QUÉBEC MOOSE AERIAL SURVEYS: METHODS TO ESTIMATE POPULATION CHARACTERISTICS AND IMPROVED SAMPLING STRATEGIES

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ABSTRACT: We present methods to estimate various parameters of moose populations using stratified random sampling and double sampling. Québec's winter moose population outside parks and reserves between 1987 and 1991 was estimated at 52,543 individuals. The confidence interval of this estimate is 4,917 moose, which represents a relative error of 9 % ($\alpha = 0.10$). Sex ratio is often imbalanced, with males representing less than 35 % of the adult segment. We noticed important regional variability in productivity. Southern populations were the most productive (> 60 calves / 100 females), whereas the western and northern ones were the least productive (28-44 calves / 100 females). We checked if a flight over the same sample plots could raise the power of statistical comparisons between two aerial surveys. We compared term to term moose densities in fifty-seven 60 km^2 sample plots, from two independent aerial surveys, spaced 3 to 6 years apart. Based on the 6 territories analyzed, the surface area of the track networks, as well as the number of moose per plot, which represent two density indicators, were not generally correlated between the two surveys. Variance component analysis, however, showed that the variance due to sample plots was between 4 and 72 % in the 6 territories under analysis. This shows that repeated survey design could be useful to detect changes in population densities between two aerial surveys.

RÉSUMÉ: Des méthodes sont décrites pour estimer divers paramètres des populations d'orignaux inventoriées par voie aérienne à l'aide de l'échantillonnage aléatoire stratifié et de l'échantillonnage double. Ainsi, la population hivernale d'orignaux du Québec, entre 1987 et 1991, a été estimée à 52 543 individus. L'intervalle de confiance de cette estimation serait de 4 917 orignaux soit une erreur relative de 9 % ($\alpha = 0,10$). Le rapport des sexes est généralement déséquilibré, les mâles représentant moins de 35 % des adultes. La productivité varie sur une base régionale. Les populations du sud du Québec sont les plus productives (> 60 faons / 100 femelles) alors que celles de l'ouest et du nord affichent les plus faibles valeurs (28-44 faons / 100 femelles). Nous avons vérifié si le survol des mêmes parcelles-échantillons pouvait accroître la puissance des tests de comparaison de deux estimations de densité. À cet effet, nous avons comparé terme à terme les densités d'orignaux dans 57 parcelles-échantillons de 60 km^2 survolées au cours de deux inventaires aériens indépendants espacés de 3 à 6 ans. Dans les six territoires analysés, la superficie des réseaux de pistes de même que le nombre d'orignaux de chaque parcelle, deux indicateurs de densité, n'étaient généralement pas corrélés entre les deux inventaires. L'analyse des composantes de la variance a toutefois montré que les différences inter-parcelles expliquaient entre 4 et 72 % de la variance. Cette analyse suggère que les changements de densité entre deux inventaires seraient possiblement plus faciles à déceler si certaines parcelles étaient inventoriées lors des deux inventaires.

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Moose is one of the main hunting resources coveted by Quebecers. To ensure a sound management of these populations, the Ministère de l'Environnement et de la Faune (MEF) initiated in 1987 an aerial survey program to complement the monitoring of populations and to better understand and predict their dynamics (Courtois 1991). The first five-year plan ended in 1991. It provided estimates for densities, total moose population, productivity, and age and sex ratios in all hunting zones where moose are present in significant numbers.

The survey results indicate that several zones are subject to a high level of harvesting. Indeed, densities are low and declining in some zones. As a result, the Ministry proposed a new hunting plan introducing a selective harvest (Ministère du Loisir, de la Chasse et de la Pêche 1993), mainly aimed at protecting cows to enhance recruitment. Computer simulations showed that the management strategy chosen might result in an annual increase of about 2 %. However, the protection of cows while maintaining the same hunting pressure on bulls might result in a greater imbalance of the sex ratio. Crête *et al.* (1981) suggested maintaining 40 % bulls in the adult population in order to maximize female productivity while the actual management plan seeks a proportion of 30 %.

It will be necessary to verify to what extent the target objectives have been attained by this management plan. Changes in total population as well as males and calves per 100 females will be the most important variables to measure. This paper presents the population status before the implementation of the plan. We made an estimate of the Québec total population and computed the variance associated with it. Methods to calculate the sex and age ratios and their variance under stratified random (Cochran 1977) and two-phase (Rivest *et al.* 1990) sampling plans are defined and results are presented. As changes could be small in some hunting zones, it will be necessary to carefully consider the survey and analysis techniques in order to detect changes, however small, in the demographic parameters of moose populations, both at the provincial and hunting zone levels. With this goal in mind, we evaluated the relevance of surveying the same plots to maximize the statistical power of density comparisons.

MATERIAL AND METHODS

The characteristics of the Québec moose population was estimated using aerial surveys conducted at the hunting zones level during the five-year plan 1987-1991 (1150 sampling plots). The Cochran (1977) procedure was used to estimate age and sex ratios of the population in each hunting zone surveyed by stratified random sampling. We used this method to develop a suitable one to calculate sex ratios under two-phase sampling. In both methods, the ratios are obtained, first of all, estimating the numerator and the denominator independently for each stratum and summing them up for the entire study area taking into account the weight of each stratum. The calculation of the global variance integrates the weighted contribution of each stratum.

When the data are collected according to a stratified random sampling plan, Cochran (1977) showed that the proportion to be estimated could be defined as follows, for the proportion of male among adults (R) taken as an example:

$$R = \frac{Y}{X}$$

where,

Y = number of males
X = number of adult moose.

We estimate this ratio by

$$\hat{R} = \frac{\sum_h N_h \bar{y}_h}{\sum_h N_h \bar{x}_h}$$

and the estimator of its variance is given by

$$V(\hat{R})=\sum_h \frac{W_h^2\,(1-f_h)}{n_h\,\bar{x}^2}\ (S_{y_h}^2+\hat{R}^2 S_{x_h}^2-2\hat{R}S_{yx_h})\ ,$$

where,

h is the number of strata,

N_h is the number of plots in stratum h,

$\bar{x}_h$ is the mean number of adults per plot in stratum h,

$\bar{y}_h$ is the mean number of males per plot in stratum h,

$f_h=\frac{n_h}{N_h}$ is the sampling rate in stratum h,

N is the total number of plots in the studied area,

$w_h=\frac{N_h}{N}$ is the weight of the h stratum,

$S_{y_h}^2$ is the sampling variance of Y in stratum h,

$S_{x_h}^2$ is the sampling variance of X in stratum h,

S_{yx_h} is the sampling covariance between Y and X in stratum h,

$\bar{x}=\frac{\sum_h N_h\,\bar{x}_h}{N}$ is an estimation of the mean number of adult moose per sampling plot.

The sampling covariance in stratum h is calculated according to the following equation:

$$S_{yx_h}=\sum_{i=1}^{n_h}\frac{(y_{hi}-\bar{y}_h)(x_{hi}-\bar{x}_h)}{n_h^{1}}$$

In two-phase sampling, additional terms should be used to take into account the probability of each plot to be surveyed in phase 2.

The estimated proportion is still defined as previously (R = Y/X). The sampling plot probability to be selected in phase 2 was defined by Rivest *et al.* (1992) as:

$$p_{hi}=\frac{Z_{hi}}{N_h\bar{Z}_h}=\frac{\gamma_{hi}}{N_h}$$

where,

$Z_{hi}=\max(TN_{hi}/\Pi_h)^{1/2}, (1/\Pi_3)^{1/2})$ if $TN_{hi}>0$ and

$Z_{hi}=0$ if $TN_{hi}=0$

and

$$\bar{Z}_h=\frac{\sum_i Z_{hi}}{n'_h}\ .$$

where,

TN_{hi} is the surface area of the track networks in plot i from stratum h,

n'_h is the number of plots sampled in phase 1 in stratum h,

$\Pi_h = n'_h/N_h$ is the sampling rate in stratum h.

The ratio and its variance can be estimated as in completely stratified random sampling if we appropriately define Y_{hi} and X_{hi} as:

$$Y_{hi}^{*}=\frac{Y_{hi}}{\gamma_{hi}}\quad\text{and}\quad X_{hi}^{*}=\frac{X_{hi}}{\gamma_{hi}}\ .$$

In such a way, the ratio becomes:

$$\hat{R}=\frac{\sum_h N_h\,\bar{y}_h^{*}}{\sum_h N_h\,\bar{x}_h^{*}}\ .$$

The estimator of its variance is then given by:

$$V(\hat{R})=\sum_h \frac{W_h^2}{n_h\,\bar{x}^{*2}}\ (S_{y_h^*}^2+\hat{R}^2 S_{x_h^*}^2-2\hat{R}S_{yx_h^*})\ ,$$

where,

n_h is the number of plots sampled in phase 2 in stratum h,

$S_{y_h^*}^2$ is the sampling variance of Y^* in stratum h,

$S_{x_h^*}^2$ is the sampling variance of X^* in stratum h,

$S_{yx_h^*}$ is the sampling variance between Y^* and X^* in stratum h,

$\bar{x}^*=\frac{\sum_h N_h\,\bar{x}_h^{*}}{N}$ is an estimation of the mean number of adult moose per sampling plot.

The above method does not consider the fact that probability of selection in phase 2 is estimated and not precisely known. However, their contribution to the estimator variance is considered negligible.

Two independent ratios can be compared using the normal approximation:

$$z = \frac{\hat{R}_1 - \hat{R}_2}{\sqrt{V(\hat{R}_1) + V(\hat{R}_2)}}$$

where,

z = the normal deviate,

$\hat{R}_1$ and $\hat{R}_2$ = the two ratios to be compared.

This approximation is valid when the number of plots flown over in phase 2 is (30).

Among the 1150 plots surveyed between 1987 and 1971, 47 were resampled during a second plan. We compared term to term moose densities in these 60 km^2 (6000 ha) sample plots flown over twice in zones 1, 2, 11, 14 and 17 (Courtois 1991), to which we added two total coverages of the Rimouski Wildlife Reserve (735 km^2) carried out in 1985 and 1988. For the purposes of our study, the reserve was divided into ten 60 km^2 plots (6 X 10 km positioned north-south) using the Mercator coordinates as plot boundaries. Population estimates in hunting zones were obtained by doing two-phase sampling (Rivest *et al.* 1990) or stratified random sampling (Cochran 1977).

The number of moose and the surface area of the track networks were both used as indices to estimate changes in moose densities. The number of moose was available for all sample plots of hunting zone 17, surveyed according to a stratified random plan (Goudreault and Lizotte 1985; Leblanc *et al.* 1993), and for the Rimouski reserve, totally covered (unpublished data). Hunting zones 1, 2, 11 and 14 (Desrosiers *et al.* 1986, 1989; Hénault 1991; Milette *et al.* 1989) were surveyed according to two-phase sampling design where moose were directly counted in only 25 to 33 % of the plots. For these surveys, we used the numbers of moose predicted by the regression models (Table 1) calculated using the Rivest *et al.* (1990) method. Moose track networks areas were available for most sample plots coming from hunting zones. For the Rimouski reserve and zone 11, only the number of moose observed was available for the calculations as track networks were not precisely delimited on survey maps.

We performed two types of analysis, a correlation analysis and a variance component analysis, to see if some statistical power could be gained by surveying the same plots when comparing the moose density of a territory between two different periods. Correlation (Pearson's r) and variance component analyses were carried out for each set of data. Prior to the analysis, the data were transformed by taking their natural logarithm ($X' = ln^{X+1}$) values to meet the homoscedasticity and additivity assumptions of parametric analyses; the X+1 values were taken because

Table 1. Regression models used to predict the number of moose (Y) according to the surface area of the track networks (X_1) and the number of moose seen during the mapping of the track networks (X_2) for the surveys carried out in double sampling.

Hunting zone	Year	Model	Source
01	1987	$Y = 0.89\ X_1 + 0.90\ X_2 + 0.32$	Desrosiers *et al.* (1987)
	1992	$Y = 0.37\ X_1 + 0.66\ X_2 + 1.22$	MLCP, unpublished
02	1986	$Y = 2.46\ X_1 + 0.29$	Desrosiers *et al.* (1986)
	1991	$Y = 2.15\ X_1 + 1.52$	MLCP, unpublished
14	1987	$Y = 0.50\ X_1 + 0.39\ X_2 + 0.66$	Milette *et al.* (1987)
	1992	$Y = 0.83\ X_1 + 0.31\ X_2 + 0.65$	MLCP, unpublished

some were small or equal to zero (Zar 1974). A 0.05 significance level was used in this study. Correlation (PROC CORR) and variance component (PROC VARCOMP) analyses were made with the help of SAS statistical software (SAS Institute 1988).

RESULTS

Estimation of Québec's moose population and harvest rates

The average level of the Québec population between 1987 and 1991 was estimated by summing the estimates made for each hunting zone (Courtois 1991). The variance of this estimated population is equal to the sum of the variances of each hunting zone as the estimates of each territory are considered independent and as the variance of a sum is equal to the sum of the variances (Mood *et al.* 1974: 178). The estimations are only approximations because surveys were not realized the same year. In spite of that, it is instructive to get a province-wide estimate to know the total herd size and eventually to compare that estimate with others made at different periods. Summing all 18 estimates indicates that Québec's winter moose population outside parks and wildlife reserves stood at approximately 52,543 ± 4,917 animals between 1987 and 1991 (Table 2), giving a relative error of about 9 % (= 0.10). Harvest was high relative to population size in most hunting zones. Harvest rate estimated as the % of the fall population removed by hunting was equal or higher than 15 % in 14 of the 18 aerial surveys conducted between 1987 and 1992.

Population characteristics estimates

Several ratios are used to examine the state of health of moose populations. Among those most often considered, one notes the percentage of bulls in the adult population as well as the number of males per 100 females and the number of calves per 100 females.

In Québec, the sex ratio seems imbalanced in favour of females in most hunting zones (Table 3). The percentage of males is generally around 30-40 % and the number of males / 100 females is less than 60 in about half of the hunting zones. The sex-ratio is the least skewed in nordic areas (zones 19 and 22; see Courtois and Crête 1993 for a map of hunting zones). Productivity is more variable on a geographical basis. Median value is about 55 calves / 100 females. Southern populations (hunting zones 1 to 7) are the most productive with 61-79 calves / 100 females in winter. In general, western and nordic hunting zones, particularily zones 10, 12, 14 and 22, support the least productive populations (28-40 calves / 100 females).

Potential efficiency of repeated survey plan

The correlation analysis (Table 4) detected significant correlations between the two surveys only for the surface area of the track networks in zone 14 (p = 0.011) and for the number of moose in zone 11 (p = 0.003). Other correlations were less than 0.57 and did not reach probabilities < 0.13. The small sample sizes (n = 7-14) made it difficult to attain the threshold value for rejecting the null hypothesis.

The proportion of the total variance due to the plots varies from territory to territory and was quite high in some cases, varying from 4 to 72 % (Table 5). Variance due to sample plots was often greater for the surface area of the tracks network, except for zone 1. This variable was probably influenced by external factors such as snow depth which can vary among plots irrespective of moose abundance. The among plot component of the variance is the one that would be eliminated if we were using the same plots when comparing two surveys. These results indicate that for some territories, repeated surveys for some sample plots would increase statistical power.

DISCUSSION

Population characteristics

Based on our Québec moose population

Table 2.Québec's moose population in winter, fall harvest and harvest rate between 1987 and 1991. $\hat{Y}$ = number of moose; $V(\hat{Y})$ = variance in the number of moose; CI% = confidence interval in % of the estimated population (α= 0.10).

Hunting zone	Year of survey	Winter population[a]			Fall[b] harvest	Harvest rate[c] (%)
		$\hat{Y}$	$V(\hat{Y})$	CI%[d]		
1	1987	802	69,839	54	444	36
2	1991	1,870	51,893	20	617	25
3-4-6	1988	617	1,780	11	511	45
7	1989	657	9,335	24	127	16
9	1989	807	5,769	16	165	17
10	1991	2,089	58,721	19	549	21
11	1990	463	7,302	30	107	19
12	1988	4,162	158,448	16	944	18
13	1989	5,333	660,484	25	1,217	19
14	1987	3,761	264,343	23	1,069	22
15	1990	3,707	146,557	17	1,169	24
16	1990	1,914	76,543	24	298	13[e]
17	1991	585	7,856	25	231	28
18 East	1989	3,355	165,378	20	660	16
18 West	1989	5,171	913,652	30	1,420	22
19	1988	7,809	1,838,882	29	724	8
20	1985	600	—	—	38	6
22	1991	8,841	4,444,444	39	751	8
Total		52,543	8,881,226	9	11,041	17

[a] Considering a visibility rate of 0.73 (Crête *et al.* 1986) except in zones 1 and 2 where it was estimated at 0.52 (Courtois 1991).

[b] Fall before aerial survey

[c] Harvest rate (%)= $\frac{\text{fall harvest}}{\text{winter population + harvest}}$ X 100

Estimating that mortality between fall and early winter is negligible

[d] $CI\% = t_{0.10(2),\infty} \cdot \frac{\sqrt{V(\hat{Y})}}{\hat{Y}} .100$ (Rivest *et al.* 1990)

[e] Underestimated due to incomplete native harvest records

estimate, densities were about 0.7 moose / 10 km^2 in winter outside parks and reserves between 1987 and 1991. The estimate is about 0.9 if we exclude the northern zone 22 which covers almost 30 % of Québec moose habitat and where density is very low. These estimations are only approximations because they come from 17 surveys realized during a period of about five years. Each population is dynamic, and it is quite probable that moose number could have changed in some hunting zones during that period. Only scarce information is available to describe historical changes at the province level. Brassard and Bouchard (1968) estimated density at 3.4 and 2.6 moose / 10 km^2 in central Québec in 1965 and 1968 respectively. Crête and Joly (1981) and Crête (1984) found 1.1-1.4 moose / 10

Table 3. Sex and age ratio of Québec's moose population in winter between 1987 and 1991. R = ratio; SE = standard error.

Hunting zone	Type of survey[a]	% adult males		Males / 100 females		Calves /100 females	
		R	SE	R	SE	R	SE
1	TPS	40.3	8.6	67.5	24.1	70.3	12.9
2	TPS	39.6	4.1	65.6	11.2	74.5	12.2
3-4-6	TPS	30.0	11.1	42.8	22.6	78.8	22.1
7	SRS	43.9	5.0	78.4	16.0	60.7	5.4
9	SRS	38.1	2.1	61.5	5.6	46.9	6.2
10	TPS	40.5	4.1	68.2	11.5	27.9	3.6
11	SRS	23.4	2.4	30.5	4.1	55.1	5.2
12	TPS	27.7	4.5	38.4	8.5	40.4	6.7
13	TPS	28.8	3.4	40.4	6.6	59.4	6.4
14	TPS	26.8	5.9	36.6	11.0	38.1	10.4
15	TPS	26.9	3.9	36.9	7.2	46.0	7.9
16	TPS	26.7	4.8	36.5	9.0	62.2	12.9
17	SRS	40.5	4.8	68.1	13.5	42.0	6.3
18 East	TPS	38.1	4.4	61.6	11.4	56.0	7.4
18 West	TPS	36.7	7.7	57.9	19.2	63.6	7.4
19	TPS	46.8	8.2	87.9	29.0	43.5	15.0
20	SRS	N/A	N/A	N/A	N/A	N/A	N/A
22	SRS	45.4	7.5	83.2	25.3	36.8	10.6
Median	-	38.1	-	61.5	-	55.1	-

[a] TPS = Two-phase sampling; SRS = Stratified random sampling.

km^2 between 1980 and 1984. Density seems to be declining but very large confidence intervals (30-40 %) in surveys conducted before 1987 as well as technical and study site changes between surveys preclude any definitive conclusion.

However, population characteristics in most hunting zones underscore the high hunting pressure. Densities are low and very far from carrying capacity that is about 20 moose / 10 km^2 in southern Québec and at least 4 / 10 km^2 north of St. Lawrence River (Crête 1987, 1989). Harvest rate of the Québec moose population reached 17 % outside parks and reserves between 1987 and 1991. This harvest rate is high if one considers that the net recruitment rate is about 20 % (Desmeules 1966). Moreover, northern populations are underharvested because of restricted access, which underscore the very high harvest rate of populations in southern zones. Hence, total harvest rate was 21 %, excluding hunting zones 19 and 22. Male percentage in the adult segment of the populations is also lower than the threshold aimed at the beginning of the five-year aerial plan (40 %; Crête *et al.* 1981).

Table 4. Correlation analyses for the surface area of the track networks and the number of moose for two consecutive surveys in the same sample plots. Data were transformed to their natural logarithms ($X' = \ln^{X+1}$).

Territory	Year of first survey	Year of second survey	n	Surface area of the track networks		Moose number	
				Pearson's r	p	Pearson's r	p
Zone 1	1987	1992	14	0.27	0.342	0.15	0.607
Zone 2	1986	1991	7	-0.55	0.201	0.57	0.179
Zone 11	1990	1994	14	-	-	0.72	0.003
Zone 14	1987	1992	14	0.66	0.011	0.42	0.137
Zone 17	1985	1991	9	0.36	0.338	-0.04	0.919
Rimouski reserve	1985	1988	14	-	-	0.51	0.130

- Data not avalaible

High harvest rates are responsible for imbalanced sex ratios. Males are more vulnerable to hunting because they are more mobile and less wary especially during the rutting period and also because hunters exhibit some selection towards males (Crête *et al.* 1981). Their harvest rates were 27-35 % in hunting zones surveyed between 1987 and 1991 while those of females were only 11-18 % (Courtois 1991).

Aerial survey data suggest that the actual imbalanced sex ratio does not lower productivity. We did not detect any significant correlation between male percentage or males / 100 females and calves / 100 females ($r < -0.15$; $p > 0.56$) in the 17 surveys we did between 1987 and 1991. Consequently, our results suggest that most sexually mature females can find a mate. Hunting seasons are late in Québec so that most adult males can reproduce before the hunting season. Low productivity noticed in western Québec was possibly due to predation (Crête and Jolicoeur 1987). In northern regions, Courtois *et al.* (1993) demonstrated that low female productivity could be related to low habitat quality. The necessity to maintain minimal male percentage in populations is obvious. But the optimum sex ratio is still to be found despite frequent debate in Europe as well as in America (Bishop and Rausch 1974, Baker 1975, Gebczynska and Raczynski 1989). The five-year aerial survey plan suggests that no lowering of productivity was detectable in Québec moose populations when about 30 % males was maintained in the adult segment of the populations while keeping moose hunting after main rutting period (27 september to 10 october; Claveau and Courtois 1992).

Survey strategies

One of the ultimate goals of every sampling strategy is to obtain unbiased and precise estimates of the parameters for each population under study. A series of factors directly influence the quality of the results. First, estimations can be biased. For example, in the case of moose aerial surveys, climatic conditions (sunlight, wind, depth of snow, etc.) during survey, the canopy closure, the landscape relief, the experience of the observers as well as animal behaviour can lead to underestimation of abundance through reduced animal visibility (LeResche and Rausch 1974; Crête *et al.* 1986; Gasaway *et al.* 1986). Secondly, estimates can be imprecise (i.e. with

Table 5. Variance component estimation for the surface area of the track networks (LOG_TN) and the number of moose per sampling plot (LOG_NB). Both variables were transformed to their natural logarithms as in table 2. Sample plots were surveyed on two occasions 3 to 6 years apart. PLOT = variance due to the plots; ERROR = residual variance; (%) = proportion of the variance relative to the total variance.

Zone	Dependent variable	n	Variance component			Variance component (%)	
			PLOT	ERROR	TOTAL	PLOT	ERROR
1	LOG_TN	28	0.0375	0.2371	0.2746	13.7	86.3
	LOG_NB	28	0.0209	0.1184	0.1393	15.0	85.0
2	LOG_TN	14	0.0477	0.0475	0.0952	50.1	49.9
	LOG_NB	14	0.0659	0.1072	0.1731	38.1	61.9
11	LOG_TN	-	-	-	-	-	-
	LOG_NB	28	0.7050	0.2685	0.9735	72.4	27.6
14	LOG_TN	28	0.2311	0.1248	0.3559	64.9	35.1
	LOG_NB	28	0.2428	0.3725	0.6153	39.5	60.5
17	LOG_TN	18	0.2629	0.4717	0.7346	35.8	64.2
	LOG_NB	18	0.0213	0.5749	0.5962	3.6	96.4
Rimouski reserve							
	LOG_TN	-	-	-	-	-	-
	LOG_NB	20	0.1718	0.1638	0.3356	51.2	48.8

large confidence intervals) because animals are not uniformly distributed, often clustered in best habitat types that support the most important food strata in the beginning of winter (Crête 1977; Crête and Jordan 1982; Pierce and Peek 1984; Joyal 1987; Gingras *et al.* 1989) or in areas where hunting pressure is less intense (Crête *et al.* 1981).

The two-phase sampling surveys carried out in Québec (Rivest *et al.* 1990), coupled with a good stratification, helped to attain acceptable degrees of precision (20 %, = 0.10) while reducing survey costs in several large zones (Courtois 1991). The use of airplanes to detect track networks allowed large sample sizes (n = 60-99) to counter high variability; costs could be maintained reasonably low and precision relatively high in limiting the use of helicopters to the count/classify phase.

In the future, Québec's moose aerial surveys must focus on two main objectives: 1) evaluate the impact of the new management plan and 2) obtain the most precise and the least biased density and population structure estimates.

The Québec management plan (Ministère du Loisir de la Chasse et de la Pêche 1993) is oriented towards the protection of females to promote population growth. To do so, the plan adopted five different hunting regimes going from no particular protection in some zones where the moose population is in good condition to the protection of all females during five years where moose is in a more precarious situation. As it is impossible to survey all hunting zones each year due to financial and logistical constraints, it will be necessary to continue to survey three or four zones each year. We suggest to place the focus on the first objective in five hunting zones, each one representative of a specific hunting regime adopted in the management plan. In all other zones we suggest to continue focusing on the second objective.

Survey strategy in representative zones

In the five representative zones, the survey strategy must permit detection of small density changes. In this respect, any technique capable of reducing sources of variation (spatial distribution of moose) not related to the factor (temporal density changes) that we wish to examine should be considered helpful. The best strategy in this case is to survey the same sample plots on all occasions (Cochran 1977: 345). However, this technique could give good results only if among-years distribution of moose wintering areas is not random. In other words, areas supporting higher moose densities must remain the best sites year after year despite the fact the overall density of the study area can change. If moose distribution inside the study areas changes from year to year, this will indicate important animal mobility which will preclude precision gain despite the use of repeated surveys.

Correlation and variance component analysis showed that this hypothesis is tenable at least in some hunting zones. Variance due to sample plots was between 4 and 72 % in the surveys analyzed. Eliminating this component of the variance using the same survey plots will diminish total variance thus increasing the possibility of detecting smaller density changes. This is especially the case in the absence of major changes in the habitat (i.e., clear cutting) or in the access to the territory (i.e., new forest roads, new hunting camps).

Flying over the same plots does not require changes in survey methods. The magnitude of change will be given by the difference between the two density estimates. One can also estimate the variance of this difference and test whether it is significant or not using the normal approximation. Depending on the data we obtain, there might be a more powerful test that could be investigated with the data at hand.

Survey strategy for other hunting zones

Repeated surveys seem also to be a good strategy for hunting zones not chosen to evaluate the impact of the management plan. However, all the plots in the surveys should not be the same to avoid any potential bias due to a non-representative sample in the first survey, this possibility existing in spite of random sampling. A good strategy could be to renew only 30 to 50 % (Cochran 1977) of the sample each time a survey is done. This means that for each survey we would choose randomly one third to one half of the plots among the sample plots surveyed during the previous survey and the rest of the sample among the other plots of the sampling area. This has to be done by stratum if a stratified sampling scheme is used. The formulae for estimating moose density using the Rivest *et al.* (1990) method and the one presented in the previous section for estimating sex and age ratios are still valid as long as the stratification does not change from one survey to the other.

If the stratification changes, the estimation must take into account the fact that the probabilities of selection of plots surveyed twice are not the same and calculations will become complex. It seems to us that experimentation without changing stratification is necessary before developing new formulae. Our experience shows that this could be done with sufficient confidence. During the first five-year aerial survey plan, we used total moose harvest for the previous five years to stratify hunting zones in a low, a medium and a high stratum before survey. This method was generally acceptable since, in most surveys, moose density was different in at least two of the three strata and increasing from the low to the high stratum (Courtois 1991). After 1991, we adapted the first stratification considering surface area of the track networks in the plots surveyed previously. This also gave good results, indicating that it could be acceptable not to redo the stratification for each survey. Québec hunting zones are wide (2,151 - 339,252 km^2, most of them being between 10,000 - 40,000 km^2) so, at this scale, moose distribution does not change importantly over a five-year period.

Renewing a part of the sample plots makes a compromise between obtaining a good estimate of moose density at one point in time and to increase the possibility of detecting small density changes between two periods. Further, if the density in plots surveyed twice is highly positively correlated between the two periods we could use data of both periods to obtain a more precise estimate for the second survey using composite estimate (Cochran 1977: 344). This technique is used when the same statistical population is sampled repeatedly and the same study variable is measured on each occasion. Note that the variable of interest can change over time. In our case, the statistical population is the total number of plots, which is the same over years, and the study variable is the number of moose in the plots. Density comparison between two surveys can be made using the normal approximation.

Management implications

The survey strategies proposed earlier seem well adapted to the problems Québec moose managers are faced with. Increasing the possibility to detect small density changes is obviously the most important point to be solved if we want to evaluate the positive impacts of protecting females during the next five years. Moreover, permanent plots offer several logistical advantages. Surveys planning as well as field operations will be substantially simplified. It would not be necessary to redo the drawing of the sample plots in the five representative zones and operation bases, accommodation sites and the location of fuel depots would already be known on most occasions. Those logistical advantages will contribute to justify this sampling scheme by reducing costs. In zones not specifically selected to evaluate the impact of the management plan, the composite estimate could be used to give more precise moose density estimates when positive correlation between two successive surveys will be high.

ACKNOWLEDGMENTS

The authors would like to thank Louis-Paul Rivest and François Pageau of the Department of Mathematics and Statistic of Université Laval for their assistance during the preparation of the specifications for this work and for suggestions to calculate the variance of the estimates. This report was prepared with the kind cooperation of the Direction des Opérations Régionales (D.G.O.R.) which provided the financial support as well as the unpublished data. We wish to thank in particular Guy Boucher, Serge Couturier, Éloi Mathieu, Jean Milette and Jean-Marc Parisé. We also thank Hélène Jolicoeur and two anonymous referees for helpful comments on the earlier versions of this paper.

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