this study indicate that oblique photography of post-calving aggregations is a cost-effective and precise technique for census of the Rivière George herd and should be considered for future censuses.

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