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Calving photocensus of the Rivière George Caribou Herd and comparison with an independent census

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Abstract: Vertical photographs of the calving grounds have been used since 1984 to estimate the caribou (*Rangifer tarandus*) population of the Rivière George Caribou Herd (RGCH) in Northern Québec and Labrador. In spite of large confidence intervals, the 1984 and 1988 estimates suggested that the herd stabilized at more than 650 000 caribou (fall estimate including calves) making the RGCH the largest caribou herd in the world. Between 1984 and 1990, studies suggested that the former rapid growth of the herd deteriorated the calving and summer habitats. This poor habitat quality affected physical condition, pregnancy rate and calf survival. It was important to have a valid estimate of the herd size and a photocensus was done in June 1993. Contrary to previous censuses, a slightly different sampling design was applied in 1993. Two methods were used to estimate the number of females in the June population. In the first method, the number of females was derived from the estimated number of calves on the photographs and from the June female/calf ratio. The second method was used in the previous census and is based on the number of adults on the photos and on the June female/adult ratio. It is suggested that the first method of estimating female abundance in June is better due to sampling problems associated with a strong adult sex segregation during calving. From the first method, the herd size in October 1993 was estimated at 583 829 adults (±33.79%) and at 749 869 caribou including calves (±33.15%) while the second method provided estimates of 764 221 adults (±23.55%) and 981 565 caribou including calves (±22.64%). It was possible to compare those population estimates with an independent census. In July 1993, an oblique photocensus of the post-calving aggregations was conducted by Russell *et al.* (1996). A new analysis of their raw data provided an estimate of 608 384 adults (±14.35%). Both estimates from the June and July photocensus were combined. From the first and second method respectively, combined herd size estimates were 775 891 (±13.40%) and 823 375 (±12.36%) caribou including calves. The management implications are discussed and it is emphasized that the herd is still underharvested.

Key words: Aerial survey, calving grounds, Labrador, Québec, *Rangifer tarandus*, ratio

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Introduction

Sound management of a large wild ungulate population is based on precise and unbiased population estimates. Confidence intervals around population estimates based on calving grounds census can be high for caribou (*Rangifer tarandus*) due to the clumped distribution of the animals relative to the number and shape of the sample units, the sampling fraction, the accuracy of stratification, a visibility bias, and the precision of the correction factors used to extrapolate the number of caribou estimated in the census area to an estimation of the population size (Crête *et al.*, 1991). Systematic aerial censuses have been done on Northern Québec caribou herds since 1954. A major improvement has been brought with the introduction in 1984 of the vertical photography technique (Goudreault, 1985; Crête *et al.*, 1989; 1991).

The calving grounds traditionally used by parturient females and the surrounding areas were surveyed in 1993. Major elements of the June 1993 census method were used on the same herd in 1984

(Goudreault, 1985), in 1986 (Crête *et al.,* 1987) and in 1988 (Crête *et al.,* 1989; 1991). Previously, the abundance of females outside the calving grounds was estimated from the locations of a radio-collared caribou sample. During the June 1993 census, the photosampling area was enlarged to count females not only on the calving grounds but also in surrounding areas. This photosampling technique was successfully used on the Rivière aux Feuilles Caribou Herd (RAFCH) in June 1991 (Couturier, S., unpubl. data). The reliability of the June 1993 census has been measured using an independent photocensus on the Rivière George Caribou Herd (RGCH) in July 1993. The second census technique performed by Russell *et al.* (1994) relied on the July aggregation behavior demonstrated by caribou almost every year. This technique has been used in the Northwest Territories (McLean & Russell, 1988; Russell, 1990).

Both 1993 censuses of the RGCH were done at a critical time during the herd's history. Recent studies (Couturier *et al.,* 1990; Hearn *et al.,* 1990; Crête *et al.,* 1994) confirmed earlier statements made by Couturier *et al.* (1988a, 1988b) and by Messier *et al.* (1988) on the demographic processes affecting herd growth. After having been extremely rare at the beginning of this century (Messier & Huot, 1985), the RGCH showed a rapid rate of increase until it recently became the world's largest caribou herd (Williams & Heard, 1986). The survival rate of the adults and possibly that of the calves, the pregnancy rate of the females and the physical condition of the caribou have decreased in the past decade, which has accounted for the herd's stabilization in numbers. Crête *et al.* (1996) demonstrated that the survival of females and the pregnancy rate remained relatively low until 1992-1993. Couturier *et al.* (1988a, 1988b) hypothesized that the poor condition of the RGCH females could be explained by overgrazing on the traditional calving grounds during the summer months. Recent studies confirmed the deterioration of the calving grounds and the surrounding areas (Crête & Huot, 1993; Manseau *et al.,* 1996). Dendrochronology was carried out on evergreen root and stem scars left by migratory caribou (Morneau & Payette, 1994). It confirms the intensive use of the calving grounds area from the mid-1970's until the late 1980's. Nevertheless, the foraging quality and the general condition of the herd (birth weight, calf/female ratio, etc.) seem better in 1993-1994 probably due to a change in the migratory pattern of the herd (Couturier, S., Doucet, J.G., unpubl. data).

The purpose of this paper was first, to estimate the abundance of adult females (≥ 1 year old) present in the herd in June and then, to apply the summer survival rate to compute the number of females in October 1993. The abundance of males and calves was later estimated from relative ratios observed during the fall classification. From these calculations, the total RGCH size is estimated and finally combined with an independent estimate (Russell *et al.*, 1996). The combined herd size estimate is used to discuss management implications and harvest strategy for the herd.

Methods

The calving grounds study area has been described by Crête *et al.* (1991). Couturier *et al.* (1990) presented information on the annual distribution of the migrating RGCH and RAFCH, the location of their respective calving and wintering grounds, and the weather and vegetation characteristics of the caribou habitat in Northern Québec and Labrador. Crête & Huot (1993) presented additional information on caribou density with reference to foraging quality and lichen use.

Telemetry survey

From June 4 to 10, 1993, a high altitude (2400-3000 m) aerial telemetry survey was done with a Partenavia twin-engined plane flying at 220 km/hr to determine the locations of radio-collared females. A GPS (Global Positioning System) navigating instrument was used to record locations of radio-collared animals, which were marked on 1:250 000 maps. The observation team covered 444 000 km^2 in 57.6 hours by spacing flight lines at approximately 40 km (Fig. 1). Extra telemetry flights (13.4 hours, 18-19 June 1993) were added over the Péninsule d'Ungava to determine possible herd switching. Ninety-four radio-collars of the RGCH were considered active in June 1993, of which 76 were females. Most of the radio-collars of the RGCH (82 radio-collars) were deployed in different areas of the RGCH annual range more than 8 months before the photocensus. We assumed that the distribution of the sample of radio-collared caribou was representative of the herd's distribution. The 94 radio-collars contained 35 PTT's (Platform Transmitter Terminals) which were located with the Argos satellite-monitoring system. Twenty-three PTT's were carried by females. Most satellite location data were retrieved about every four days (2 to 5 days) from Service Argos inc. (Landover, Maryland). To the 94 active RGCH radio-collars, we must add 5 females and 2 males of the RAFCH and two females of the Monts Torngat Caribou Herd (MTCH) which brings the total number of active radio-collars in Northern Québec and Labrador to 103 in June 1993. Due to budget constraints, it was impossible to do a teleme-

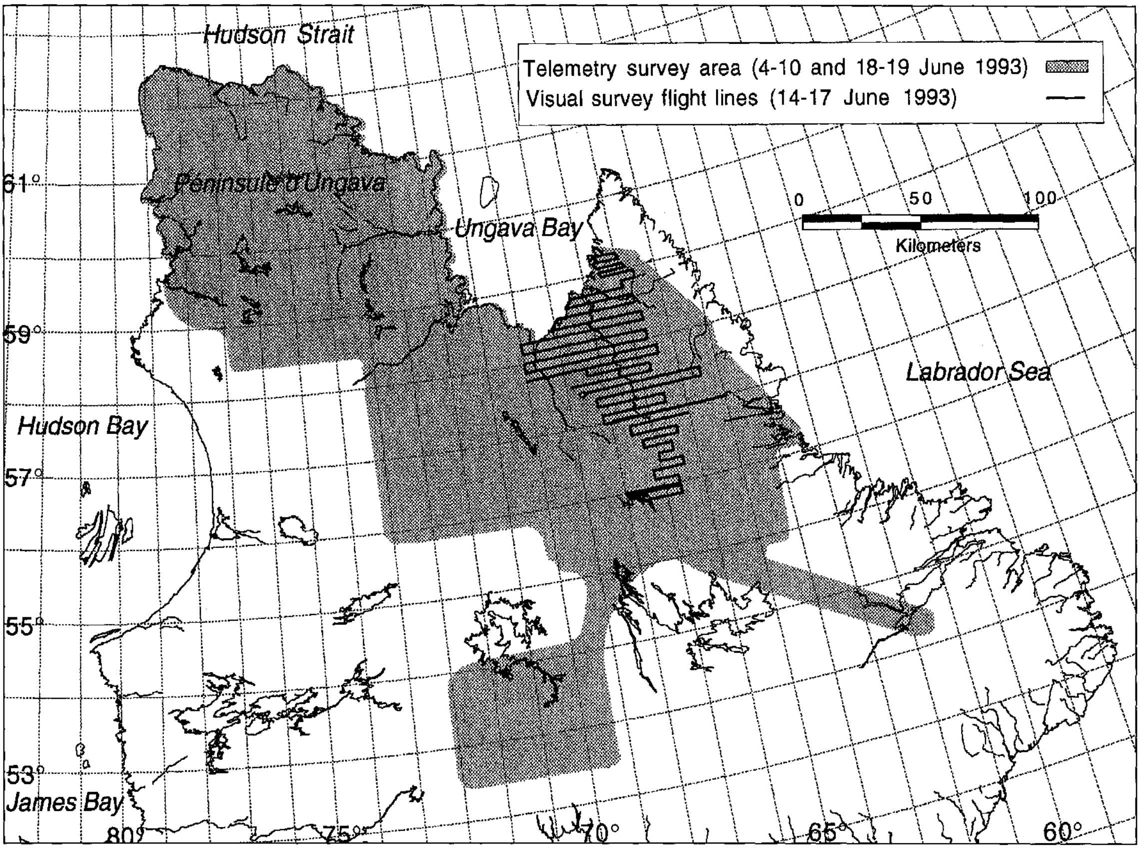

Fig. 1. VHF telemetry (4-10 and 18-19 June, 1993) and visual surveys for the strata delimitation (14 - 17 June, 1993).

try survey of the larger area used by the RGCH in October 1993 to estimate the summer survival of radio-collared females. Therefore, we used the female survival rate from June to October 1992 (Crête *et al.*, 1996).

Low-altitude visual survey

The same twin-engined plane was used from 14 to 17 June 1993 to perform the low-level (40-60 m) and low-speed (180 km/hr) visual survey of the RGCH in the area where most radio-collared females were found (Fig. 1). The goal of this survey was to estimate the abundance of females. Flight lines were spaced 13 km apart and covered 49 000 km^2 during 28.3 hours. Two observers sitting near the side-windows recorded the number of females, males and calves within a 500-meter strip band to each side of the aircraft. During June, adult sexes are distinguishable by their antler status. Data were recorded by a third person on 1:250 000 maps.

Once the visual survey was completed, female density figures were estimated by calculating the number of females observed over each 10 km segment of the flight line (hence, per 10 km^2). This information was used to delineate the sampling area and define three density strata for female caribou: low density (1 to 5 females/10 km^2), medium density (5.01 to 10 females/10 km^2) and high density (> 10 females/10 km^2). Computations of female densities allowed us to estimate the mean and the variance of densities in each stratum to determine the number of sample units using the Neyman's optimal allocation for stratified sampling (Cochran, 1977: p.99).

Helicopter vertical photocensus

Once the density strata were defined, a team of three observers boarded an Astar 350B helicopter from June 20 to 26 to carry out vertical photographic sampling. Aerial photographs were taken with an automatic aperture priority 35 mm Olympus camera equipped with a 50 mm f:1.8 lens and an automatic winder. Vertical photographs were taken at 10 s intervals with an automatic time-delay. Most photographs were taken on 36 exposure Kodachrome 64 ASA film. A Kodachrome Professional 200 ASA film was used under darker conditions. Lens aperture was set at f:4 and shutter speeds varied between 1/500 and 1/1000 s. Under darker conditions, lens aperture was changed to f:2.

One complete roll of film, from 36 to 39 color slides, was used for every sampling site and covered approximately 13 km on the flight line. Sample units were systematically distributed along east-west flight lines. On the photograph lines, the helicopter flew at an average speed of 150 to 180 km/h and tried to maintain a constant altitude of 200 to 240 m above ground level (AGL). The AGL altitude of each photograph was variable because of the topography of the terrain. The altitude of each photograph was recorded from a radar-altimeter with digital display (models TRA-3000 and TRI-40; TERRA inc.). This radar-altimeter has a precision of 6.1 m for altitudes between 122 and 305 m. Most photographs were taken between 180 and 270 m.

Composition counts on the sampling area in June 1993

From 19 to 25 June 1993, a second helicopter team studied the herd composition on the photocensus area to determine the composition of the adults, as distinguishing sexes on aerial photographs is impossible. The sampling design of the composition counts was based on satellite radio-collars locations. Observers landed near a satellite radio-collar and used binoculars to classify a target sample size of 300 caribou per site. Field observations included many different categories of which 3 were kept for analysis: adult male (≥ 12 months old), adult female (≥ 12 months old) and newborn calf.

Composition counts of the RGCH in October 1993

The October 1993 sampling design was determined from Argos satellite telemetry data. Once in the area of the satellite radio-collar, observers used a vantage point on the ground to classify a target sample size of 300 caribou for that particular location. Composition ratios (male/female, calf/female) were used to estimate the relative abundance of males and calves in the fall population.

Analysis of aerial photographs

Counts of adults and calves on each color slide were made by visually scanning a grid, which divided the surface into ten equal parts. Projections were made onto a 56.0 cm by 37.5 cm white surface using a Kodak (Carousel 5600) slide projector. To confirm the observations made by the first observer, 35 sample units (i.e. 35 slide films) were randomly drawn and analyzed independently by a second observer with previous experience in this type of work. Both observers had the choice of keeping or discarding a photograph from the analysis due to technical flaws (out of focus, exposure problems, etc.). When a slide was discarded by one observer, it was also rejected for the other observer. A paired sample analysis of 1212 photographs showed no difference in counts of adult caribou in 1155 slides, representing a 95.3% agreement between observers. A 96.8% agreement (1173 slides) was found for the calf count.

Statistical analysis

The mean number of photographs per sample unit was 33.1 (16 to 38). The AGGREGATE command of the SPSS software package (Norusis, 1990) clustered data (number of caribou (y), photographed area (x), snow cover, etc.) of all 36 slides to create the sample unit. Differences between strata ($\alpha \leq 0.05$) were tested using the ONEWAY command (Norusis, 1990), followed by a Scheffé test (Sokal and Rohlf, 1981). Unless otherwise indicated, estimates in this study are presented with their 90% confidence interval ($\alpha = 0.10$).

The photocensus is based on a two-stage stratified sampling plan with clusters of photos allocated systematically in two dimensions. An estimate of caribou abundance was calculated using the separate ratio estimator. This ratio was the mean number of caribou counted for all sample units ($\bar{y}_h$) in stratum h over the mean photographed area of a sample unit ($\bar{x}_h$) in stratum h. The estimator from the 3 strata is shown in the following equation (Cochran, 1977: 164, equation 6.44):

$$\hat{Y}_{Rs} = \sum_{h=1}^{3} \frac{\bar{y}_h}{\bar{x}_h} X_h$$

where X_h is the total area of stratum h.

The variance of this estimator is found by modifying equation 6.45 in Cochran (1977: 164) as follows:

- the finite population correction factor is neglected. This factor becomes unimportant since the sampling fraction is close to zero in this study;
- the total number of sample units in stratum h (N_h) is unknown and is estimated by $X_h/\bar{x}_h$

Therefore, we can consider the following equation for the variance:

$$V(\hat{Y}_{Rs}) \simeq \sum_{h=1}^{3} \frac{X_h^2}{n_h \bar{x}_h^2} (S_{yh}^2 + R_h^2 S_{xh}^2 - 2R_h \rho_h S_{yh} S_{xh})$$

To obtain an estimator of the above variance, the equation parameters must be substituted by their estimated values from the sample. For example, the expression $S_{yxh} = \rho_h S_{yh} S_{xh}$ is estimated from the sampling covariance between y'on and x'on in stratum h:

$$S_{yxh} = \sum_{i=1}^{n_h} \frac{(Y_{hi} - \bar{Y}_h)(X_{hi} - \bar{X}_h)}{n_h - 1}$$

Thereby, for each stratum, we can compute an estimation of the variance using equation 6.13 (Cochran, 1977: 155).

As we know the altitude AGL of the aircraft, the focal length of the camera lens (50 mm) and the film format (24 mm by 36 mm), it is possible to compute the area covered on the ground by each slide:

$$S = 0.3456\ A^2$$

where : S = area in m^2
A = altitude of aircraft above ground level in m
0.3456 = correction factor for focal length (0.50 m) and 35 mm film format

Radio-telemetry data were used to calculate the summer survival rate of adult females (≥ 2 years) with the program MICROMORT (Heisey & Fuller, 1985). Combined estimates for the June and July post-calving photocensus were computed using the procedure described by Gasaway *et al.* (1986). This method weighs each independent estimate by the inverse of the sampling variance of that estimate so that the combined estimate has the smallest variance possible of any weighted unbiased combination of the two independent estimates. The population estimates $\hat{N}_1$ and $\hat{N}_2$ and their respective variances $V(\hat{N}_1)$ and $V(\hat{N}_2)$ can be combined to obtain the combined estimate, $\hat{N}_c$ and its associated variance, $V(\hat{N}_c)$ as shown in the following equations:

$$\hat{N}_c = \frac{(\hat{N}_1 V(\hat{N}_2)) + (\hat{N}_2 V(\hat{N}_1))}{V(\hat{N}_1) + V(\hat{N}_2)}$$

$$V(N_c) = \frac{V(\hat{N}_1) V(\hat{N}_2)}{V(\hat{N}_1) + V(\hat{N}_2)}$$

Results

Delimitation and stratification of the sampling area in June 1993

Ninety-eight VHF radio-collars (98) were located in June 1993. Most (89) belonged to the RGCH, from which 72 were carried by females (Table 1). Of this group of females, 57 (79%) were found within the three density strata of the photocensus sampling area. With RGCH females near the sampling area (< 50 km), the presence of VHF radio-collared females rose to 92%. After the telemetry survey and before the aerial photography, satellite monitoring showed that the females travelled slowly toward the center of the high density stratum located on Rivière George, north of 58°N. Males showed a slight tendency in the opposite direction, moving away from the sampling area occupied by females. Twenty satellite radio-collared females of the RGCH out of 22 (91%) and 2 males out of 12 (17%) were located within the sampling area at the time of the photography (Table 1).

Table 1. Locations of radio-collared caribou during the telemetry survey (n = 103[a]) and from Argos satellite data (n=37).

Herd	Location	Radio-collared caribou, (8-10 June 1993)[a] (including Argos collars)			Argos radio-collared caribou, (22-26 June 1993)		
		Females	Males	Total	Females	Males	Total
RGCH	High density	34	1	35	10	2	12
(94 active collars)[b]	Medium density	12	0	12	2	0	2
	Low density	11	1	12	8	0	8
	< 50 km[c]	9	7	16	2	4	6
	50 - 200 km	2	7	9	0	5	5
	> 200 km[d]	4	1	5	1	1	2
	Total (RGCH)	72	17	89	23	12	35
RAFCH	In the 3 strata[d]	2	1	3	0	0	0
(7 active collars)	>200 km	3	1	4	0	0	0
MTCH	In the 3 strata[d]	1	0	1	1	0	1
(2 active collars)	<50 km	1	0	1	1	0	1
TOTAL		79	19	98	25	12	37

[a] Includes 11 locations that were made between 6 and 7 June and between 15 and 24 June 1993.
[b] Five active radio-collars (4 females and 1 male) of the RGCH were not located during the survey.
[c] Distance from the photocensus sampling area.
[d] Possible herd switching.

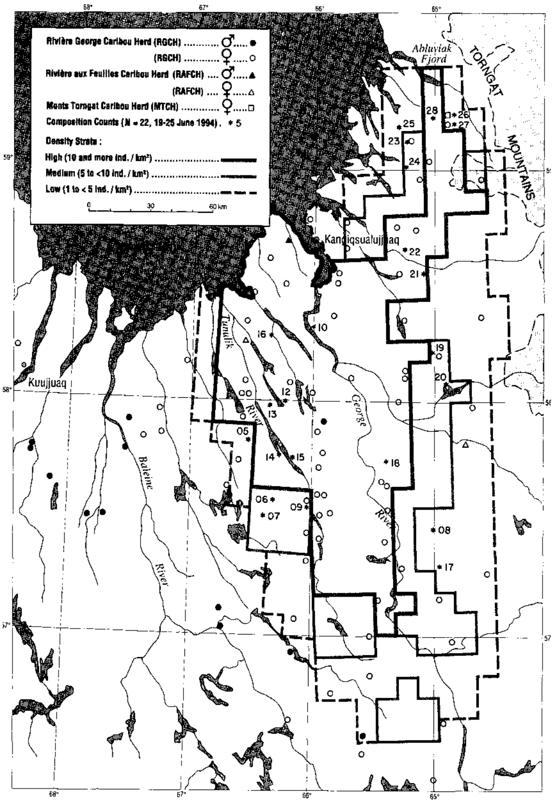

Fig. 2. Stratification pattern, locations of most VHF and satellite radio-collared caribou (8-10 June 1993, includes some locations that were made from 6-7 June and from 15-24 June 1993) and composition sampling locations (19-25 June 1993).

Two females (PTT 8318 and 14230) were within 10 km of the sampling area on June 25 but were visually observed a few days before within the medium density stratum. All satellite radio-collared females were therefore in the sampling area during photography.

Locations of most (82 out of 98) VHF radio-collars were found in the northeastern part of the herd range (Fig. 2). Most radio-collared males in large aggregations were located between Kuujjuaq and Rivière Baleine in June 1993. They were regularly observed during frequent flights to the study area. It became possible to visually follow male group displacements and to notice that they did not approach the photocensus sampling area.

June 1993 photocensus

During aerial photography, 181 sample units were surveyed from 20 to 26 June 1993 with 118, 32 and 31 sample units in the high, medium and low density strata, respectively. The adult and calf numbers were significantly different between the high density stratum and the two lower density strata whereas a non-significant difference was found between the latter (Table 2). Therefore, a third density stratum was not needed and did not increase the precision of the sampling. The mean sample unit size was 0.525 km². The aerial photographic sampling fraction accounted for 0.288% of the sampling area. Snow cover was very low due to an early spring in Northern Québec and Labrador. A total of 652 003 ± 19.45% adult (≥ 1 year old) caribou and 244 674 ± 23.86% calves were estimated in the sampling area.

Composition counts of the RGCH in June and October 1993

In late June 1993, 24 satellite radio-collars were found within the photocensus sampling area. Two of these were carried by males but were mistakenly not included in the composition count. A visual contact was made in 20 out of 22 cases. Of the 20 satellite radio-collared female observed, 11 had calf at heel, 2 had recently lost their progeny (distended udders and no calf at heel) and 7 were not parturi-

Table 2. Some results of the Rivière George Caribou Herd stratified photocensus, June 1993 (standard errors are shown in brackets).

Variables[1]	High density n=118	Medium density n=32	Low density n=31	ALL STRATA n=181
Adults/sample unit	23.77^{A} (3.18)	4.47^{B} (1.51)	1.58^{B} (0.52)	16.56 (2.21)
Calves/sample unit	9.13^{A} (1.47)	1.47^{B} (0.55)	0.48^{B} (0.26)	6.29 (1.00)
Adult density (caribou/km²)	43.95^{A} (6.23)	9.79^{B} (3.09)	2.8^{B} (0.88)	30.88 (4.31)
Calf density (calves/km²)	17.15^{A} (3.06)	3.35^{B} (1.18)	0.75^{B} (0.42)	11.90 (2.07)
Mean sample unit area (km²)	0.538^{A} (0.011)	0.488^{A} (0.020)	0.514^{A} (0.022)	0.525 (0.009)
Altitude (m)	219.6^{A} (1.91)	211.1^{A} (3.36)	214.5^{A} (3.07)	217.3 (1.49)
Snow cover (%)	2.4^{A} (0.4)	3.0^{A} (0.8)	8.0^{B} (1.5)	3.5 (0.4)
Sampling area (km²)	14 255	6 793	12 019	33 067
Sampling fraction (%)	0.446	0.230	0.133	0.288
Adult estimate	563 262^{A} (74 254)	54 974^{B} (17 750)	33 767^{B} (10 791)	652 003 (77 105)
Calf estimate	216 268^{A} (34 423)	18 069^{B} (6 724)	10 338^{B} (5 459)	244 674 (35 496)

[1] Pairs of numbers followed by a different letter within a row differ at $\alpha \leq 0.05$ (ANOVA and Scheffé test).

ent (Table 3). This gives a pregnancy rate of 65% in the satellite radio-collared female sample. The estimated female/adult ratio was 0.8855 ±3.98% over the sampling area, with no significant differences between density strata. Relative abundance of calves or birth rate can also be found from the June composition data. We assumed that the calving was completed at the time of the classification. The calf/female ratio was 0.5547 ±20.03% and its inverse, the female/calf ratio was 1.8027 ±20.03%.

During the fall composition count of the RGCH, 19 sample units were surveyed from 21 October to 2 November 1993. Male/female and calf/female ratios were 0.4925 ±31.75% and 0.4245 ±5.99%, respectively. For comparison, fall composition data of the RGCH from 1973 to 1993 are shown in Table 4.

Extrapolation for the RGCH size from the June 1993 photocensus

The previous census method requires the application of the female/adult ratio from the June 1993 composition count to the estimated adult number counted on photos. In this case, the adult estimate of 652 003 caribou (Table 2) had to be multiplied by 0.8855, resulting in a female estimate of 577 373 for June 1993. As the female summer survival rate is 0.8869 and the adult sex ratio is 0.4925 male/female, the size of the population in October 1993 would have been 764 221 ±23.55% adult caribou. Adding the calf cohort to the adults resulted in a total herd size estimate of 981 565 ±22.64% caribou (Adult's method, Table 5).

We caution the use of the female/adult ratio in June 1993 since the result of 0.8855 might be slightly biased, being too high in comparison with previous

Table 3. Composition counts of the Rivière George Caribou Herd, 19 - 25 June 1993 (n=22).

Location[a]	PTT[b]	Calf at heel	Males (≥1 an)	Females (≥1 an)	Calves	TOTAL	Calf/ Female	Female/ Adult
5 (L)	4900	No	53	69	3	125	0.043	0.566
6 (M)	8318	No	53	91	1	145	0.011	0.632
7 (M)	14230	No	52	94	3	149	0.032	0.644
8 (L)	15196	Yes	18	176	83	277	0.472	0.907
9 (M)	4921	No	129	424	48	601	0.113	0.767
10 (H)	4924	No	31	269	40	340	0.149	0.897
12 (H)	14225	?[c]	17	216	95	328	0.440	0.927
13 (H)	11123	Yes	21	186	87	294	0.468	0.899
14 (H)	4920	Yes	21	235	154	410	0.655	0.918
16 (H)	15201	?[c]	5	328	272	605	0.829	0.985
17 (L)	15199	Yes	43	202	60	305	0.297	0.824
18 (H)	4918	No	39	211	57	307	0.270	0.844
19 (M)	15200	Lost[d]	31	248	139	418	0.560	0.889
20 (M)	8317	Yes	28	84	37	149	0.440	0.750
21 (H)	15197	Lost[d]	23	276	179	478	0.649	0.923
22 (H)	15193	Yes	29	241	129	399	0.535	0.893
23 (M)	11125	Yes	4	293	265	562	0.904	0.987
24 (M)	3599	Yes	4	252	199	455	0.790	0.984
25 (L)	15194	Yes	22	300	244	566	0.813	0.932
26 (L)	3598	Yes	10	342	282	634	0.825	0.972
27 (L)	4922	No	5	214	180	399	0.841	0.977
28 (H)	11131	Yes	7	239	211	457	0.883	0.972
		13/20[e]	645	4990	2768	8403	0.555	0.886
		7.7 %	59.4 %	32.9 %				

[a] Number refer to Figure 2; H, M and L refer to high, medium and low density strata, respectively.
[b] The platform terminal transmitter (PTT) identification number: all PTT's are carried by female caribou.
[c] This satellite radio-collared female was not observed during the classification.
[d] The calf was assumed to be dead based on distended udder of the female.
[e] Out of 20 satellite radio-collared females that were observed, 13 gave birth or 65%.

Table 4. Composition counts during the rutting period for the Rivière George Caribou Herd, 1973 to 1993[a].

Date	n[b]	Males (≥1)	% Males	Females (≥1)	% Females	Calves	% Calves	Total	Calf/fem	Male/fem	Fem/adult
10-23/10/73			29.8		45.1		25.1	2 092	0.557	0.661	0.602
4-5/1074			29.1		48.4		22.5	1 593	0.465	0.601	0.625
4-19/10/75			27.9		47.8		24.3	24 060	0.508	0.584	0.631
20-31/10/76			24.0		50.9		25.1	7 619	0.493	0.472	0.680
12-22/10/77			23.8		48.8		27.3	2 900	0.559	0.488	0.672
1-8/10/78			36.9		42.6		20.4	27 769	0.479	0.866	0.536
21-24/10/79			31.3		46.6		22.1	13 938	0.474	0.672	0.598
23-25/10/80			30.7		44.8		24.5	9 079	0.547	0.685	0.593
19-20/10/81			29.9		44.6		25.5	6 338	0.572	0.670	0.599
19-25/10/82			29.5		45.8		24.8	4 050	0.541	0.644	0.608
24-26/10/83			35.0		43.0		22.1	7 034	0.514	0.814	0.551
22-24/10/84			28.8		51.6		19.6	5 527	0.380	0.558	0.641
21-29/10/85	12	2 453	29.2	4 275	51.0	1 660	19.8	8 388	0.388	0.574	0.635
30/10-10/11/86	14	1 735	28.7	3 070	50.8	1 244	20.6	6 049	0.405	0.565	0.639
31/10-5/11/87	10	710	24.4	1 570	54.1	624	21.5	2 904	0.397	0.452	0.689
10/88	11	1 904	28.2	3 687	54.6	1 160	17.2	6 751	0.315	0.516	0.660
23/10-2/11/89	14	885	31.8	1 403	50.4	493	17.7	2 781	0.351	0.631	0.613
13-21/10/90	14	1 408	30.0	2 603	55.4	686	14.6	4 697	0.264	0.541	0.649
22-25/10/91	18	2 225	23.7	5 446	58.1	1 698	18.1	9 369	0.312	0.409	0.710
26/10-1/11/92	14	1 184	19.9	3 835	64.4	940	15.8	5 959	0.245	0.309	0.764
21/10-2/11/93	19	1 470	25.7	2 985	52.2	1 267	22.1	5 722	0.4245	0.4925	0.670
Mean 73-93			28.5		50.0		21.5		0.438	0.581	0.636
Mean 73-83			29.8		46.2		24.0		0.519	0.651	0.609
Mean 84-93			27.0		54.3		18.7		0.348	0.505	0.667

[a] Counts from Messier *et al.* (1988): 1973 to 1984, or made by: S. Luttich, LWD: 1985, 1991 and 1992; D. Vandal, MLCP and S. Luttich: 1986; D. Vandal: 1987; D. Le Hénaff, MLCP and S. Luttich: 1988; S. Couturier, MLCP: 1989, 1990 and 1993.

[b] Between 1988 and 1990, sampling sites were selected from VHF radio-collars locations. Since 1991, they are selected from satellite radio-collar locations.

data. As the outlying areas of the calving grounds were included in the June 1993 census and that more adult and yearling males are normally found in these areas, we expected the female/adult ratio to be lower than in previous censuses. The female/adult ratio was 0.86 on average on the calving grounds in the RGCH censuses done from 1984 to 1988 (Crête *et al.,* 1991). The photocensus of the RAFCH in 1991 is the only available data with a similar sampling design. Female/adult ratio was 0.77 and 0.41 for the high (calving grounds) and low (outlying areas) density strata respectively (Couturier, S., unpubl. data).

Another estimating tool was found for the female cohort. Having considered that the calf count on aerial photographs is accurate and that the June 1993 calf/female ratio is reliable, we used the inverse of this ratio (female/calf=1.8027) to estimate the abundance of females in June 1993. This resulted in a decreased precision because of the larger confidence interval for this ratio. This method relies on estimating the number of calves present on the slides and extrapolating for the number of females from the female/calf ratio in the photocensus area. A total of 244 674 ±23.86% calves was estimated in June. By multiplying the female/calf ratio to this number, we obtain an estimate of 441 086 ±31.29% adult females present in June 1993. Using the summer survival rate, we obtained the intermediate result of 391 185 ±32.06% female caribou in October 1993. According to the male/female ratio, the adult population was 583 829 ±33.79%. From the calf/female ratio, we estimated 166 041 ±32.63% calves. The total RGCH population estimate was 749 869 ±33.15% caribou in October 1993 (Calfs method, Table 5).

Discussion

Composition counts in June and October 1993

In spite of a seemingly acceptable sample size (n=22 sample units for 8403 classified caribou), some pro-

Table 5. Herd size calculation for the June 1993 photocensus of the Rivière George Caribou Herd, based on the number of calves (Calfs method) and on the number of adults (Adult's method) followed by the combination of each result with the Post-calving photocensus estimate.

	Estimate	Confidence interval (α = 0.10)
• Calfs method (From the number of calves in June)		
Number of calves in the June photocensus	244 674	± 23.86%
Female/calf ratio in June 1993	1.8027	± 20.03%
Number of females in June 1993	441 086	± 31.29%
Summer survival rate of females	0.8869	± 6.98%
Number of surviving females in Oct. 1993	391 185	± 32.06%
Male/female ratio in October 1993	0.4925	± 31.75%
Number of adults in October 1993	583 829	± 33.79%
Calf/female ratio in October 1993	0.4245	± 5.99%
Number of calves in October 1993	166 041	± 32.63%
Total herd size (including calves)	749 869	± 33.15%
• Adult's method (From the number of adults in June)		
Number of adults in the June photocensus	652 003	± 19.45%
Female/adult ratio in June 1993	0.8855	± 3.98%
Number of females in June 1993	577 373	± 19.86%
Summer survival rate of females	0.8869	± 6.98%
Number of surviving females in Oct. 1993	512 054	± 21.05%
Male/female ratio in October 1993	0.4925	± 31.75%
Number of adults in October 1993	764 221	± 23.55%
Calf/female ratio in October 1993	0.4245	± 5.99%
Number of calves in October 1993	217 344	± 21.90%
Total herd size (including calves)	981 565	± 22.64%
• Combined estimates including calves		
Calfs method and Post-calving census[1]	775 891	± 13.40%
Adult's method and Post-calving census[1]	823 375	± 12.36%

[1] Computed from Russell *et al.* (1996).

blems possibly affected the June composition count. Since we not only surveyed the calving grounds but also the outlying areas where many adult and yearling males were normally found, the June 1993 female/adult ratio seems too high. We thereby expected to find a female proportion closer to 0.75 in June considering that many males were not on the photocensus area. Such a proportion would have brought the fall population to 647 000 adults or 831 000 caribou including calves. Due to the different sampling plan used in past censuses, very few comparison data are available to determine the relative abundance of females on our sampling area. An unusually high female proportion in our June 1993 composition count can be due to several reasons. Certain areas were not surveyed as thoroughly as others, namely the southern and eastern portion. Also, two satellite collars carried by adult males were located within the high density stratum of the sampling area and were unfortunately not included in the composition survey. Including these collars to the sampled groups would have decreased the female proportion, bringing the population estimate down.

In October 1993, care was taken to cover the entire rutting distribution of the RGCH (400 000 km^2) and all satellite radio-collars were visited. This effort permitted to determine the male/female ratio at 0.49, which is very similar to the 1984-1993 average. The extrapolation for the total number of caribou in the fall largely relies on the two ratios found during the October 1993 composition count.

Proposed improvements to calving grounds photocensus

Some improvements of the 1993 method could be beneficial to subsequent census efforts. To carry out a better coverage of the herd and to decrease the confidence interval, a minimum of 200 sample units should be obtained during the aerial photography of the sampling area. Also, a minimum of 30 sample units should be inspected during the June and October composition counts. Although large scale movements were not observed during the June 1993 census, this eventuality remains, both within the density strata and in outlying areas. Such movements could invalidate the stratification process and the final estimate. We recommend to eliminate the visual survey and encourage the use of radio-telemetry to determine the density strata. This would shorten the census by 5 days, an important economy of time that eliminates problems associated with caribou movements. This proposed change would require having at least 125 active radio-collars in the herd, of which a third would be satellite radio-collars. Moreover, the telemetry survey is not really weather-dependent while the visual survey is often delayed by flying conditions.

We recommend to use only two density strata. A third stratum in June 1993 was found useless probably due to caribou movements between stratification and photography. The surface area represented by each stratum decreases as the number of strata rises, which in turn, increases the chance that caribou movements, even on a small scale, scramble the initial stratification. Two density strata were successfully used in the 1991 census of the RAFCH (Couturier, S., unpubl. data).

We suggest to give more importance to the calf/female ratio in subsequent censuses. During calving, we believe that it is easier to correctly find an unbiased estimate for the female/calf ratio than for the adult sex ratio. Segregation of sexes among adults is greater at this time and a low samphng effort could result in a biased female/adult ratio, which may have occurred in June 1993. Unfortunately, the confidence interval of the female/calf ratio is larger and suggests that the sample size should be increased to reach a better precision. Since it is possible to find two estimates for female abundance in June: one from the female/adult ratio and the other from the female/calf ratio, we could attempt to combine both estimators. This would hopefully result in smaller variance than their respective variances but care should be taken to correctly evaluate the covariance between both female abundance estimators.

Comparison with an independent census

A second independent photocensus was done on the RGCH in July 1993 by Russell *et al.* (1996). Their results can be compared to those found in our study. The results in the post-calving census are twofold. First, all photographed caribou belonging to selected aggregations are counted. The selection of the counted groups with the use of the telemetry data prevents the possibility of recounting the same caribou twice and provides a minimum count for the caribou population. However, the minimum count is not the total population size since many caribou groups are not tallied (not located during telemetry, not seen during the survey or not fully aggregated). Second, while photographing the caribou aggregations, a telemetry survey was carried out to identify radio-collared caribou. Thereby, the July 1993 census estimated the RGCH size by extrapolating for missing radio-collars from the photographed aggregations.

Russell *et al.* (1996) shown that the minimum adult population size of the RGCH was 358 460 in July 1993. These caribou were associated with 72 of the total of 92 radio-collars considered active in July 1993. Using the Petersen index method (White & Garrot, 1990), Russell *et al.* (1996) estimated the RGCH size at 540 040 ±12.8% (C.I. at α=0.10) adult caribou in July 1993. By attempting to take into account groups less aggregated (with one radio-collar only, poor aggregation conditions), those missed but with a radio-collar and those without radio-collars, we performed a new analysis with the data set collected by Russell *et al.* (1996). A detailed description of the statistical methods is given in Rivest *et al.* (1994). This proposed method relies on a stochastic model to correct small biases caused by missed groups and those that are less aggregated. Rivest *et al.* (1994) calculated a similar estimate for the adult population of 608 384 ±14.35% caribou. The fall herd size including calves became 781 408 ±14.65%. This result, and its confidence interval, was combined to our fall estimates (Table 5). The combined estimates were 775 891 ±13.40% and 823 375 ±12.36% for our two calculation methods, respectively. Both combined results with past censuses of the RGCH are shown in Fig. 3.

RGCH management implications

Survival and productivity monitoring could be more sensitive to detect demographic trends of the RGCH than comparison of successive population estimates derived from aerial censuses. Between 1976 and 1988, the low precision of aerial censuses impeded detecting minor changes in population size. However, the results of the 1993 aerial censuses show that it will now be possible to reach confidence intervals of 20% at a=0.10. This precision raises the question of the optimum interval length between successive censuses. Between 1980 and 1988, a 2-year interval has been used in surveying the RGCH. This has been lengthened to 5 years since 1988. Caribou managers of the Northwest Territories (Williams, M., pers. comm.) and elsewhere in North

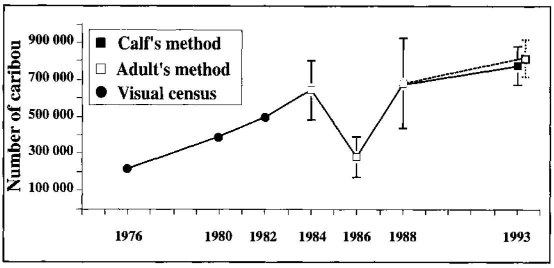

Fig. 3. Fall herd size estimates (including calves) for the Rivière George Caribou Herd, 1976 to 1993 (confidence interval at α = 0.10 are shown, both combined estimates are presented for 1993).

America have been surveying large migratory herds at 2 to 4 year intervals. On one hand, it may be useless to shorten the 5-year interval if the annual rate of change of the population is small (≤ 5%). On the other, it may be inappropriate at this time to lengthen the interval because all observers agree that the RGCH is now at a very critical demographic state where a major decline is likely to occur.

If we could predict the rate of change in the size of the RGCH, it would be possible to determine the optimum census interval with the method described by Gerrodette (1987) and used recently in the software TRENDS (Gerrodette, 1993). To stay on the safe side, we suggest that the worst possible scenario for the RGCH is a major decline with a rate of change of 15% per year. In such circumstances and with 20% confidence interval of the estimates, TRENDS shows that the optimum census interval for the RGCH should be 4 years. For a rate of change of 10% annually, the analysis shows that a 5-year interval could detect significant changes within the population. The cost of a mistake would be much higher if a decline goes undetected longer than necessary instead of a reduced census efficiency. We suggest that the 5-year interval between successive censuses should be kept for the RGCH.

Between the censuses, an equal attention should be paid annually to autumn calf/female ratio and to the adult female survival rates because they both contributed significantly to the recent change in the demographic trend of the RGCH (Crête *et al.*, 1994). Both satellite and VHF radio-telemetry of the RGCH will continue to be necessary for estimating survival, and for regular management of the herd: harvest development, determining the habitat use, particularly on the calving grounds; deriving a sampling tool for the determination of the population ratios; etc. Crête and Huot (1993) recommended that radio-telemetry will also be necessary for monitoring the movements of the RGCH near training areas of military aircrafts in Northeastern Québec and Labrador. The energetic and survival consequences of low-level flying on caribou are not known for the RGCH and may represent a threat to the herd, particularly for the calving females. Luick *et al.* (1996) and Kitchens *et al.* (1996) have suggested that increased exposure to low-level flying may increase the energy expenditure while decreasing the probability of pregnancy. The monitoring of caribou movements by radio-telemetry will also continue to be useful in the area of hydro-electrical reservoirs (Doucet *et al.*, 1992).

Although the 1993 census slightly differed from previous ones and according to the differences between the density strata, we consider that the high density stratum closely represents the traditional calving grounds of the RGCH. The high density strata in the 1993 census covered 14 255 km^2, which is lower than the 22 857 km^2 calving grounds area observed in 1988 (Crête *et al.*, 1989) and the 20 250 km^2 area observed in June 1987 (Vandal & Couturier, 1988). No complete calving grounds delimitation has been done for the RGCH between 1989 and 1992. The June 1993 high density stratum should be designated as the calving grounds of the RGCH and be protected under the Québec Wildlife Habitats Act.

Demographic trends and regulation factors

Results of the June 1993 RGCH photocensus and their comparison to a second independent census suggest that the RGCH still remains the largest caribou herd in the world (Williams & Heard, 1986). Although many observers of the RGCH have mentioned that this herd can not increase anymore, it remains important to study the factors that have made 1993 a good year for the herd. The 73% increase in the calf/female ratio in the fall (Table 4) is a good indicator that the herd is in better condition and that a population decline will not occur in the short-term. From scientific monitoring of the commercial harvest in Labrador, physical condition of the caribou, especially fat reserves, were better in April 1993 than in previous years (Luttich, S.N., unpubl. data). Birth weights of both sexes combined increased from 5.08 kg (standard error =0.10, n=49) in 1992 to 6.85 kg (s.e.=0.17, n=45) in June 1993 (Couturier, S., and Luttich, S.N., unpubl. data). Large-scale mortality of newborn calves (49 calf carcasses observed), unrelated to predation, have been fortuitously observed in June 1992 during 8 hours of helicopter flights under poor visibility conditions. By excluding 2 cases of predation, no other calf mortality was found in June 1993 during extensive low-level flights under very good visibility conditions.

Earlier mentions on the deterioration of the general condition of the RGCH were made by

Couturier *et al.*, (1988a, 1988b). During the following years, other observers (Messier *et al.*, 1988; Couturier *et al.*, 1989 and 1990; Huot, 1989; Hearn *et al.*, 1990) have confirmed that many demographic indicators gave insight as to the stabilization or the decrease of the herd's size. Some intrinsic mechanisms have been identified, namely by Messier *et al.* (1988), Hearn *et al.* (1990), Crête *et al.* (1990a), and Crête & Huot (1993). Knowledge and interest on the RGCH-habitat relationship (Huot, 1989; Crête *et al.*, 1990b; Crête *et al.*, 1993; Manseau *et al.*, 1996; Morneau & Payette, 1996) and on the climate's effect on the herd (Crête & Payette, 1990; Maarouf *et al.*, 1994) has increased. The deterioration of the summer habitat has been identified as a key factor in this herd's regulation. Predation by wolves could become an important element in the demography of the RGCH (Heard & Williams, 1992; Heard, 1994) and deserves closer attention in the future management of the herd.

Since the beginning of the 1990's, most observers expected to see a decrease in the herd size without being able to predict when this would begin nor how fast it would proceed. The size of the RGCH observed in 1993 by two independent censuses coincides with a stabilization of certain demographic parameters. We hypothesize that the better condition of the RGCH observed in 1993 can be attributed to the considerable change in the migratory behavior of the adult females of the herd. Most females of the RGCH spent their 1992-1993 and 1993-1994 winters near the Labrador Sea coast. This change in the migratory pattern probably accounted for an economy in their energy budget so that they showed a better physical condition in spring 1993. Low snow cover, a suitable habitat and especially a lower energy expenditure related to a shortened migratory route between the wintering grounds and the calving grounds (based on satellite tracking, Couturier, S. & J. Doucet, unpubl. data) might explain for the better condition in 1992-1993 by comparison to previous years. It will be important to obtain data on physical condition of the females, their pregnancy rate and the birth weight of calves in spring 1994 and later. If our hypothesis is valid, the October 1994 calf/female ratio will again be relatively high due to the repeated use of the eastern wintering grounds used by many females in 1993-1994. Although the use of the Labrador coast seems to be an interesting solution for the females of the herd, we do not believe that this will solve the problems to which the RGCH is faced because of the limited availability of habitat in this region.

Demographic indicators must be monitored very closely in the upcoming years to rapidly adjust the way in which we carry out the analysis of the herd's general condition. New findings will have to be rapidly communicated to the users of the RGCH. Although little chances exist, an increase in the herd's size could be dangerous to the relatively poor summer habitat that remains an important problem. At best, managers and observers should hope that the RGCH stabilizes at its actual level or somewhat lower due to a substantial increase in the annual harvest. In 1992-1993, Québec sport hunters and Natives harvested 12 454 and 4657 caribou, respectively. In the same year, 14 932 caribou were taken in Labrador. If we inflate the above kill figures by 20% for the unreported crippling loss (Miller, 1983; Davis *et al.*, 1980), the total RGCH harvest reached about 38 000 caribou, an amount unprecedented in the monitoring of this herd. The combined 1993 census results confirm that the RGCH is still underharvested and that a harvest increase is still the best strategy in trying to decrease the pressure on the habitat. However, as Couturier *et al.* (1990) have stated, a flexible harvest strategy must be implemented to allow yearly reevaluation of the quotas if the RGCH begins to decline rapidly.

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