Journal of Applied Ecology (1986) **23**, 751–761

PREDICTING AND CORRECTING HELICOPTER COUNTS OF MOOSE WITH OBSERVATIONS MADE FROM FIXED-WING AIRCRAFT IN SOUTHERN QUÉBEC

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SUMMARY

(1) During winter moose (*Alces alces* L.) aerial surveys, a crew aboard a fixed-wing aircraft flew plots initially to delineate track networks visible in the snow; immediately following, a crew in a helicopter made counts of animals associated with each track network.

(2) Two models that predict helicopter counts of moose, based on observations made only from fixed-wing aircraft, were computed by using eighty-five 60-km^2 plots covered in 1980–84 by both types of aircraft. The crude model used the overall ratio aeroplane counts : helicopter counts (0·29) to predict helicopter counts. The elaborate model was composed of three linear regressions that used aeroplane counts and percentage area covered by track networks to predict helicopter counts; the regression differed when aeroplane counts equalled 0, 1–2, or more.

(3) The elaborate model produced better predictions than the crude model: using cross-validation for seven recent aerial surveys, mean helicopter counts predicted by the elaborate model departed at worst by 23% from observed mean counts.

(4) Visibility bias was estimated with the help of radio-collared moose; 88% ($n = 59$) of the animals occupied track networks visible from fixed-wing aircraft while 83% of moose within track networks were observed during helicopter searches. Therefore, 73% of the moose were seen during early winter helicopter counts over mixed forests of Québec.

(5) All recent surveys produced imprecise density estimates because of inadequate sample size and poor stratification. Double sampling with regression, using elaborate models, is proposed in order to improve precision of estimates without increasing costs.

INTRODUCTION

The moose (*Alces alces* L.) is a very important game species throughout the boreal forest of the northern hemisphere. The recent annual harvest by sport hunters has averaged 70 000 animals in North America (Timmermann 1986). For this continent, Québec is the jurisdiction where hunting pressure is the highest (Crête 1986); more than 140 000 hunting licences were sold in 1984, and the harvest reached 11 000 animals. Consequently, harvest rates have been high in Québec, exceeding often 20% of pre-hunt populations (Crête, Taylor & Jordan 1981; Crête & Jolicoeur 1985). Moreover, moose hunting has had a significant economic impact, with expenses of Québec hunters exceeding $60 000 000.

Sound management of heavily harvested animal species requires periodic assessment of population size. Aerial census remains the most suitable technique for counting big animals

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inhabiting large areas (Caughley 1977). In Québec, moose are censused after leaf fall, when snow covers the ground. Moose habitat is characterized by dense forest canopy, frequent snowfalls and deep snow cover. The aerial census technique has been developed using intensive helicopter searches for moose over track networks that are visible in the snow; a fixed-wing aircraft precedes the helicopter to delineate track networks (Crête & St-Hilaire 1979). Censuses have been carried out in January when moose are more visible than later in winter (Lynch 1975), and within a period of 5 days of a snowfall (Bergerud & Manuel 1969; Novak & Gardner 1975). Regression analysis disclosed a significant relationship between the number of moose sighted from a fixed-wing aircraft preceding a helicopter and the number sighted from the helicopter (Crête & St-Hilaire 1979). Some recent censuses were undertaken using fixed-wing aircraft only, and regression models were employed to predict moose densities that would be obtained if the area had been searched from a helicopter (Crête & Joly 1981).

Aerial surveys of moose require sampling because this species is harvested over more than 600 000 km^2. Aerial censuses are costly, and managers must maximize the precision of their density estimates with their limited budgets. Renting single-engine fixed-wing aircraft is less than half as expensive as renting single-turbine helicopters. Regression models relating helicopter counts of moose and observations made from fixed-wing aircraft have opened the possibility of predicting density without using helicopters; this, in turn, can allow increasing the number of plots surveyed when sampling over large areas, as funds initially devoted to helicopter counts are diverted to aeroplane charters. In this paper, we examine the consistency of predicting helicopter counts of moose in southern Québec.

Aerial counts of moose, as for most large mammals, are biased, however, because some animals are not seen; the visibility bias is caused by lack of time to visually scan the entire study area and by the visual screening effect of vegetation (Caughley 1974). Eliminating visibility bias by refining techniques is improbable. Therefore, alternatives have been explored recently on different species in order to correct population or density estimates: (i) models based on differing visibility of group sizes (Cook & Martin 1974: Samuel & Pollock 1981), (ii) models based on increasing counts with longer search periods (Caughley 1974; Caughley, Sinclair & Scott-Kemmis 1976), (iii) models derived from the line–transect technique (Thompson 1979; Burnham, Anderson & Laake 1980), (iv) models based on the mark–recapture method (Rice & Harder 1977; Magnusson, Caughley & Grigg 1978; Crête 1979; Caughley & Grice 1982), and (v) correction factors computed directly from recognizable animals of known location (Floyd, Mech & Neilson 1979; Rolley & Keith 1980).

Using this last approach, we estimated visibility bias when moose censuses are carried out with combined fixed-wing aircraft and helicopters; we determined the percentage of moose that occupy track networks observed from fixed-wing aircraft and the percentage of moose seen during intensive helicopter searches of track networks.

STUDY AREA AND METHODS

Prediction models

Crête & St-Hilaire (1979) used only eight points from large (168–669 km^2) study areas to compute their regression models. For sampling, they recommended 60-km^2 plots (6 × 10 km), a size which was adopted in subsequent aerial censuses. We used eighty-five

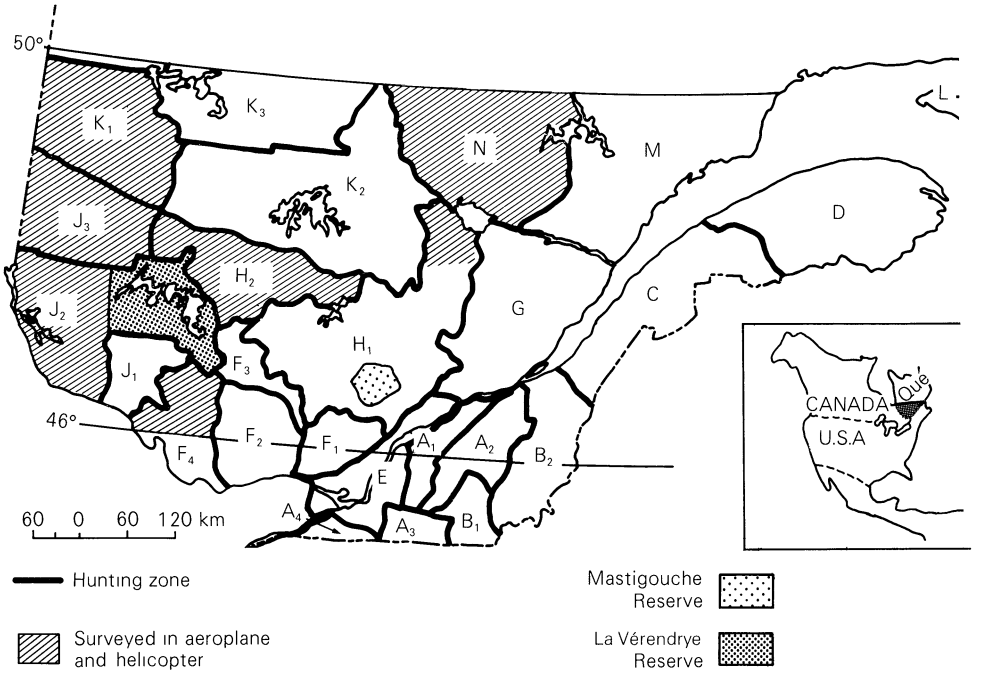

FIG. 1. Portions of southern Québec where moose aerial censuses were carried out by means of fixed-wing aircraft and helicopters in 1980–84.

60-km^2 plots covered between 1980 and 1984 by both fixed-wing aircraft and helicopters for our statistical analysis. These data originated from simple or stratified random sampling without replacement of hunting zones F4, H1, H2, J2, J3, K1 and N (Fig. 1). Plots were surveyed in accordance with Crête & St-Hilaire's (1979) guidelines.

A De Havilland Beaver was flown over each plot along twelve north–south transect lines, 500 m apart, at a mean altitude of 64–197 m. Two observers sat behind, on each side of the aircraft, reporting to the navigator the number of moose seen and the presence of fresh and old tracks visible in the snow. The navigator charted location of moose seen and delineated independent track networks during the course of the survey. Flying altitude was systematically noted approximately five times over each plot, while snow depth was measured occasionally in mixed forest stands, in the vicinity of the bases. Helicopter crew members, one navigator-observer and one observer, were then provided with maps indicating existing track networks; they flew over each track network, trying to count all moose.

Two models were considered. In the crude one, the helicopter count (HC) for a given plot was predicted by

$$HC = \hat{b}.AC$$

where AC is the aeroplane count over the same plot and $\hat{b}$, the inverse of AC/HC (i.e. the sum over the eighty-five plots in the data set of the helicopter counts divided by the sum of the aeroplane counts).

After a thorough statistical analysis of the data set, an elaborate prediction model was proposed. The equation predicting HC depended on the value of AC:

$$\text{(i) When } AC = 0: HC = \hat{b}_{01}TTN + \hat{b}_{02}TTN^2,$$
$$\text{where } TTN = \text{minimum } (7, TN).$$
$$\text{(ii) When } AC = 1,2: HC = \hat{b}_{11} + \hat{b}_{12}TTN,$$
$$\text{where } TTN = \text{minimum } (13, TN).$$
$$\text{(iii) When } AC > 2: HC = \hat{b}_{21}AC + \hat{b}_{22}TN,$$

where TN is the percentage of the plot area covered by track networks.

Weighted least squares (Draper & Smith 1981) were used to estimate the $\hat{b}$s. The weighting variable was TTN in the first two equations, and TN in the last one. The influence of snow depth and flying altitude on moose visibility was also evaluated during the course of the regression analysis.

Cross-validation (Stone 1978) served to assess the accuracy of the predictive models for the seven surveys used to compute them. For each survey, mean HC was predicted with the two models whose parameters had been estimated using data of the other six surveys.

Correction factors

Radio-collared moose were used to estimate the percentage of moose in track networks that were visible from fixed-wing aircraft and the visibility rate of moose from helicopters during intensive searches over those track networks. Studies were conducted in the La Vérendrye and Mastigouche Game Reserves in January 1982 and 1983 (Fig. 1). Experimental flights followed guidelines of Crête & St-Hilaire (1979). Fixed-wing aircraft used were a De Havilland Beaver in the La Vérendrye Reserve and a Cessna 206 in the Mastigouche Reserve; the helicopter was a Bell 206B in the former Reserve and a Hughes 500D in the latter.

Radio-equipped moose wearing collars visible from the air were first located by the navigator in the fixed-wing aircraft or by somebody else aboard an aircraft not involved in the surveys. These animals were cows with or without calves in the La Vérendrye Reserve and orphaned calves or calves with their dam in the Mastigouche Reserve. The locations of radio-collared moose were plotted on 1:50 000 topographic maps. The moose were encompassed by a 9-km^2 plot (3 × 3 km), and five north–south transect lines, spaced 500 m apart were drawn. A fixed-wing aircraft flew over each plot within 24 h of radio-location; observers told the navigator where moose tracks were seen. The navigator noted if radio-collared moose occupied one of the identified track networks by a subsequent telemetric or visual location. When the location was made by the crew navigator, observers were asked not to look at the ground during the final stage of localization. Moreover, they were told that some plots might contain no radio-tagged moose, in order to eliminate the need to find at least one track network.

Helicopter crew members were then provided with maps indicating existing track networks and were instructed to count all moose sighted within these networks. They, too, were informed that each plot could contain from zero to many collared animals. In most cases there was one collared moose per plot.

To simulate normal aerial census, eight pairs of observers and five navigator-observer teams were tested in fixed-wing aircraft and helicopters, respectively. Moreover, guidelines

prescribed by Crête & St-Hilaire (1979) were followed, except for the 5-day period after the last snowfall which had to be extended on a few occasions.

Desmeules (1965) showed that moose increase their use of dense forest canopies as winter advances. To estimate the impact of this behaviour on moose visibility, two observers aboard a De Havilland Beaver counted, on five occasions during winter of 1982, all moose they saw when flying a permanent transect located half in the south-east part of the La Vérendrye Reserve and half immediately outside. Telemetry studies indicated that moose are sedentary in this study area. In addition, the number of moose seen from fixed-wing aircraft in January and March was compared for the same season for four areas studied by Crête & St-Hilaire (1979).

RESULTS AND DISCUSSION

Prediction models

Overall, observers in fixed-wing aircraft saw 29% of moose that were counted from the helicopter ($n = 607$). Thus, the crude model for predicting HC was given by

$$HC = AC/0{\cdot}29$$

However, AC/HC ratio varied with AC (Fig. 2a); it increased from 0 when $AC = 0$ to approximately 0·5 when AC exceeded 2. For this reason, the data were divided in three when constructing the elaborate model. The behaviour of moose helps to explain the variability of AC/HC ratio. Moose visibility from an aeroplane varies, in particular with time of day (Crête & St-Hilaire 1979); moose are more visible when actively feeding than when ruminating. On the other hand, snow depth and presence of crust may incline animals to stay close to conifers. AC seems, then, more sensitive to moose behaviour than HC; helped by the presence of tracks, observers in highly manoeuvrable helicopters see animals more consistently.

Fig. 2(b, c, d) illustrates why regression analysis had to be weighted; the range of possible values for HC was proportional to TN (or TTN). For example, when $AC = TN = 0$, the helicopter did not survey the plot (Crête & St-Hilaire 1979); thus, HC equalled 0, an exact prediction. When $AC = 0$ and $TN = 1$, the possible values for HC ranged from 0 to 3, while HC could vary from 2 to 9 when $AC = 0$ and $TN = 5$.

Among the original eighty-five plots, six had $AC = TN = 0$ and bore no information with respect to developing the predictive models; however, they were used for density estimates. Moreover, five were outliers according to the Cook's D statistic (Draper & Smith 1981: p. 170) and were rejected, which left seventy-four plots for the estimation procedure. The best fits were variable (Table 1): it was a polynomial for $AC = 0$, a simple linear regression for $AC = 1, 2$, and a multiple linear regression when $AC > 2$. TN was an independent variable in all three models. When pooling all the data, a significant ($P = 0{\cdot}01$) but minor ($r = 0{\cdot}36$) correlation was detected between HC and snow depth; the inclusion of this variable did not improve our elaborate models statistically ($P = 0{\cdot}25$). In all analyses, flying altitude (range 64–197 m) had no detectable influence on visibility ($P > 0{\cdot}1$). This was surprising because visibility is generally affected by altitude (Caughley, Sinclair & Scott-Kemmis 1976). Possible explanations for the lack of precision on altitude estimates are the hilly terrain, too small a sample, failure to test a higher threshold altitude >200 m, or the overwhelming influence of other variables.

Our elaborate models yielded good fits, with R^2 values of 0·84, 0·73 and 0·94. By cross-validation they produced estimates closer to HC than the crude one in five times out

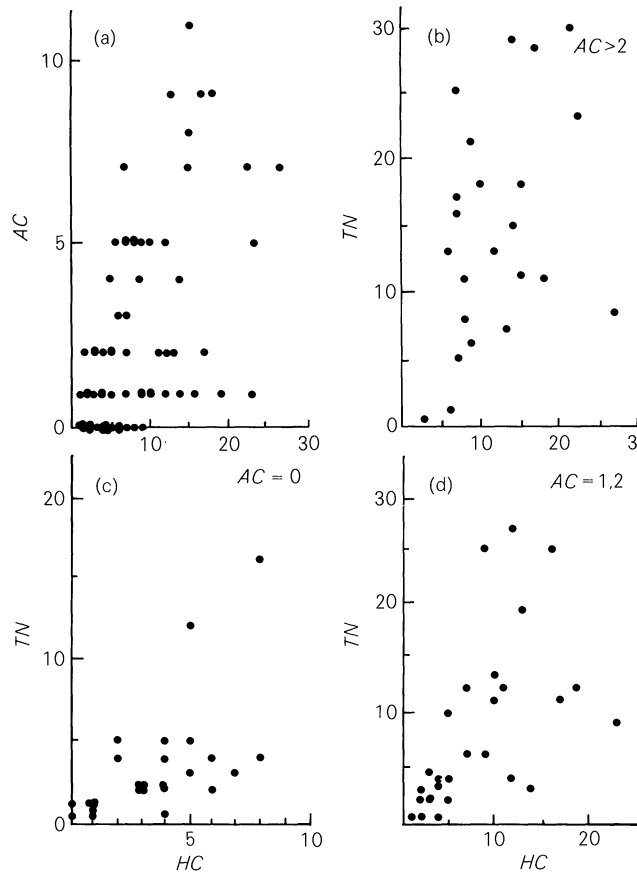

FIG. 2. Relationship between helicopter counts (*HC*) of moose over eighty-five 60-km² plots, and corresponding aeroplane counts (*AC*) or percentage plot area covered by track networks (*TN*), for seven aerial surveys of moose done between 1980 and 1984 in southern Québec.

TABLE 1. Regression models that predict helicopter counts of moose from the number of moose seen by two observers aboard a fixed-wing aircraft (*AC*) and from the percentage of the area covered by track networks (*TN*). Aeroplanes flew in a straight line at a speed of 165 km h^{-1} and at an altitude of 100–200 m above ground level. Three regressions were computed according to *AC* per 60-km² plot, the plot size actually used in Québec for moose aerial census

	Variables	Parameter estimates	Covariance matrix of the estimates	
No moose seen from aeroplane	*TTN**	1·72‡	0·073	−0·014
d.f. = 25, $R^2 = 0{\cdot}84$, $S^2 = 0{\cdot}93$	*TTN*²	−0·12¶	−0·014	0·003
1–2 moose seen from aeroplane	intercept	1·11§	0·246	−0·035
d.f. = 23, $R^2 = 0{\cdot}73$, $S^2 = 1{\cdot}50$	*TTN*†	0·92‡	0·035	0·013
>2 moose seen from aeroplane	*AC*	1·23‡	0·016	−0·006
d.f. = 20, $R^2 = 0{\cdot}94$, $S^2 = 0{\cdot}83$	*TN*	0·28‡	−0·006	0·005

* When $AC = 0$, TTN = minimum (7,*TN*).
† When $AC = 1,2$, TTN = minimum (13,*TN*).
‡ $P < 0{\cdot}0001$.
§ $P < 0{\cdot}05$.
¶ $P < 0{\cdot}06$.

TABLE 2. Uncorrected moose density [moose km^{-2} (S.E.; *n*)] obtained from helicopter counts or predicted by an elaborate and a crude model using observations made from fixed-wing aircraft, according to seven surveys carried out in January in Québec between 1980 and 1984. Cross-validation was used for predicting in the elaborate and the crude model

Hunting zone sampled	Year	Snow depth*	Helicopter count	Elaborate model estimate	Crude model estimate
F4†	1983	31	0·148(0·043§; 8)	0·146	0·161
H1†	1980	45	0·131(0·046; 7)	0·146	0·124
H2‡	1984	66	0·111(0·032; 14)	0·119	0·098
J2‡	1984	65	0·138(0·044; 16)	0·141	0·171
J3‡	1983	32	0·180(0·064; 9)	0·140	0·261
K1†	1980	52	0·074(0·028; 11)	0·057	0·072
N‡	1984	98	0·050(0·027; 19)	0·054	0·014

* As estimated in mixed forest stands.
† Simple random sampling.
‡ Stratified random sampling.
§ Estimated according to Cochran (1977) for simple or for stratified random sampling.

of seven (Table 2). The maximum departure from mean *HC* was 23% for the elaborate models as compared to 72% for the crude model. Furthermore, the elaborate models produced predictions closer to *HC* than those of the crude model in 79% of the seventy-four plots. Regression models were then superior to the crude one; they produced reasonable predictions under a wide range of snow depths during three different winters.

Correction factors

Overall, 88% ($n = 59$) of moose occupied track networks visible from fixed-wing aircraft, and the visibility rate in helicopters averaged 83% ($n = 40$). Therefore, approximately 73% of moose present in mixed forest stands of southern Québec were seen during January aerial counts (Table 3). Because of the small sample, no statistical test was performed to evaluate the influence of the study area or the year. However, scrutinizing our data set does not suggest that snow depth (1982 = 40 cm, 1983 = 25 cm) or study area influenced visibility rate. Additional plots containing no marked moose were also surveyed: sixteen with fixed-wing aircraft, eighteen with helicopters.

Because the same animals were often used to estimate both the proportion of animals occupying visible track networks and the percentage of moose seen from helicopters in

TABLE 3. Proportion of moose occupying track networks visible from fixed-wing aircraft, and visibility rate of these animals from helicopters, as determined from females and calves equipped with a visible radio collar in two areas of southwestern Québec, January 1982 and 1983

	Fixed-wing aircraft		Helicopter	
	1982	1983	1982	1983
La Vérendrye Reserve	11/12	25/28	8/10	16/18
Mastigouche Reserve	4/5	12/14	1/1	8/11
Combined proportion	0·88(0·04*; 59†)		0·83(0·06*; 40†)	

* S.E.
† *n*.

visible networks, independence of the two estimates could be doubtful. However, the comparison of the number of moose seen and missed by one or both types of aircraft ($n = 40$) indicated that there was not a tendency to miss the same animals with the two types of aircraft ($\chi^2 = 0{\cdot}18$; 1 d.f.; $0{\cdot}50 < P < 0{\cdot}75$), suggesting acceptable independence of the two estimators.

As males older than 10 months represent *c.* 15–40% of moose populations inhabiting southern Québec (Crête, Taylor & Jordan 1981), estimation of visibility rate, which was determined only with females and calves, could have been biased. But cows with and without calves behave very differently: in the La Vérendrye Game Reserve, 89% ($n = 47$) of cows with calves were observed with their calves only, while only 19% ($n = 86$) of cows without calves were solitary. When compared to males, cows without calves were similarly distributed among the three groups: alone (19%), in groups of the same sex (25%), and in mixed groups of males and females (55%) ($\chi^2 = 2{\cdot}37$; 2 d.f.; $P > 0{\cdot}25$). On the other hand, studies in Ontario suggested that females with calves are less visible from the air because they tend to search for dense conifer stands (Novack & Gardner 1975; Thompson 1979). Visibility rates of cows with and without calves were then compared. From fixed-wing aircraft, fifteen out of sixteen cows with calves occupied visible track networks, as compared to twenty out of twenty-three for females without calves. By helicopter, all twelve cows with calves were seen, whereas thirteen out of seventeen females without calves were found. We concluded that females with and without calves were similarly visible from the air and that male visibility rate was probably close to our estimates, this social group apparently behaving like cows without calves. Therefore, our correction factors may be appropriate for the entire population.

The low visibility rate of moose from helicopters illustrates the difficulty of seeing animals over mixed forests of eastern North America. Even with an intensive search of 14 min km^{-2} (S.E. = $2{\cdot}1$; $n = 35$), 17% of moose were missed. Also 12% of moose occupied track networks invisible from an aeroplane flying transect lines 500 m apart: missed networks were used by sedentary animals and were usually located in dense coniferous stands. In contrast, visibility rates in interior Alaska ranged from 85 to 100% in various habitats during early winter when flying with a fixed-wing aircraft; search intensity was only 5 min km^{-2} (W. C. Gasaway *et al.* unpublished report; Alaska Dept Fish Game 1979).

Table 4 indicates that moose visibility from fixed-wing aircraft generally decreased by half between January and late March. A reverse trend was observed in study area Z-79, but it seems attributable to the small number of animals seen, i.e. five in January and eight in March. Data collected in 1982 were insufficient for firm conclusions, but they suggested that, by mid-February, moose visibility had dropped considerably. Lynch (1975) observed the same trend in Alberta. Therefore, our estimates of visibility rate are valid only for January aerial surveys.

Improving precision of corrected density estimates

The estimation of correction factors with radio-marked moose is very expensive, although their precision could be improved by taking advantage of animals marked for other purposes. Meanwhile, we suggest that our general correction factors are applied to density estimates for all aerial censuses of moose in southern Québec. Users should also estimate the precision of corrected mean densities.

Suppose that $\bar{y}$ and $v(\bar{y})$ represent respectively an uncorrected mean density and its variance (e.g. helicopter count, Table 2). The corrected density ($\bar{y}_c$) is obtained by dividing

TABLE 4. Number of moose seen by two observers aboard a fixed-wing aircraft during repeated winter flights over the same transect lines in southern Québec

Study area	Date	Distance flown (km)	Moose seen per 100 km	Snow depth (cm)
R-78*	12 January 1978	578	2·7	65
	9 March 1978	896	1·1	67
Z-78*	12 January 1978	1 062	1·5	65
	9 March 1978	1 025	0·1	67
R-79*	12 January 1979	942	4·8	85
	22 March 1979	942	2·5	33
Z-79*	12 January 1979	1 338	0·4	85
	18 March 1979	1 057	0·8	49
La Vérendrye Reserve	7 January 1983	520	2·1	40
	20 January 1983	520	3·7	47
	10 February 1983	520	0·8	79
	3 March 1983	520	0·8	71
	16 March 1983	520	0·6	71

* From Crête & St-Hilaire (1979)

TABLE 5. Mean uncorrected and corrected moose density (moose km^{-2}), standard error of these means (S.E.) and confidence intervals (C.I.; $\alpha = 0{\cdot}10$), expressed as a percentage of the means, for seven aerial surveys carried out in January in Québec, 1980–84. The number of 60-km^2 plots necessary to achieve a target precision of $\bar{x} \pm 20\%$ ($\alpha = 0{\cdot}10$), assuming negligible sampling fraction, is also given

Hunting zone sampled	Uncorrected			Corrected			n for target precision
	$\bar{X}$	S.E.	C.I.	$\bar{X}$	S.E.	C.I.	
F4	0·148	0·043	55	0·203	0·062	58	54
H1	0·131	0·046	68	0·179	0·065	71	68
H2	0·111	0·032	51	0·152	0·046	53	93
J2	0·138	0·044	56	0·189	0·063	58	128
J3	0·180	0·064	66	0·247	0·090	68	86
K1	0·074	0·028	69	0·101	0·039	71	118
N	0·050	0·027	94	0·068	0·038	96	429

$\bar{y}$ by the correction factor $F(0{\cdot}73)$; F represents the product of the proportion of moose occupying track networks visible from fixed-wing aircraft (A) and of the visibility rate of moose from helicopters within track networks (H).

On the other hand, $V(F)$ is needed in order to estimate $V(\bar{y}_c)$. According to Mood, Graybill & Boes (1974),

$$V(F) = V(A)H^2 + A^2\,V(H) + V(A)V(H)$$

and

$$V(\bar{y}_c) = \frac{V(\bar{y})}{F^2} + \bar{y}^2 V\left(\frac{1}{F}\right) + V(\bar{y})V(1/F).$$

A and H must be independent for the first equation to be valid.

If n_A and n_H represent the number of moose used to estimate A and H respectively, $A\ n_A$ and $H\ n_H$ have binomial distributions; $V(A)$ and $V(H)$ can be estimated with the usual formula (Cochran 1977).

Lastly, the univariate delta method (Bishop, Fiendberg & Holland 1975) shows that

$$V\left(\frac{1}{F}\right) = \frac{1}{F^4} V(F).$$

These calculations, applied to results of recent surveys, did not indicate that the precision of the correction factors was the main source of variability for density estimates of moose (Table 5); they increased the confidence intervals by only 2–3%. But all density estimates were imprecise, even with stratified sampling. In fact, stratification was not highly successful in any survey. We estimated the sample size that would have been necessary to achieve a precision of $\bar{X} \pm 20\%$ ($\alpha = 0{\cdot}10$) for our seven recent surveys, assuming negligible sampling fraction (Table 5). This target precision has been proposed in Alaska for moose density estimates (W. C. Gasaway *et al.*, *op. cit.*) It would have been necessary to survey between 54 and 429 plots to reach our target precision. Samples would have to have been particularly large where density was low. Obviously, available funds do not allow for such increase in sample size.

The great variability of moose distribution still remains the most important variance component of corrected population estimates. In most recent surveys, stratification was poor and needs to be improved to achieve desired precision. Managers should be able to delineate few (2–4) but truly homogenous strata. However, better stratification will not eliminate the need for an adequate sample, which was too small in recent surveys.

The consistent relationship found between observations made from an aeroplane and a helicopter indicates another way to improve precision of density estimates without increasing costs. We found that regression models varied slightly between surveys so it would be more appropriate to develop models for each survey than to use general ones. Double sampling for regression (Cochran 1977) is an interesting approach in such a direction. During the first phase of sampling, a large number of plots would be surveyed with fixed-wing aircraft only; at the second phase, some of those plots would be searched with a helicopter. Regression models would be estimated with data obtained on plots covered by the two types of aircraft, and density would be predicted for all plots censused at the first phase. We will experiment with such an approach; in particular, we will have to determine the optimum allocation for plots to be covered by both types of aircraft, and for plots to be covered by aeroplane only.

ACKNOWLEDGMENTS

This study was successful because of the skill and prudence of pilots from Service aérien du Gouvernement du Québec, and from the following companies: Air Kipawa, Service aérien Calumet, Hélimax and Les Ailes du Nord. The personnel of Service de l'aménagement et de l'exploitation de la faune at Hull, Jonquière, and Rouyn gladly participated in the experiment. M. Thibault prepared the programs which were used for statistical computations. D. Brown and L. Orman improved the English. K. H. Pollock proposed the use of double sampling. J. Doucet, W. C. Gasaway, D. Reed and J. Tremblay carefully reviewed previous drafts of the manuscript.

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(Received 23 August 1985; revision received 26 March 1986)