AERIAL SURVEYS OF MOOSE POPULATIONS IN SMALL CENSUS ZONES

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ABSTRACT: We developed a simple, precise and relatively inexpensive technique to estimate moose (*Alces alces*) populations in small census zones (< 1500-2000 km^2) such as parks and wildlife reserves. A two-phase sampling plan was adopted. In phase 1, we used fixed-wing aircraft to survey the entire area using flight lines spaced 500 m apart in order to locate track networks, draw them on 1:50,000 topographic maps, and determine their area. In phase 2, a sample of the identified track networks was intensively searched by helicopter to count moose. Total population was estimated by extrapolating the mean number of moose per track network to the total number of networks counted in phase 1. We compared three approaches to estimate the mean number of moose per track network and its variance: a direct estimation using the arithmetic mean per track network, and two methods that accounted for the size of track networks (quotient and regression estimations). The regression estimation model provided the most precise estimates. A confidence interval of 20 % (α = 0.10) can be achieved by counting moose on 30 to 50 % of the track networks. This two-phase approach can reduce survey costs by 25-35 percent as compared to the usual total count previously used in small census zones.

Keywords: aerial survey, cost, quotient estimation, regression, track network, two-phase sampling, variance

RÉSUMÉ : Nous avons mis au point une technique simple, relativement peu coûteuse et précise pour estimer les populations d'orignaux dans des territoires de faible superficie (<1 500 - 2 000 km^2). Cette technique s'applique particulièrement bien pour les territoires structurés du Québec (parcs, réserves fauniques, zecs et pourvoiries) qui sont de dimension relativement faible et pour lesquels il n'existe pas de budgets récurrents. Les territoires à inventorier sont d'abord survolés totalement à l'aide de virées équidistantes de 500 m afin de localiser les réseaux de pistes et de mesurer leur superficie. Un échantillon des réseau de pistes est par la suite survolé de nouveau pour y dénombrer les orignaux. La population totale est estimée en extrapolant le nombre moyen d'orignaux par réseau de piste à l'ensemble des réseaux de pistes recensés. Nous avons comparé trois méthodes pour estimer le nombre moyen d'orignaux par réseau de piste et sa variance : une estimation directe utilisant la moyenne arithmétique et deux estimations faisant intervenir la superficie des réseaux de pistes, soit une estimation quotient et une estimation par régression. C'est ce dernier modèle qui fournit les estimations de population les plus précises. Un intervalle de confiance d'environ 20 % (α = 0,10) peut être obtenu en effectuant le dénombrement des orignaux sur 30 à 50 % des réseaux de pistes. Cette technique permet de réduire les coûts d'inventaire de 25 à 35 % par rapport aux dénombrements complets précédemment utilisés dans les petits sites d'étude.

Mots-clés: coût, échantillonnage double, estimation quotient, inventaire aérien, régression, réseaux de pistes, variance

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Aerial surveys are often the primary means of estimating total population sizes (Timmermann 1974, 1993; Gasaway and Dubois 1987), moose densities and calculating harvest rates. Many surveys are done each year but their high costs prevent greater use. In recent studies, we have estimated average investment for aerial surveys to be \$1400 per 60-km² plot (\$23.33 / km²), excluding salaries (Courtois *et al.* 1996), a cost high enough to significantly limit the use of aerial surveys. Until recently in Québec, aerial surveys were restricted to hunting zones, since the investment was justified by the high harvest rate noted in these areas. Before 1995, no specific program or standardized technique existed for smaller areas such as parks, wildlife reserves, ZECS (zones where exploitation is controlled by hunter's associations) or outfitter's areas. When a particular management need was identified, these areas were surveyed using *ad hoc* budgets and a variety of sampling strategies, usually simple random sampling over 60-km² sample plots, stratified random sampling or total counts on the entire census zone.

However, computer simulations conducted by Gingras *et al.* (1989) demonstrated that it was necessary, in the absence of effective stratification, to survey at least twenty 60-km² plots (1200 km²) to reach a 20 % confidence interval ($\alpha = 0.10$) when groups of moose were randomly distributed and densities approximated 2 moose / 10 km². A considerably higher number of plots must be surveyed at lower densities, approaching 60 plots (3600 km²) at densities of 1 moose / 10 km², typically found throughout the province (Courtois *et al.* 1994). Frequently, parks, reserves and other similar areas occupy less than 3000 km². Thus, population estimates precise enough to be used for management purposes in these sites often required total counts. This was particularly true when moose distribution in the surveyed area was not well known, preventing effective stratification.

Total counts are obviously the most reliable survey approach to use since the total moose population is determined. The primary uncertainty is the moose sightability rate. However, total counts are expensive, warranting examination of alternative survey approaches in order to reduce costs. With this goal in mind, we tested a two-phase aerial survey plan that involves locating all concentrations of moose tracks in the snow (track networks) and then intensively counting moose only in a sample of the track networks found. We compared three methods to estimate total moose population and identified the most precise one.

METHODS

Between 1985 and 1988, six aerial surveys were conducted in several hunting zones situated in different ecological areas to help ensure generalisation of our results. These zones included Aiguebelle Park (78°50'W, 48°30'N; January 1989, a coniferous - white birch forest), Forestville (69°18'W, 48°45'N) and Iberville (69°30'W, 48°40'N) ZECS (January 1989, coniferous forest dominated by balsam fir and white birch), the ZEC de la Rivière Blanche (71°50'W, 47°15'N; January 1987 and February - March 1988, mixed forest composed of balsam fir, white birch and yellow birch), the Portneuf reserve (72°20'W, 47°15'N; January - February 1985, balsam fir, white birch and yellow birch), and La Vérendrye reserve (77°10'W, 47°20'N; January 1986, mixed forest, fir and yellow birch; Crête and Jolicoeur 1987).

Surveys were conducted between mid-January and mid-February using the approach recommended by Courtois (1991). Snow cover must exceed 30 cm and the survey was suspended for 24 h after any snowfall $\geq$10 cm to allow an adequate elaboration of fresh track networks. The survey team comprised the pilot and a navigator at the front of the aircraft and two observers seated behind them. In phase 1, moose track networks visible in the snow were mapped by flying the entire census zones over north-south transects at 500 m intervals and using De Haviland Beaver single-engine airplanes or Bell 206 B helicopters flying at 160 km / h at an average altitude of 110 m above the ground (Courtois and Crête 1993). The navigator located all areas used by moose on 1:50,000 topographic maps by means of a cross every time a moose track was seen by the observers. The track networks were precisely defined at the end of each day by encircling the concentration of tracks on the maps. The area of the track networks was thereafter calculated in the laboratory using a planimeter. During phase 2, which is realised $\leq$24 h after phase 1 to prevent moose leaving the track networks identified, all or a systematic sample of the track networks were flown over again at low altitude and low speed to count and classify (adult males, adult females and calves) moose according to the method proposed by Crête and Goudreault (1980). The proportion of track networks surveyed in phase 2 depended on available budgets.

Mean moose number per track network was used to estimate total moose population size. We compared three methods to estimate the mean number of moose per track network and its variance: a direct estimation using the arithmetic mean per track network covered in phase 2 and two estimations taking into account the area of each track network, a quotient estimation and a regression estimation. Formulae originated from Cochran (1977: 153-154, 193-195). The following notation was used in equations presented below:

Y = total population of the study area

y_i = number of moose seen in phase 2 in the track network i

$\bar{y}, \bar{y}_q, \bar{y}_r$ = mean number of moose in track networks visited in phase 2 according to the direct, quotient (q) or regression (r) methods

N = number of track networks observed in phase 1

n = number of track networks sampled in phase 2

$F - n/N$ = sampling rate

x_i = total area of the track network i

$\bar{x} = \sum_{i=1}^{n} x_i / n$ = mean area of track networks sampled in phase 2

$\bar{X} = \sum_{i=1}^{N} X_i / N$ = mean area of track networks observed in phase 1

CI ($\alpha=0.10$) = confidence interval (α = 0.10)

The direct method uses the arithmetic mean to estimate the number of moose per track network and its variance. To estimate total moose population, this method postulates that the mean and its variance remain constant from one track network to the next:

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

$$v(\bar{y}) = \frac{S^2}{n}(1-f) \quad \text{where, } S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(\bar{y}_i - y)^2$$

The quotient estimation procedure assumes that the number of moose in a track network is proportional to its area. In such cases, the variance could be reduced because the covariate (area of track networks) is known:

$$\bar{y}_q = (\bar{y}/\bar{x}) * \bar{X}$$

$$v(\bar{y}_q) = \frac{S_q^2}{n}(1-f)$$

where,

$$S_q^2 = \frac{1}{n-1} \sum_{i=1}^{n} (y_i - (\bar{y}/\bar{x})\ x_i)^2$$

The regression estimation procedure relies on the same hypothesis as the quotient estimation, but the number of moose per track network and its variance are estimated using the linear regression (Rivest *et al.* 1990) of the number of moose on the area of each track network:

$$\bar{y}_r = \bar{y} + b\ (\bar{X}-\bar{x})$$

$$v\ (\bar{y}_r) = \frac{S_r^2}{n} (1-f)$$

where,

b = slope of the regression curve of y_i on x_i

$S_r^2 = \frac{1}{n-2} \sum_{i=1}^{n} (r_i - \bar{r})^2$ = MSE of the regression

r_i = residuals of the regression

$\bar{r}$ = mean residual

The total population and its variance were calculated by extrapolating estimations of the mean number of moose per track network and its variance determined in phase 2 to the total number of track networks counted in the census zone. Values were then divided by the moose sightability rate (0.73, Crête *et al.* 1986) to correct for moose present in track networks missed in phase 1 as well as for moose not found in identified track networks (Rivest *et al.* 1990).

$$Y = N * \bar{y} / 0.73$$

$$v\ (Y) = N^2 * v\ (\bar{y}) / 0.73^2$$

$$\text{CI}\ (\alpha = 0.10) = \text{Y} \pm 1.65\ \sqrt{v(Y)}$$

Population densities, standard errors and confidence intervals were obtained by dividing population parameters by the total area of the census zones. This method underestimated total variance, since the variance of the sightability rate is not considered. However this can be corrected using the methods described by Crête *et al.* (1986).

An estimation of the number of track networks that should be surveyed in phase 2 can be calculated when estimates of the mean number of moose per track network and the total number of track networks in the census zone are available (Cochran 1977:77):

$$n_{opt} = \frac{N}{\left(\frac{L * \bar{y}}{z}\right)^2 * \frac{N}{S^2} + 1}$$

where, L = confidence interval expressed in % of the mean (e.g. 0.20 for a 20 % CI), z = 1.65 at α = 0.10.

RESULTS

Area of census zones ranged from 320 to 1308 km^2 (Table 1). The total number of track networks differed (39 - 167) from one census zone to the next. Moose were counted in all track networks in La Vérendrye, Portneuf and Rivière-Blanche census zones. Sampling rates varied between 0.42 and 0.85 in the remaining three areas. The mean area of track networks ranged from 0.42 to 1.55 km^2 and its variance increased proportionally to the mean area of track networks (r = 0.80, P = 0.05). The area of the track networks was quite variable in each census zone, with the coefficient of variation ranging from 81 to 281%.

Estimations of mean number of moose per track network varied from 1.18 to 2.40 depending on the census zone and method used (Table 2). The mean number of moose per track network was not proportional to the mean area of track networks of each census zone (r = 0.15, P = 0.77) probably due to different snow and survey conditions. However, within the same census zone, we observed a significant correlation (P < 0.006) between the area of track

Table 1. Area of moose census zones, total number (N), mean area ($\overline{X}$), standard error (SE) and coefficient of variation (CV) of track networks identified in phase 1, number (n) surveyed in phase 2 and sampling rate (F), during 1985-1989, Québec.

Site	Area	Year	Phase 1				Phase 2	Sampling rate
	(km²)		N	X	SE	CV (%)	(n)	(F)
La Vérendrye[1]	1 080	1986	167	1.55	0.21	175	167	1.00
Portneuf	774	1985	72	0.42	0.04	81	72	1.00
Rivière-Blanche	729	1987-88	44	0.47	0.11	155	44	1.00
Forestville	1 308	1989	82	0.73	0.13	161	70	0.85
Iberville	438	1989	39	0.58	0.08	85	20	0.51
Aiguebelle	320	1989	121	0.47	0.12	281	51	0.42

[1]Southern part of the reserve (study site of Crête and Jolicoeur 1987)

Table 2. Comparison of three methods (direct, quotient, regression) used to estimate the mean number of moose per track network at six census zones in Québec and sampling rate required in phase 2 to obtain a confidence interval of 20 % (α = 0.10) for total moose population estimates after the regression model. $\bar{y}$ = mean number of moose per track network; S^2 = variance of the estimate; a = ordinate at the origin; b = slope of the regression; r^2 = coefficient of determination; P = significance level.

Site	Direct		Quotient		Regression						Track networks to cover in phase 2	Sampling rate at optimum intensity
	$\bar{y}$	S^2	$\bar{y}_q$	S_q^2	$\bar{y}_r$	S_r^2	a	b	r^2	P	(n_{opt})	(F_{opt})
La Vérendrye[1]	1.82	8.14	1.82	3.60	1.82	2.78	0.51	0.84	0.66	0.001	43	0.26
Portneuf	2.40	3.31	2.40	3.71	2.40	2.61	1.30	1.60	0.21	0.001	22	0.30
Rivière-Blanche	2.07	2.86	2.07	5.07	2.07	1.24	1.30	1.70	0.56	0.001	14	0.31
Forestville	2.07	3.46	1.98	4.87	2.03	1.11	1.20	1.20	0.68	0.001	15	0.18
Iberville	1.65	1.82	1.68	1.31	1.67	1.26	0.50	2.00	0.31	0.006	17	0.43
Aiguebelle	2.16	13.7	1.18	19.6	1.74	9.91	1.30	0.98	0.28	0.001	78	0.64

[1]Southern part of the reserve (study site of Crête and Jolicoeur 1987)

networks and the number of moose, using the regression models.

The regression method produced the smallest variance in the average number of moose per track network. Important differences noted in regression coefficients between each survey indicate that a specific model must be calculated for each census zone. The second most precise method was by direct estimation. It produced lower variances than that of the quotient method in four of the six census zones.

The regression method was used to estimate the total moose population at each site, as well as a density estimate and confidence interval of the estimate for each census zone (Table 3).

Populations (89 - 416 moose) and densities (1.7 - 9.0 / 10 km^2) varied greatly among census zones. In the three sites (Forestville, Iberville, Aiguebelle) that were not totally surveyed, the confidence interval (α = 0.10) varied from 3.9 to 30.2 %.

Based on the total number of track networks in each census zone, the mean number of moose per track network and its variance, we estimated that a confidence interval of $\pm$20 (α = 0.10) could be obtained by surveying between 14 and 78 track networks in phase 2, which represents sampling rates of 18 to 64 % (Table 2).

DISCUSSION

One of the primary sources of variation in moose aerial surveys is related to the distribution of animals throughout their habitats. This is particularly true in areas of low density where moose concentrate in the best available habitats thereby increasing between-plot variance in simple or stratified random sampling. The use of habitat quality to stratify survey areas often proves inadequate at low densities (< 1.5 / 10 km^2) because many good habitats remain empty, as no animal is available to occupy them. Using our approach, this sampling error is removed because census zones are totally surveyed to locate all track networks. The only source of variation in addition to sightability rate is that originating from the number of moose per track network. During January and February when moose were surveyed, the number of individuals per track network averaged 2.0-2.5 but varied between one and more than 10. Our sampling strategy gave precise estimates because a part of this source of variation was controlled, by taking into account the area of each track network, which usually correlated the number of moose that a specific track network contains (Rivest *et al* 1990). We used only linear regression because this model gave good results with other sampling techniques (Rivest *et al.* 1990).

The correlation between moose number and track network area explains the greater precision obtained with the regression method. However, no general linear model

Table 3. Moose population parameters derived from six census zones in Québec using the regression method. *Y* = population; *v* (*Y*) = population variance; CI % = confidence interval expressed in percentage of the mean. Moose densities were obtained by dividing *Y* by the area of the census zone.

Site	Total population				Corrected density	CI %
	Uncorrected		Corrected[1]		in census zone	(α=0.10)
	Y	*v*(*Y*)	*Y*	*v*(*Y*)	(moose / 10 km^2)	
La Vérendrye[2]	304	462.25	416	870.25	3.9	-
Portneuf	173	187.69	237	353.44	3.1	-
Rivière-Blanche	91	54.76	125	102.01	1.7	-
Forestville	167	15.21	229	29.16	1.7	3.9
Iberville	65	49.00	89	92.16	2.0	17.5
Aiguebelle	210	1474.56	288	2,777.29	9.0	30.2

[1] Sightability rate estimated to 0.73 (Crête *et al.* 1986).
[2] Southern part of the reserve (study site of Crête and Jolicoeur 1987)

can be used. Moose density, snow conditions, survey teams, methods used to delimit networks on survey maps, etc. change among census zones and by year making it necessary to calculate a new model for each survey. For example, the highest densities were noted in Aiguebelle Park even though this census zone had one of the smallest mean track network areas.

It was expected that the quotient method would produce more precise population estimates than the direct method because of the known relationship between the track network area and the number of moose. However, five regression models gave significant ordinates ($P \leq 0.008$), demonstrating that the regression did not pass through the origin. This probably explains the lack of gain in precision with the quotient method.

Our survey approach meets the two needs that are frequently expressed in Québec: (1) to obtain reliable population estimates for small census zones, and (2) to limit the cost of such surveys compared to the usual total count previously used in these sites. Our study indicated that it would be easy to obtain a confidence interval of ± 20 % (α = 0.10), the threshold generally accepted for this type of work (Gasaway and Dubois 1987). To achieve this objective, it would be sufficient to count moose on only one third to one half of the track networks. At moose densities of about 2.0 / 10 km^2, costs of flying over sample plots to locate track networks in phase 1 was generally similar to that necessary to count moose in phase 2, hence about 0.17 flying hour per km^2 per phase. Compared to total coverage (phase 1) and complete count (phase 2), the total coverage and partial count survey method that we propose will result in reducing survey costs by 25 % (count on 1/2 of the track networks) to 35 % (count on 1/3 of the track networks). A computer program to process these types of data has been developed to facilitate calculations (Leblanc *et al.* 1996). This software includes correction for different sightability rates of moose.

Our technique, developed in small census zones (>2000 km^2), should work on larger areas but cost would become prohibitive due to the complete coverage of the census zone with transects spaced 500 m in phase 1. To further reduce survey costs, one could examine existing survey data and maps to evaluate the proportion of track networks that would be missed by increasing spacing between flight lines during phase 1. It likely would be possible to calculate a sightability rate of the track networks in phase 1 that would depend on the distance between flight lines, mean area of track networks, depth of snow, and other meteorological conditions. A more cost effective sampling plan could then be developed if the variance due to the distance between flight lines is not very high.

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