Adapting sampling plans to caribou distribution on calving grounds.

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Abstract: Between 1984 and 1988, the size of the two caribou herds in northern Québec was derived by combining estimates of female numbers on calving grounds in June and composition counts during rut in autumn. Sampling with aerial photos was conducted on calving grounds to determine the number of animals·km^{-2}, telemetry served to estimate the proportion of females in the census area at the time of photography in addition to summer survival rate, and helicopter or ground observations were used for composition counts. Observers were able to detect on black and white negatives over 95 percent of caribou counted from a helicopter flying at low altitude over the same area; photo scale varied between ≈ 1:3 600 and 1:6 000. Sampling units covering less than 15-20 ha were the best for sampling caribou distribution on calving grounds, where density generally averaged ≈ 10 individuals·km^{-2}. Around 90 percent of caribou on calving grounds were females; others were mostly yearling males. During the 1-2 day photographic census, 64 to 77 percent of the females were present on the calving areas. Summer survival exceeded 95 percent in three summers. In autumn, females composed between 45 and 54 percent of each herd. The Riviére George herd was estimated at 682 000 individuals (± 36%; α = 0.10) in 1988. This estimate was imprecise due to insufficiens sample size for measuring animal density on the calving ground and for determining proportion of females on the calving ground at the time of the photo census. To improve precision and reduce cost, it is proposed to estimate herd size of tundra caribou in one step, using only aerial photos in early June without telemetry.

Keywords: caribou, census, aerial photography, Riviére George, Riviére aux Feuilles.

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Introduction

Accurate and precise population estimates facilitate sound wildlife management. For large mammals, aerial counts have been a technique used in various situations to estimate population size. Caribou *(Rangifer tarandus* L.) numbers were mainly derived from strip transects in the sixties and the seventies, although random plots and aerial photography also were used (Siniff & Skoog 1964; Parker 1975). More recently, oblique and vertical aerial photographs have been used, particularly for populations that spend part of their annual cycle on the tundra (Davies *et al.* 1985; Goudreault 1985; Heard 1985; Valkenburg *et al.* 1985; Whitten 1985). Photos have been taken when caribou occupy concentration areas, at parturition or during the following months.

In Québec, population estimates are now derived from vertical photographs taken over calving grounds during the first half of June (Goudreault 1985). Total population size is extrapolated from the number of females present on the calving ground, based on population structure during the following autumn (Heard 1985). A reconnaissance flight precedes photography to delineate boundaries of calving grounds. Because these areas cover many thousands of square kilometres, sampling is necessary. Study areas are stratified according to caribou density and photos are systematically spaced over strata, making it possible to estimate the total number of animals. Simultaneously, sex and age structure of caribou occupying the study area is determined by helicopter sampling because many yearlings and some adult males accompany females. These sex and age structures are used to estimate total number of ≥ 1 year-old females present on the calving ground. Total herd size is estimated during the following rut by cross-multiplication, using the ratio of females ≥ 1.5 years old/total number of caribou in autum, including calves.

Population sizes of caribou estimated by photographing the animals on the calving grounds exhibit variable precision and may be biased. Precision depends on the variability of animal disitribution over study areas, sample size, plot size, sampling fraction, accuracy of stratification and the precision of ratios used to convert the number of animals appearing on the photos into a total population estimate. On the other hand, final estimates may be biased if some animals remain undetected on photos, if snowdrifts or rocks are counted as caribou, if some females are located outside delineated calving areas as the time of the census and if mortality of females occurs between June and November. In this paper, we determine the best plot size when sampling with vertical photographs over calving grounds, we examine conditions necessary to obtain unbiased variance estimates and to achieve acceptable precision levels of estimates of population size, and we estimate correction factors necessary to eliminate bias.

Study areas

Data were collected on the Riviére George calving ground in 1984, 1986 and 1988 and on the Riviére aux Feuilles calving area in 1986 (Fig. 1). The first area covered 8.990, 15.300 and 22.860 km^2 in 1984, 1986 and 1988, respectively, whereas the Riviére aux Feuilles calving ground occupied 6.300 km^2. The Riviére George area lay mainly on a hilly plateau where the altitude range between 500 and 750 m, but also

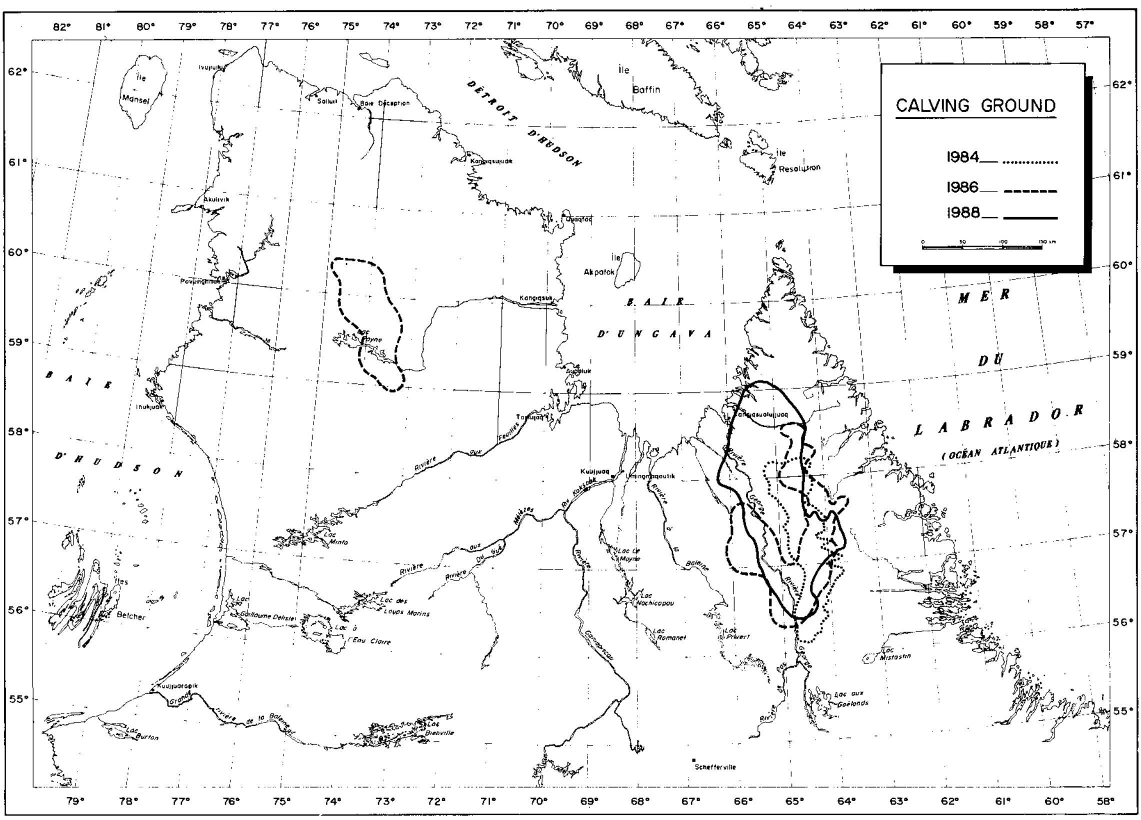

Figure 1. Location of the Riviére George (East) and Riviére aux Feuilles (West) caribou calving areas in northern Québec at the time of their photo census between 1984 and 1988.

covered some lowlands along the river. Barren-ground tundra is the most common cover type and occurs on the high watershed plateaux; forest tundra ecotone occupied tributary branches while lichen-forest occurs along the main river valley and at elevations below 400 m. The Rivière aux Feuilles calving ground, located north of the tree line, occupied a gently rolling plateau of barren-ground tundra averaging 225 m in elevation. Census of the calving ground was intended for the peak of calving. Based on limited information (Le Hénaff pers. comm., Crête *et al.* 1989), calving appears to occur during the first week of June at the Rivière aux Feuilles area, approximately 7-10 days earlier than on the other calving ground. At the time of photography, snow covered, 47, 39 and 34 percent, respectively, of the ground on the Rivière George area the first, the second and the third year, and 41 percent at the Rivière aux Feuilles ground.

Methods

Photography of calving grounds

A reconnaissance flight was conducted during the few days preceding the photography with a twin-engine DC-3 to delineate census areas. The aircraft, carrying one navigator and two observers seated on opposite sides, flew transectlines spaced at 13-40 km intervals, at an altitude of 200 m above the ground. Observers reported the approximate number of caribou seen; moreover the presence of newborn calves and adult females with hard polished antlers was noted as being typical of calving areas. The final boundary of the census area was drawn on the day of photography in 1984 and 1986, but during the reconnaissance flight in 1988.

Photographs were taken with a RC-5 (Wild) camera equipped with a calibrated 157-mm lens, mounted on the DC-3 aircraft. They were distributed systematically along transect lines as this type of allocation was much more practical than random sampling, while being statistically accepptable (Seber 1986). The airplane flew at relatively constant altitude so that the scale of photos varied between 1:3 650 and 1:6 130, as a result of irregular topography. The altitude above the ground was estimated at the centre of each photo with the help of the incorporated camera altimeter and 1:50 000 topographic maps, showing contour lines at 15.3 m intervals. The altimeter was adjusted at each roll change. Photos were taken at 20-25 second intervals to prevent overlap in frames. In addition, photographs were taken with a 35-mm camera (50-mm lens) installed on a Bell 206B helicopter in 1988 on the same day as the RC-5 camera was used. Thirty clusters of 10-20 photos were distributed randomly over the calving ground. The altimeter of the aircraft and topographic maps served to estimate the height above the ground at which photographs were taken.

During photography with the DC-3 aircraft, transect lines were spaced so that 800-1000 photos would systematively cover each calving ground, requiring two days of photographing effort. Photography was restricted to two days because animals are highly mobile at this time. Nonetheless, poor weather in early June often impedes aerial photography in northern Québec. As a result, the aircraft flew every second transect line to have a complete coverage of the census area at the end of the first day of work in the case of weather changes that would result in interference. The crew navigator, using the number of observed animals and notes taken during earlier reconnaissance flights, had the task of drawing the final boundary of the calving area and delineating two strata of caribou density during the photography.

At the laboratory, caribou were counted as transparencies on black and white negatives with a 3.5-15x stereoscope; newborn calves were not recorded. At 20x20 cm transparent grid, divided in 100 cells, was superimposed onto the negatives, which covered 23x23 cm, to facilitate the tally and to eliminate distortion at the periphery of photos. The area (A) covered by each photo (m^2) was estimated with the formula: $A = SxH^2/f = 1.274\ H^2$, where S represents the side of the grid (0.2 m), H the altitude above the ground (m), and f the focal distance (0.157 m).

Herd composition on calving grounds

Simultaneously with photography, the sex and age composition of caribou present on the census area was estimated by random sampling from a helicopter. Sampling-plots were rectangular (1x5 or 10 km) and they were flown over slowly to count caribou; animals were aged based on their size, as newborn calf, yearling or adult. Sex of adults could be ascertained by the presence of hard polished antlers for females and the observation of genitalia for antlerless caribou. Sex of yearling was determined by the presence of a vulva patch, which was often difficult to observe from the air because of the frequent clumping in large groups; sex ratio was then obtained from a subsample of easily observable animals.

Proportion of females on calving grounds and summer survival

The proporiton of ≥ 1 year-old females located inside the delineated calving group at the time of the census was estimated using radio-tagged animals. Caribou from the Riviére George herd have been equipped with radio collars since the autumn 1983 and monitored animals appear representative of the entire herd (Hearn *et al.* 1990). Their location was determined a few days before photography. This correction factor could be estimated for the Riviére George herd only, because at the time of the surveys, no animals in the other herd has been radio-collared. In 1988, radio-tagged individuals present in and at the periphery of the calving ground also were located on the day of photography. Telemetry also served to estimate survival between June and early November, as radio-collars had mortality sensors. Immobile radio-collars were generally recovered to confirm the death of animals (Hearn *et al.* 1990).

Autumn composition of herds

Sex and age composition of each herd was estimated in late October and early November. Sampling plots were randomly selected within the accessible area occupied by radio-tagged animals (mostly females) for the Riviére George herd and within the area believed to be used by the Riviére aux Feuilles herd during autumn. Sampling was stratified according to caribou density in 1988. All animals observed from on-ground vantage points in the course of approximately 1 hour were classified as calf, ≥ 1.5 year-old male or ≥ 1.5 year-old female, based on their size, body morphology and the presence or absence of a vulva patch.

Detectability of caribou on photos and scaling with body length

Proportion of caribou visible on photos was estimated by blind comparison of counts on 35-mm black and white negatives with on-site low-level helcopter counts over the same area. The 35-mm camera, installed through the floor of a Bell 206B helicopter hovering at an altitude of 340 m, was equipped with a 85-mm lens, so that photo scale was similar to the one obtained with the RC-5 camera. Each photo covered 1.2 ha. Immediately after taking the photograph, the helicopter, carrying 2 observers plus the pilot, flew at low-level over the same area to count all caribou (except calves). In 1986, 12 and 10 photos of different sites showing between 1 and 33 caribou were taken at the Riviére aux Feuilles and Riviére George area respectively; 30 additional groups were photographed in 1988. The caribou visible on these photos were counted by three independent observers, half-way through the processing of regular photos of each calving ground.

Unlike photos taken with the RC-5 camera, verifying the exactness of the estimated area covered by each 35-mm photo, as derived from the altitude and the focal distance with recognizable landmarks on topographic maps, was not possible due to the small area photographed. Nevertheless, the scale of 24 35-mm photos showing caribou was precisely determined with the help of two readings of a hand-held altimeter graduated at 3 m intervals; one done when photographing, the other on the ground in the centre of the photographed area. The scale equals the focal distance over the altitude (f/h). The length of each animal appearing on the photos was measured with a stereoscope and linear regression relating caribou length with the scale of the photo were computed using the procedure REG of SAS (SAS institute Inc. 1985). Five regressions were computed according to animal posture: standing still, moving, standing head bent, lying stretched, lying grouped.

Selection of optimal plot size on aerial photos

Relative net precision, assuming constant costs per unit, was used to select the optimal size of sampling plots for counting caribou on 20x20 cm aerial photographs (Cochran 1977:234). One subsample of 10 photos was randomly selected in each density stratum on the Riviére aux Feuilles and Riviére George calving grounds in 1986. Comparisons involved plot size covering 2, 5, 10, 20, 50 and 100 percent of the photographs. For each size, one reading was taken randomly per photo to estimate the variance among unit totals (s^2: Cochran 1977:234); variance estimates were corrected for the lack of independence between data sets (Cochran 1977:238). Average sizes of photographs varied between 0.62 and 0.80 km² according to subsamples.

Estimating of standard errors of means
To produce unbiased population estimates, each part of calving grounds must have an equal chance of being photographed. However the area covered by each photo varied between transect lines because of change in cloud cover and irregular topography. Results were then expressed in terms of density (caribou•km^{-2}) for each photo to reduce to minimum positive bias for transect lines flown at above average altitude.

Because we did not use systematic sampling in two dimensions (Cochran 1977:277) RC-5-photos along transect lines were much closer (≈ 1 km) than between transect lines (13-40 km: Fig. 2). The objection was raised that transect lines, not photos, constituted sampling units (D. Heard, pers. comm.), which supposes that within-transect variance is smaller than between-transects. We formed clusters of 10, 20 and 30 consecutive photos on the same transect line and we compared within and between cluster variance by means of a nested analysis of variance (Proc GLM:SAS Institue Inc, 1985). Comparison of within and between variance served to select cluster size producing unbiased variance estimates of mean caribou densities.

As, on the one hand, the select plot size was much smaller than total area covered by 1 RC-5 photo and, on the other, the scale of photos could not be enlarged because of equipment and aircraft constraints, stratified three stage sampling was selected to estimate the number of caribou occupying each calving ground (Cochran 1977:274). The cluster of photos made the primary units, the complete photo, minus margins (20x20 cm) represented the secondary units and an area covering 5 percent of the photo (2x10 cm) made up the tertiary unit. Preliminary computations on 1984 and 1986 data were conducted to estimate the gain in precision obtained when increasing the third stage sampling (f_3 = number of tertiary units counted per photo/20). Because precision increased little when doubling the sampling fraction from 0.5 to 1, caribou were counted on 10 tertiary units per photo (f_3 = 0.5), which saved manpower. In the case of 35-mm photos, the sampling plan was reduced to two stage sampling, the single photo being the secondary unit.

Because the area covered by each photo was variable, calculations of the mean density of caribou per calving ground (and its standard error:SE) had to integrate three stage sampling and ratio estimators (Cochran 1977:150). Separate ratios (y/x = caribou•km^{-2}) were calculated in each stratum as it is the most precise method (Cochran 1977:168), before a weighted density was estimated for total calving grounds. SE of ratios was estimated by computing s_y^2 and s_x^2 in Cochran's (1977) formulae 6.13 with equation 10.16, and s_{yx} as $r(s_y^2\ s_x^2)^{1/2}$, where r is the coefficient of correlation between y_i and x_i.

Visibility rate of caribou on photographs and proportion of ≥ 1 year-old females on calving grounds and in autumn also were calculated by ratio estimators, as were SE. Proportions derived from telemetry (percentage of females located outside the calving ground and summer survival rate) were estimated, based upon the binomial distribution. Animals were widely spaced and the assumption of independence between individuals was acceptable.

At all steps of the computation to convert caribou densities on calving grounds to a total population estimate, variables were multiplied or divided together. There is a loss of precision associated with such operations, and resulting SE were estimated with formulae used by Créte *et al.* (1986). For compunting confidence intervals, a t distribution was used; when the estimate was the product of 2 random variables, the smaller of the degrees of freedom was taken (Gasaway *et al.* 1986). In the text, means are given with their SE and the sample size.

Results

Except in 1984, photograps could be taken only 1 day for each census due to bad weather. Moreover, a complete photo coverage of the Riviére George calving area was impossible in 1986 (Fig. 2), although the reconnaissance flight and helicopter observations made it possible to stratify south of the area. On the other hand, both series of photos taken in 1986 were slightly overexposed; this problem was partially corrected by using a new processing technique, but photo interpretation remained more difficult than in 1984 and 1988.

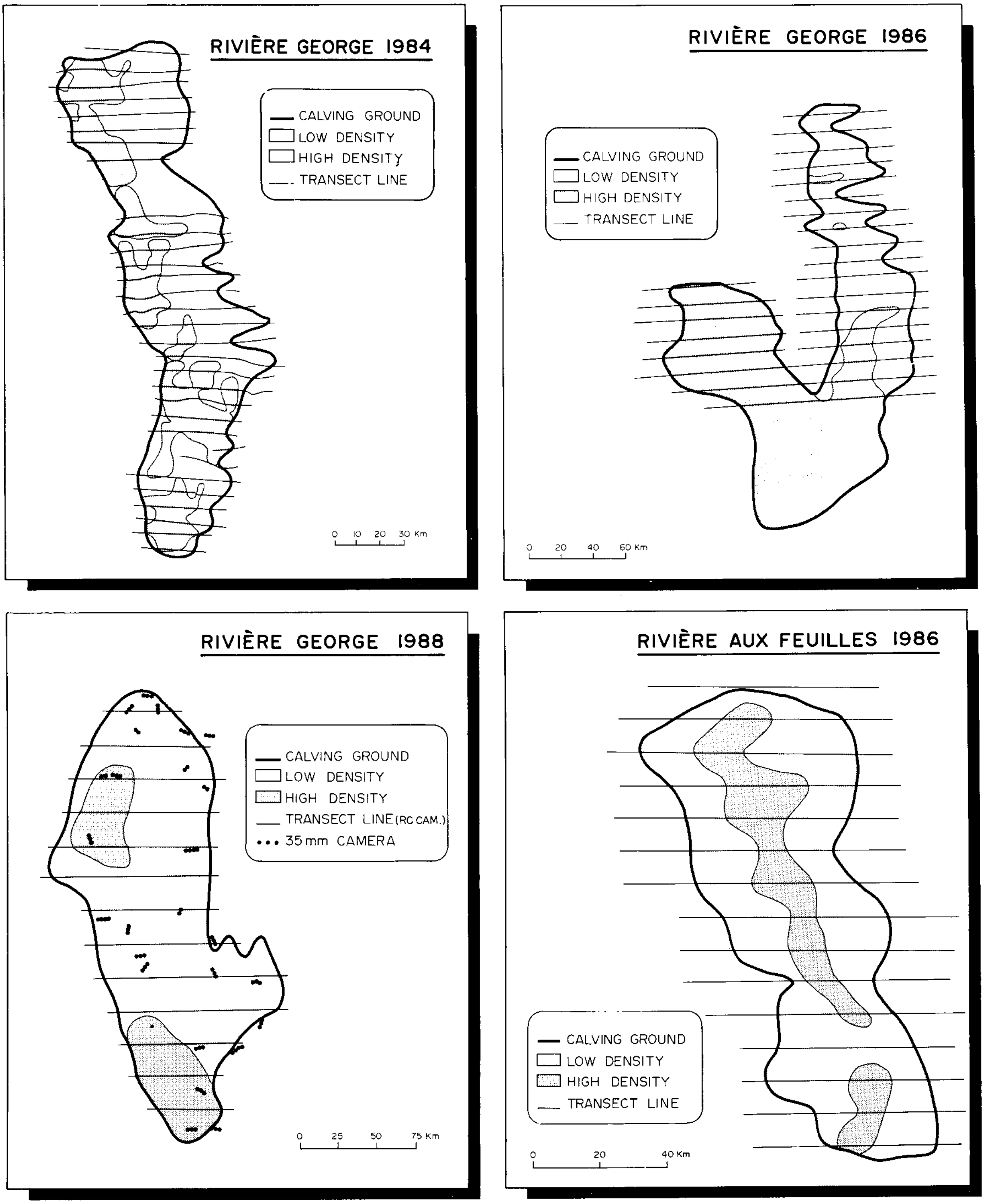

Figure 2. Transect lines along which RC-5 photos were taken over the Riviére George and Riviére aux Feuilles calving areas, and sampling plots used with a 35-mm camera in 1988, according to 2 strata of caribou density, northern Québec.

Selection of optimal plot and cluster size

Although caribou densities varied between the 4 subsamples of photographs, results were consistent (Table 1). In all cases, units covering 5 or 10 percent of the entire photo represented the best sampling area. For practical reasons, a rectangle covering 5 percent of the grid (2x10 cm) was selected as a compromise for third sta-

Table 1. Computation of the relative net precision (Cochran 1976:239) in order to select a sampling unit which, for a given effort, provided the best statistical precision when counting caribou on aerial photos. Riviére George and Riviére aux Feuilles calving grounds, June 1986. For a given row, the highest value of relative net precision indicates the best sampling unit.

	Area covered by 1 photo (km^2)	Number of photos	Caribou km^{-2}	Area covered by sampling units Percent photograph					
				2	5	10	20	50	100
Riviére George									
High density stratum	0.74(0.06[a])	10	11.4	187	303	153	151	100	143
Low density stratum	0.80(0.05)	10	5.0	114	166	125	145	130	100
Riviére aux Feuilles									
High density stratum	0.62(0.04)	10	14.4	325	350	400	350	200	100
Low density stratum	0.64(0.02)	10	5.4	100	141	326	193	228	170

[a] SE

ge plot size when using RC-5 photos. As 35-mm photos covered a few hectares each, they were of adequate size as secondary units when sampling with this type of camera.

Caribou density on consecutive photos along transect lines was more homogenous than that on different lines. Although short transect length often precluded forming clusters of 20 or 30 consecutive photos, comparison of within and between cluster variance (Table 2) helped to select the number of photos per cluster: we chose 20 for the Riviére George area in 1988 and 1986, and 10 for the two other cases.

Table 2. Results (F-values) of an analysis of variance for caribou density on aerial photos taken along transect lines and grouped in clusters of 10, 20 or 30 consecutive photos. The model was: density = line cluster (nested in line). When the ratio F-line/F-cluster approaches 1, it indicates that within and between cluster variability is comparable. Photos taken over the Riviére George and Riviére aux Feuilles calving areas between 1984 and 1988 according to 2 density strata.

Area	Number of photos per cluster					
	10		20		30	
	Line	Cluster	Line	Cluster	Line	Cluster
Riviére George 1988						
High density	13.10	2.35	10.46	0.84	–[a]	–
Low density	.[b]	.[b]	13.41	6.27	13.38	16.73
Riviére George 1986						
High density	5.88	2.91	7.16	6.12	–	–
Low density	5.55	0.61	–	–	–	–
Riviére George 1984						
High density	1.74	3.79	–	–	–	–
Low density	1.87	1.09	–	–	–	–
Riviére aux Feuilles 1986						
High density	–	–	–	–	–	–
Low density	3.93	4.49	–	–	–	–

[a] Insufficient sample size
[b] Not computed

Detectability of caribou on photos and exactness of scale

There was good agreement between the number of caribou counted on photos taken from the helicopter and visual counts made from the same aircraft when flying over the same area at low altitude (Table 3). In general, visibility exceeded 95 percent; small sample size, including a few photos which contained trees, may explain the lower detectability estimated for the Rivière George area in 1986. When there was not perfect agreement between the two counts, deviation was never great.

The exactness of estimating the area covered by RC-5 photos with the altitude and the focal distance could be verified with 21 photos showing landmarks precisely located on 1:50 000 topographic maps. According to the focal distance-altitude approach, the surface averaged 0.60 km^2 (SE = 0.03), as compared to 0.58 km^2 (SE = 0.03) based on landmarks; the two means do not differ statistically ($t = 0.3$; $P > 0.5$). On the other hand, the size of caribou appearing on 35-mm photos was closely related to the scale for the five postures considered (Table 4). There were 73 photos showing caribou among those taken when sampling with a 35-mm camera in 1988. They covered 0.028 km^2 (SE = 0.003) each when the area was estimated with the focal distance and the altitude. The corresponding surface area averaged 0.026 km^2 (SE = 0.002) when the scale was estimated with the size of caribou on negatives, using the linear regression with the highest R^2 (Table 4). The two means are not statistically different ($t = 0.6$; $P > 0.5$).

Caribou density on calving grounds

Stratification was successfull for all surveys with caribou density on the high density stratum at least doubling that in the low one (Table 5). Caribou were particularly concentrated in 1984, averaging 32.7 individuals·km^{-2}; in other years, mean density varied around 10 animals·km^{-2}. We believe that density estimates were biased downward in 1986, due to the poor quality of photographs. Conversely, the huge difference between estimates made with the RC-5 and the 35-mm camera in 1988 was attributable to different sampling plans, amplified by the relatively small sample size. The two sets of photos were taken over the same area on the same day. Nonetheless, random sampling was used for the 35-mm photos, as opposed to systematic allocation along transect lines for the other type of photos. For the 35-mm photos, two adjacent clusters in the high density stratum fell in an area of very high caribou concentration: 158 animals·km^{-2}; in the remaining seven clusters, the density averaged 22 caribou·km^{-2}, which is close to the estimate of 18 derived with RC-5 photos. In the low density stratum, the north of the calving ground was oversampled with the 35-mm camera. As this area should have been classified in the other stratum, the average density of the five clusters drawn there (35 animals·km^{-2}) inflated the mean of the low density stratum. In the remaining 16 clusters, the density averaged 12 caribou·km^{-2}, as compared to a mean of 8 when estimated with the other set of photos. The two 1988 density estimates where combined to improve the precision; the weighting factor was the in-

Table 3. Proportion of caribou detected on 35-mm black and white negatives by three observers (A, B, C) during blind comparison as compared to the number of animals counted during low level flight in helicopter over the same area immediately after photography. Photos taken over two calving areas of northern Québec in 1986 and 1988.

	Rivière George			Rivière aux Feuilles
	1988		1986	1986
	A	B	C	C
Average proportion	0.98	0.96	0.90	0.96
SE	0.02	0.02	0.05	0.04
N	52	52	10	12
% exact concordance	73	73	60	83

Table 4. Parameters of the linear regression y = m x + b predicting the inverse of photo scale (y) with the length (mm) of caribou on photos (x) according to five postures. Measurements taken on 25 photos with known scale.

Caribou posture	m (SE)	b (SE)	R^2 adjusted[a]	n[b]
Standing up,still	-17 641(1136)	11 193(368)	0.80	59
Standing up, moving	-13 928(763)	9 777(290)	0.85	58
Standing up, head bent	-17 333(992)	11 113(330)	0.92	26
Lying, stretched	-24 882(2661)	12 108(5 62)	0.74	31
Lying, grouped	-26 174(3819)	12 073(802)	0.67	23

[a] Procedure REG (SAS Institute Inc. 1985)
[b] Number of caribou measured

Table 5. Area (km²) covered by the 2 density strata in the caribou calving ground used by the Riviére George and the Riviére aux Feuilles herds between 1984 and 1988, and mean caribou density (SE;n) as estimated from counts on negatives of black and white aerial vertical photos taken with a RC-5 or a 35-mm camera.

	Riviére George				Riviére aux Feuilles
	1984	1986	1988		1986
	RC-5	RC-5	RC-5	35-mm	RC-5
Area					
High density stratum	3712	9867	4912	4912	1581
Low density stratum	5278	5451	17945	17945	4777
Caribou·km^{-2}					
High density stratum	58.12(3.74;38)	10.88(2.24;19)	18.12(4.93;11	52.16(20.74;9)	13.71(2.67;11)
Low density stratum	14.75(0.98;55)	4.22(1.08;19)	8.20(1.63;40)	16.73(4.39;21)	6.06(1.21;35)
Weighed mean	32.66(1.65;93)	8.51(1.49;38)	10.33(1.66;51)	24.34(5.64;30)	7.96(1.13;46)

Table 6. Proportion of males and females per age class among caribou present on the calving grounds at the time of the photo census and total proportion of females, northern Québec, 1984-1988.

Area	Adult		Yearling		Proportion (SE;n[a])
	Male	Female	Male	Female	of females ≥ 1 year old
Riviére George 1988	< 0.01	0.78	0.09	0.13	0.91(0.08;33)
Riviére George 1986	0.04	0.56	0.16	0.24	0.80(0.08;25)
Riviére George 1984	0.04	0.71	0.10	0.15	0.86(0.04;32)
Riviére aux Feuilles 1986	< 0.01	0.69	0.07	0.24	0.93(0.16;3)

[a] Number of sampling sites; stratified sampling in 1988, random in order years.

verse of the variance of the mean, while the variance of the resulting mean was computed as the inverse of the sum of the inverse variance of the two combined means: the combined density was 11.45 caribou·km^{-2} (SE = 1.59).

Herd composition on calving grounds

The composition counts conducted by helicopter confirmed the observations made during reconnaissance flights preceding photography; most caribou on calving grounds were adult females (Table 6). Few adult males associated with females there, but many yearlings accompanied them. Among yearlings, sex-ratio favoured females. Animals in this age group often tended to aggregate and this distribution inflated the standard error of the means.

In 1988, it was possible to monitor the movement of many radio-tagged females during the week preceding photography (Fig. 3). Of the six crossings of the calving ground limits, five were inward; in general, animals were converging toward the northwest corner of the survey area. Based on telemetry flights over the complete range of the Riviére George herd during thè preceding ≈ 10 days, proportion of females on the calving ground at the time of the survey was estimated at 77 percent in 1984 and 1986 and at 64 percent in 1988 (Table 7). Proportion of yearling and adult females on calving grounds at the time of the census was very similar.

Table 7. Estimated proportion of adult and yearling females on the Riviére George calving ground at the time of census based on location of radio-tagged caribou during the week preceeding the survey, 1984-1988.

Year	Adult	Yearling	Combined (SE)
1988	20/32	3/4	0.64(0.08)
1986	57/73	4/6	0.77(0.05)
1984	5/6	12/16	0.77(0.09)

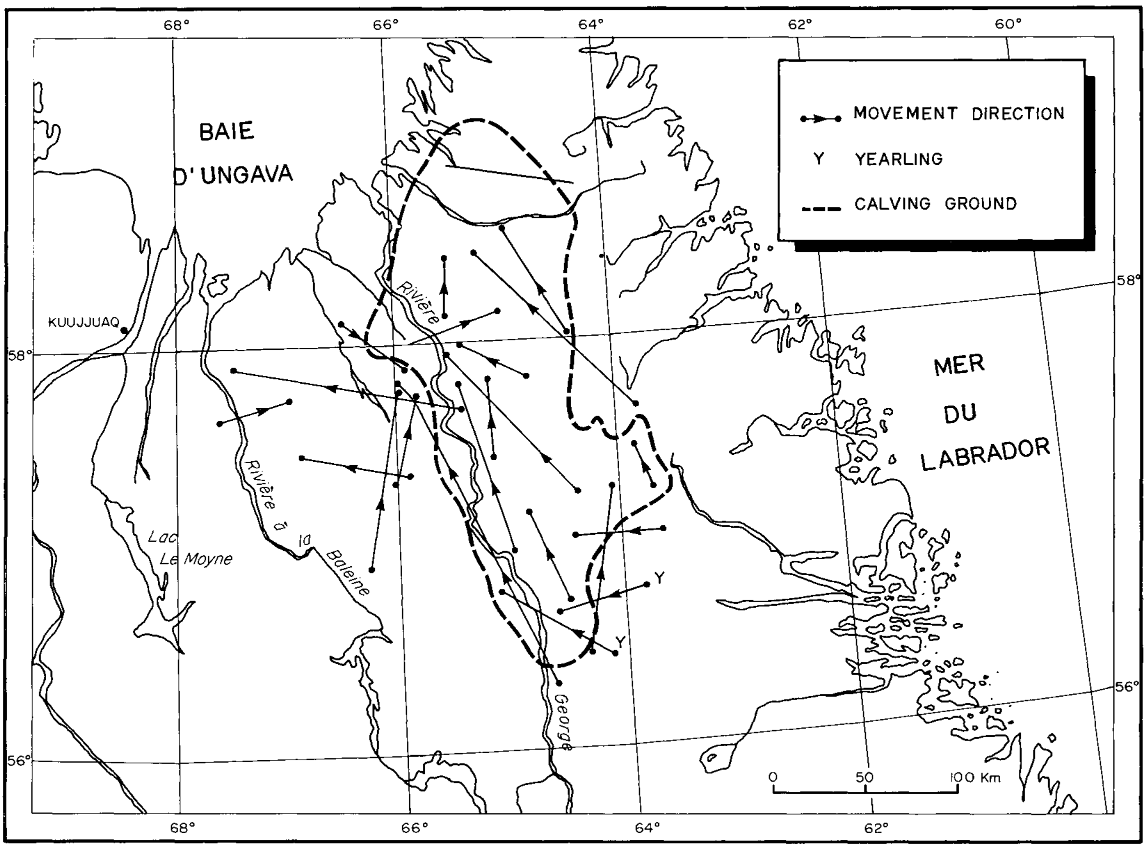

Figure 3. Movement of radio-tagged females at the periphery of the Riviére George caribou calving ground between June 5-6 and 14, 1988.

Summer survival and autumn composition of the herd

Over 95 percent of the radio-tagged females survived from calving time to rut every summer in the Riviére George herd (Table 8). Summer mortality was similar for yearlings and older females. Our survival estimates differ slightly from Hearn's *et al.* (1990) summer rate because we did not take exactly the same period or use the same data base.

Yearlings and older females made up 52(1;12), 51(2;10) and 54(1;11) percent of the Riviére George herd during rut in 1984, 1986 and 1988 respectively. At the Riviére aux Feuilles area, females ≥ 1 year-old composed 45(0.01;5) percent of the herd in 1986. A higher percent of females among Riviére George caribou in recent years resulted from decreasing calf production (Messier *et al.* 1988).

Population estimate

More than 250 000 animals occurred on the Riviére George calving area in 1984 and 1988 during the photo census (Table 9). The best precision was obtained in 1984 because of a larger sample size and a more homogenous caribou distribution over the study area than in the two other years. The 1986 estimate (130 400) is biased due to poor photo quality and incomplete coverage (Fig. 2) (Crête *et al.* 1989). Calf production and survival rate of radio-tagged animals indicated that the herd finite rate of increase decreased from 1.13 to 0.99 between 1983 and 1987, without catastrophic mortality during this period (Hearn *et al.* 1990). Moreover, the 1988 and 1984 data are consist with preceding census (Messier *et al.* 1988; Crête *et al.* 1989). The Riviére George herd probably peaked around 700 000 individuals by 1986-1987, but the 1988 estimate was imprecise. As the 1988 and 1984 estimates did not differ statistically (t = 0.22;P> 0.50), they can be pooled to improve the precision of the herd size estimate (Gasaway *et al.* 1986): There were 655 000 (±21%; α=0.10) caribou associated with the Riviére George calving area between 1984 and 1988. In 1984, the greatest lost of pre-

Table 8. Summer survival rate of yearling and adult radio-tagged female caribou belonging to the Riviére George herd, northern Québec 1984-1988.

Year	Adults	Yearlings	Combined[a] (SE)
1988	17/17	4/5	0.97(0.04)
1986	69/73	6/6	0.96(0.02)
1984	9/9	18/19	0.99(0.021)

[a] Weighted according the proportion of yearlings and adults in the herd (Table 6.).

Table 9. Number of caribou associated with the Riviére George calving ground at all steps necessary to estimate herd size. The confidence interval is expressed as percentage of the estimate (α = 0.10). For each operation, the variance of the estimate was calculated with formulae used by Crête *et al.* (1986).

	1988	1986	1984
All animals on the calving ground, calves excluded	261 700(±23%)	130 400(±30%)	293 600(±8%)
Females on the calving ground, as counted on photos	238 200(±28%)	104 300(±34%)	252 500(±11%)
Females on calving ground, corrected for animals missed on the photos	243 100(±28%)	115 900(±35%)	260 300[a](±12%)
All females in the herd in June, including the ones outside the calving ground	379 800(±35%)	150 500(±37%)	338 000(±23%)
All females in the herd in fall, excluding calves	368 400(±36%)	144 500(±38%)	334 700(±24%)
All caribou associated with the Riviére George calving area in fall, including calves	682 100(±36%)	283 300(±39%)	643 600(±25%)

[a] Visibility rate used = 0.97 (ES = 0.02).

cision occurred when correcting for females located outside the census area, due to insufficient number of radio-tagged animals. In 1986-1988, the imprecision depended mostly on the too small number of clusters of photos taken over the calving ground; moreover, the estimation of the proportion of females outside the census area resulted in a great lost of precision. The size of the Riviére aux Feuilles herd was not estimated because the absence of radio-tagged animals in 1986 precluded estimating correction factors.

Discussion

The origin of the census technique we used is easy to trace back. Knowing that caribou aggregate on the tundra for parturition at relatively high density and in predictable areas, biologists concluded that it would be easy to census adult femals on calving grounds. However, the accumulation of data, particularly with telemetry studies, revealed that yearlings often accompany adult females there and that not all adult females are present at the same time on calving grounds. Correction factors requiring telemetry are necessary with such an approach to obtain unbiased estimates. In addition, there must be a large number of animals ($\approx$ 100) under telemetry surveillance in each herd to produce an estimate useful for management purposes, i.e. with a confidence interval of $\pm$ 20-25% (α = 0.10: Crête *et al.* 1986; Gasaway *et al.* 1986). Moreover, the field work must be conducted in June and October-November with the actual technique, to produce an estimate of the total herd size. Field work is very expensive in the North, particularly on caribou: the actual range of the Riviére George herd exceeds 600 000 km^2, which necessitates much flying time. Our 1988 census cost more that 200 000 $ and it is imperative to minimize expenses.

Caribou in all sex and age categories often aggregate by the thousands in July on the tundra. The photography of such groups also has been used to estimate herd size (Valkenburg *et al.* 1985). Radio-tagged animals are necessary to lo-

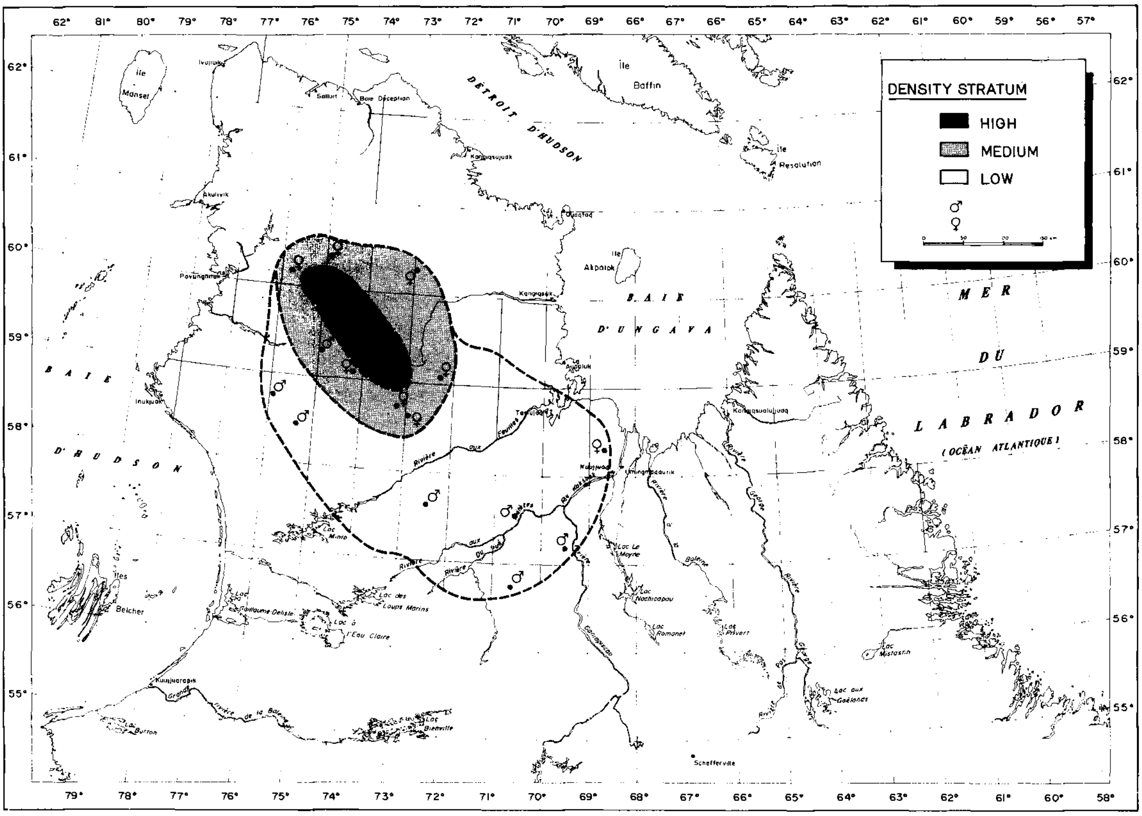

Figure 4. Distribution, according to their sex, of adult caribou from the Riviére aux Feuilles herd in early June 1988, and delineation of 3 density strata.

cate all groups in such a vast herd. This technique assumes that all animals in a census herd are photographed. This assumption is difficult to accept, particularly for a herd numbering more than half a million animals dispersed over thousands of square kilometres. Moreover, caribou do not form large groups in some years (D. Heard, pers. comm.), which complicates survey programming.

Figure 4 shows the distribution of radio-tagged caribou belonging to the Riviére aux Feuilles herd at the time of parturition in early June 1988: most females were concentrated on the calving ground, some others were in the periphery mixed with males, and many males lag behind to the south. This distribution is probably typical of that of most herds at parturition; few males have been monitored in the Riviére George area but they appeared to behave as in the other herd.

To diminish the cost and to improve the precision of herd size estimates for caribou calving on the tundra, we propose to modify the technique to eliminate the use of telemetry and to derive estimates in one step only. A reconnaissance flight, lasting a few days, should precede the census to stratify the area in three density zones (Gasaway *et al.* 1986): calving ground (high density), surrounding areas (intermediate density) and the rest of the range (low density). Caribou density would then be estimated with two-stage stratified sampling. Photos should be taken with a 35-mm camera mounted on a helicopter. The 35-mm camera possesses many advantages over the RC-5: the area covered by one photo is better adapted to caribou distribution, it is less expensive to operate, lens availability permits flights at lower altitudes which allows censuses to proceed despite low cloud ceilings, and the variety of films is greater; in particular, colour slides allow counting newborn calves. Helicopter is preferable to twin-engine fixed-wing aircraft because of its better manoeuvrability, because it is independent from airstrips and because composition counts can be done in parallel with photo census. There should be 10-30 photos per cluster and the cluster should be allocated systematically in two dimensions (Cochran 1977:227). The problems created with random sampling in 1988 with the 35-mm camera (Table 5) and the homogeneity between consecutive photographs on transect lines well illustrated the necessity to space sampling sites equally. To reach the target precision of ±20-25 percent of the estimate (Crête *et al.* 1986; Gasaway *et al.* 1986), 150 clusters of photos should suffice. If the target precision could not be reached, or if the costs were too high, the census could be restricted to the calving ground and the surrounding areas, and the estimate limited to the number of females in the herd.

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