LINEAR ANALYSIS OF FACTORS AFFECTING THE ACCURACY OF MOOSE AERIAL INVENTORIES

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ABSTRACT: Ontario has been using a standard aerial survey methodology since 1975 to estimate moose (*Alces alces*) abundance. Data have been collected on 13838 survey plots. Collection of flight and environmental conditions, in addition to the number of moose observed permits assessment of the importance of these factors to moose surveys. Calculation of multiple regression models included variables representing biological factors as well as sightability factors. Resurvey of 104 randomly selected quadrats immediately after the initial survey allowed more accurate assessment of sightability bias.

To explore the relationships between recorded variables and density of moose seen, multiple regression analysis was conducted on standard survey data. This analysis explained about 30% of the total variance in numbers of moose seen among plots. Variables were interpreted as those explaining biological and habitat factors, environmental factors, and flight condition factors. Many of the 19 variables contributed significantly to the models, although partial correlation coefficients were generally weak (r^2 ranging from 0.0002 to 0.1747). Two variables interpreted as biological and habitat factors explained a total of about 8% of the variance. The most meaningful of the sightability variables was time-on-plot, accounting for 15% of the variability, with other sightability factors explaining less than 2% of the variability. Crew size and individual crew experience were important factors affecting sightability of moose.

To calculate a linear correction coefficient, regression analysis was conducted on resurvey data from northwestern Ontario. Average sightability was 79% as estimated by the linear correction model. In this model only 5 variables were significant in accounting for 13% of the variance in survey results. The significant sightability factors were snow depth, crust, time spent on-plot during the inital survey, aircraft type, and cloud cover.

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Aerial surveys of large mammal populations are conducted in many jurisdictions and there is ample evidence that not all animals are detected by such surveys (Caughley 1974, Caughley *et al.* 1976, LeResche and Rausch 1974, Gasaway *et al* 1978, Norton-Griffiths 1976).

For moose, Gasaway *et al* (1978) report one of the highest and lowest error estimates for sightability (proportion of the true number of moose observed). In early winter 98% of their radio collared moose were seen with intensive searches while in late winter, with poor snow conditions, none of the moose were seen in spruce dominated sample units. Other authors report values between these.

Several Ontario and Quebec studies have been conducted using the technique of duplicate surveying of the same sample quadrat (Novak and Gardner 1975, Snider 1984, Crete *et al* 1986, Gollat 1988). Sightability estimates from these studies range from 0.34 to 0.94. Thompson (1979) estimated sightability on 500 m wide transects between 0.38 and 0.57 depending on the openness of the habitat.

Sightability of moose may be affected by many factors including cover conditions (Bergerud and Manual 1969, LeResche and Rausch 1974, Gasaway *et al* 1978, Thompson 1979), observer experience (LeResche and Rausch 1974, Gasaway *et al* 1978, Thompson 1979), aircraft type (Novak and Gardner 1975, Gollat 1988), snow conditions (Bergerud and Manual 1969, LeResche and Rausch 1974, Gasaway *et al* 1978), time of year (Lynch 1975, Gasaway *et al* 1978, Crete *et al* 1986), altitude (Caughley 1974) and airspeed (Caughley 1974). Pollock and Kendall (1987) present an excellent review and comparison of the techniques used to estimate the amount of bias in aerial surveys.

Ontario has been conducting aerial surveys of the moose population since the early 1950's. In 1975 a provincially standardized survey methodology was established (OMNR 1975). Although based on standard methods, Ontario's moose surveys cannot be considered uniform. Habitat and survey conditions are highly variable across the province and several different aircraft types have been used. However, the methodology specifies recording of environmental, aircraft related and other variables peripheral to the actual population assessment with the objective of assessing their impact and adjusting survey results to 'standard' conditions. This report uses multiple regression models to assess sightability bias based on 15 years of surveys.

The major problem of using environmental and flight data collected at the time of the survey to assess sightability is that there is no independent estimate of the true population on the quadrat at the time of the survey. To more accurately evaluate factors affecting sightability under normal survey conditions, duplicate surveys of randomly selected quadrats have been flown in the Northwestern Region of the Ontario Ministry of Natural Resources since 1986 (Bisset 1991). These resurveys are similar in principle to those described by Gasaway *et al* (1986). These data were also evaluated using a multiple regression model.

The purpose of this paper is to evaluate sightability factors contributing to components of variability in the observed density of moose (as estimated from standard survey data), and to estimate a linear correction model from analysis of the number of missed moose in resurvey data.

METHODS

Standard Population Survey Techniques

Standard moose population inventories in Ontario are quadrat surveys using either simple or stratified random plots selected without replacement. These surveys are conducted within Wildlife Management Units (WMUs) normally between December and February. An effort is made to survey each WMU at least every three years, although weather and funding may preclude this.

The objective of the surveys is to count all moose within 2.5 kilometre by 10 kilometre quadrats. Guidelines recommend that a minimum of four transects be flown at altitudes of 100 to 200 m (330 to 660 ft) above ground within each quadrat. This pattern is believed to give complete coverage of the quadrat with visual overlap from one line to another. Transect lines are used only as a means of systematically covering the plot and additional lines may be used where habitat conditions required greater search effort. When fresh moose tracks are observed they are circled to count all moose associated with the tracks. If, in the opinion of the crew, moose associated with the tracks are on the quadrat but not seen a "missed aggregate" is recorded.

Additional information is recorded for crew experience, flight conditions (aircraft type, altitude, airspeed, start and stop time), and survey conditions (hours since snow, crust, temperature, and cloud). The codes for crew experience changed in 1981 from 'years of experience' to 'hours flown in the last five years'. Because 'experience' is measured roughly as 'time in a plane', the relative values of the two coding structures was likely the same and they were used as if they were one.

Resurvey Techniques

Since 1986, about 10% of sample quadrats in the Ministry of Natural Resources Northwestern Region have been randomly selected for resurvey. An impartial person subsampled the quadrats from those selected for survey and prepared an envelope for each quadrat with a note inside to either "refly" or "continue". After completion of each quadrat the crew opened the envelope and took the appropriate action.

The objective of the resurvey flight was to use all information obtained on the original survey (tracks, groups, age and sex characteristics, etc) to determine the number of moose missed. The resurvey recorded the number of moose observed on the quadrat during both surveys, excluding moose known to have moved onto the quadrat after the original survey. Aircrews were asked to note if moose were observed moving on or off the quadrat between surveys. All surveys were completed with four place fixed or rotary wing aircraft.

Statistical Techniques

Standard aerial survey data and resurvey data were converted into two SAS[1] data sets consisting of 13,954 records and 122 records, respectively. Several continuous variables were reclassified into workable groups. Time-on-plot was grouped into 10 minute periods, temperature into 10°C classes, date into two week periods, altitude into 25 m intervals and speed into 20 km/hr classes. Although it would have been preferable to work with continuous rather than grouped data, this grouping was done primarily to deal with inconsistencies in data recording over the 12 years, and probably closely represents the precision of the raw data.

Three multiple linear regression models were calculated using the SAS procedure REG; the STEPWISE option was used for analysis of the standard survey data, and the MAXR option for the resurvey data. The STEPWISE option performs a forward stepwise regression that re-evaluates the F statistics for all variables already included in the model; at each each step it drops any variable which no longer has a value equal or greater to the specifed threshold (in this study, 0.15). The MAXR option results in the best 1, 2, 3, etc. variable model. Although the MAXR approach is in some ways superior to the STEPWISE approach, it is computationally more intensive.

Multi-collinearity among regressors was analysed by decomposing the variance estimates with respect to each eigenvalue, and by estimating variance inflation factors for each regressor (regressions of each variable on all other variables in the model). The general form of the models were:

$$Y = \mathrm{WMURANK} + \mathrm{YR} + \mathrm{STRAT} + \mathrm{PI} + \mathrm{NA} + \mathrm{LO} + \mathrm{RO} + \mathrm{CRAFT} + \mathrm{HGTCLASS} + \mathrm{SPEEDCLASS} + \mathrm{ORDER} + \mathrm{ON\_TM} + \mathrm{TIMECLASS} + \mathrm{TEMPCLASS} + \mathrm{DATECLASS} + \mathrm{CLOUD} + \mathrm{HSS} + \mathrm{CRUST} + \mathrm{DEPTH} + \mathrm{ERROR}$$

where explanation of the dependent variables is as presented in Table 1.

For the resurvey data the continuous dependent variable (Y') was sightability, calculated as:

$$Y = N_s / N_r \qquad (1),$$

and, $$Y' = \mathrm{arcsine}(Y) \qquad (2)$$

where N_r is the sum of moose observed in both the initial standard survey and additional moose observed in the reflight survey, and N_s is the number of moose observed in the initial standard survey, and with the following conditions: if $N_r = 0$, then the record was deleted, but if $N_s = 0$ and $N_r \neq 0$, then $Y = 0$.

The arcsine transformation of sightability was used since a proportional estimate would be expected to follow a binomial distribution (Zar 1984). Based on exploratory analysis, the square root transformation of count data was judged inappropriate.

The continuous dependent variable for standard survey data was the number of moose observed per plot (i.e., N_s). Two variations of this model were calculated to identify the importance of the survey crew. In the first model CREWSIZE was used to assess differences related to the number of potential observers. In the second model, experience of the pilot (PI), navigator (NA), and left and right observers (LO & RO) replaced

Table 1. Description of variables used in the multiple regression models of sightability of moose during aerial surveys.

CONTINUOUS DEPENDENT VARIABLES:	
No. of moose seen on quadrat (used for standard survey data)	TOT
Arcsine transformation of percent moose seen on plot (used for resurvey data)	ARCSEEN
CONTINUOUS INDEPENDENT VARIABLES:	
SIGHTABILITY FACTORS:	
Flight Conditions:	
Pilot experience (5 groups)	PI
Left observer experience (5 groups)	LO
Navigator experience (5 groups)	NA
Right observer experience (5 groups)	RO
Crew size (3 groups = 2,3,4)	CREWSIZE
Aircraft type (1 = helicopter, 2 = airplane)	CRAFT
Aircraft altitude (7 groups)	HGTCLASS
Speed of the aircraft (8 groups)	SPEEDCLA
Order plot was flown	ORDER
Start time	ONTM
Time-on-plot	TIMECLAS
Date of survey (9 two week groups)	DATECLAS
Environmental Conditions:	
Temperature (7 groups)	TEMPCLAS
Cloud cover (5 classes, 1 = bright, 5 = heavy overcast)	CLOUD
Hrs. since last snowfall (6 classes)	HSS
Snow crust (3 groups, 1 = heavy, 3 = no crust)	CRUST
Snow depth (6 groups)	DEPTH
INDEX OF BIOLOGICAL AND HABITAT FACTORS:	
Stratum (4 groups, 1 = highest)	STRAT
Year of survey	YR
Population density (7 groups)	WMURNK

CREWSIZE to assess the impact of individual crew members and their experience. The models have to be stated separately because for crews less than four, crew experience would be a missing variable for one or more crew members, and these records would have been excluded from analysis.

The models may be interpreted as:

Number of moose per quadrat = Biological & habitat quality factors + sightability factors + unaccounted factors.

Sightability factors may be considered as having two components: 1) environmental conditions (temperature, cloud cover, hours since last snowfall, snow crust conditions, and snow depth) and 2) flight conditions (aircraft type, altitude and speed, and crew experience, crew size, start time, date of the survey, and time spent on the plot). A third sightability component, habitat cover, was not included. Both forest canopy closure and species composition might affect sightability, and this component of variance in sightability is not accounted for in the study.

Biological and habitat quality factors were not measured explicitly, but population density would be expected to increase as various biological and habitat factors became more favourable. To account for such differences in habitat quality and population size across the province, the average population densities for each wildlife management unit (WMU) over the 15 years were ranked and the rank (WMURNK) included as a variable. WMUs stratify the province into areas each with roughly similar habitat suitability for moose or deer. Within each WMU the habitat is further stratified based on expected densities of moose; thus stratum (STRAT) was included as an indicator of relative population density and habitat quality within the WMU. Provincial moose populations have been generally increasing over the period of the surveys included in the analysis, thus year of the survey (YR) was included to account for the possible effect of population density on sightability. It is recognized that these indices are crude estimators of the factors they represent, but they are the only ones available which are measured in relation to population surveys and which apply to the entire survey area.

An alpha level of $p < 0.15$ was the minimum threshold for inclusion of an individual variable into the multiple regression model. The overall model was considered significant only if $p < 0.05$.

RESULTS

Standard Survey

Standard survey data was analysed by multiple regression to explore relationships between number of moose seen per plot and various environmental and flight condition factors. Once having accounted for habitat and biological factors (i.e., WMU and stratum), then the remaining variance in plot density may be related, in part, to environmental and flight condition factors. Collinearity occurred only among the aircraft height and speed variables, so aircraft speed was removed from the analysis. No evident trends were detected in the residual plots to suggest model specification for the standard survey analysis was incorrect.

Two models were expressed, one with crewsize included among the dependent variables, and the other with individual crew experience included as variables. The latter expression only considered crews with four members present (pilot, navigator, right observer and left observer), while the former expression considered crews of all possible sizes.

With CREWSIZE as a variable, the model explained 29% of the total variability in number of moose per quadrat. Twelve of the 15 variables were significant (Table 2). When CREWSIZE was replaced by individual crew experience (PI, NA, LO, RO), the model explained 32% of the variance, and 14 of the 18 variables were significant (Table 3).

The importance of the variables were essentially the same in both models although some minor differences occurred. In each case the partial correlation coefficients (r^2 values) were weak, ranging from 0.0002 to 0.1747, but were highly significant because of the very large sample size.

In both models the two variables representative of biological and habitat related factors (WMURNK and STRAT) account for about 8% of the total variability, or 25% of the explained variability. Sightability factors accounted for approximately 22%, leaving about 70% of the variability unexplained. This remaining variance in density among plots is a function of factors not adequately accounted for by the included biological and sightability variables. These might include hunting pressure, predation, habitat suitability, and canopy cover. With such high unexplained variance, the relative importance of the sightability variables are perhaps more instructive than their magnitude.

Time spent on the plot was by far the most important of the sightability variables ($r^2 = 0.1470$ and 0.1747 for the respective models).

Table 2. Analysis of standard survey data, with crewsize included as an independent variable. Statistics are those generated during the stepwise multiple regression procedure (stepwise partial r^2 and cumulative model R^2), and statistics of the final model (partial regression coefficients, variable significance, and squared partial correlation coefficients). The partial r^2 in column 5 represents the amount of variation accounted for by the variable, holding the influence of all other variables constant. Dependent variable is total number of moose seen per quadrat. $N = 13838$, model $R^2 = 0.29$, and model prob > $F = 0.0001$.

	Stepwise r^2	Model R^2	Slope	Prob>F	Partial r^2
Intercept			-2.325	0.0001	
Time-on-plot	0.1913	0.1913	0.140	0.0000	0.1470
WMU Population density	0.0540	0.2453	0.701	0.0001	0.0640
Stratum within WMU	0.0170	0.2623	-0.928	0.0001	0.0220
Altitude class	0.0088	0.2758	-0.001	0.0001	0.0129
Crew size	0.0123	0.2849	0.998	0.0001	0.0122
Order quadrat flown	0.0026	0.2873	0.025	0.0001	0.0037
Cloud cover	0.0021	0.2894	0.260	0.0001	0.0034
Date of flight	0.0020	0.2913	-0.237	0.0001	0.0031
Snow depth	0.0014	0.2925	-0.272	0.0001	0.0025
Hours since snow	0.0012	0.2941	-0.112	0.0001	0.0016
Aircraft type	0.0004	0.2952	0.378	0.0030	0.0006
Snow crust	0.0004	0.2956	-0.156	0.0045	0.0006
Year of survey	not significant				
Temperature	not significant				
Start time	not significant				

Table 3. Analysis of standard survey data, with indivdual observer experience included as independent variables. Statistics are those generated during the stepwise multiple regression procedure, and for the final model. See Table 2 for explanation of variables. Dependent variable is total number of moose seen per quadrat. $N = 12139$, model $R^2 = 0.32$, and model prob > $F = 0.0001$.

	Stepwise r^2	Model R^2	Slope	Prob>F	Partial r^2
Intercept			-0.302		
Time-on-plot	0.2067	0.2067	0.156	0.0000	0.1747
WMU Population density	0.0578	0.2645	0.683	0.0001	0.0606
Pilot experience	0.0160	0.2805	0.253	0.0001	0.0006
Stratum within WMU	0.0138	0.2943	-0.858	0.0001	0.0195
Altitude class	0.0094	0.3037	-0.011	0.0001	0.0082
Right obs experience	0.0029	0.3067	0.151	0.0001	0.0022
Order quadrat flown	0.0025	0.3091	0.150	0.0001	0.0035
Snow depth	0.0022	0.3114	-0.321	0.0001	0.0037
Date of flight	0.0019	0.3133	-0.214	0.0001	0.0022
Cloud cover	0.0012	0.3145	0.217	0.0001	0.0025
Hours since snow	0.0012	0.3157	-0.115	0.0001	0.0017
Left obs experience	0.0006	0.3162	0.087	0.0025	0.0008
Navigator experience	0.0003	0.3165	0.063	0.0340	0.0004
Snow crust	0.0001	0.3166	-0.088	0.1165	0.0002
Year of survey	not significant				
Aircraft type	not significant				
Temperature	not significant				
Start time	not significant				

This is about 45% of the total explained variance. Time-on-plot has a positive effect on moose observed and may have the strongest effect because the more moose on the plot, the more time is spent searching. An alternative explanation is that when more time is spent searching, more moose are seen. Time-on-plot is significant in the resurvey study (see next section), and this suggests, at least to some degree, that greater search effort results in more moose being seen.

Crew characteristics are relatively important. Both the size of the crew and the crew experience are significant positive factors and account for about 1% of the total variance. The pilot appears to be the most important member of the crew and ranks second in importance among the sightability variables.

Other variables had slightly different orders of importance between the models but their importance to the model (i.e.partial correlation and regression coefficients) were similar. Several other flight condition factors were significant including, date, order the plot was flown, aircraft type and altitude. These factors accounted for another 2% of total variability or 7% of the explained variability. Date and altitude are negative factors, but order and aircraft type are positive. There is no obvious reason to expect that more plots per day should enhance the ability to observe moose, although light conditions do change with order of the plot.

Aircraft type is significant in the first model which included crew size but not in the model which included individual crew experience. This difference may be explained by the way data is used within the models. Each analysis considers only those records which are complete in all respects. The model using crew size included all records and detected apparent differences between aircraft types. Only four passenger aircraft are included with crew experience, and no difference between helicopters and planes are apparent.

These results suggest that the use of two and four place helicopters is, on average, less effective than the use of four passenger fixed wing aircraft, but that four place rotary and fixed wing aircraft are equal.

Four environmental factors: snow depth, crust, sky condition, and hours since snow, were significant. These explained 0.8% of the total variation or 2.8% of the explained variation. Snow depth and hours since snow are negative factors as expected, because they cause moose to move into cover, and reduce the ability to use track aggregates to find moose. Sightability improves as sky conditions become more overcast. This is not an expected result because moose tracks show up better under bright conditions and therefore overall sightability should increase on bright days. However, under bright conditions there is strong visual contrast and pattern in the forest. Dark moose may be harder to detect than on dull days when pattern and contrast is less.

Opposite of what was expected, lower snow crust was associated with lower moose densities (note that 1 is high crust, and 3 is low crust). This may result because many areas of the province are not subject to extensive crusting conditions during the normal survey period, or because of unexpected movement activity associated with crusting. Areas with the greatest frequency of hard crusts (Northeastern and Algonquin Regions) also have higher moose densities within the surveyed area than other Regions.

Resurvey Data

Analysis of the resurvey data by multiple regression was done to derive a simple linear model to predict the number of moose that would have been seen if a resurvey had been done on every plot. Our estimate of the true number of moose, N_r, is based entirely on the sum of moose seen in the initial survey, and those additional moose seen on the resurvey flight. The accuracy of this estimate is limited by the inherent assumptions of such data, such as no unaccounted movement of animals on or off the plot.

Moderate collinearity occurred among aircraft speed and aircraft type, and subsequently among statum and navigator, so aircraft speed and stratum was removed from the analysis. Analysis of standardized (Student) residuals was conducted for analysis of outliers, and this lead to the removal of three observations. Plots of residuals against predicted values was conducted for analysis of model specification, and this revealed some "bounding" of the residuals, probably as a result of the arcsine transformation. Several alternative models were investivated, but all were less satisfactory. Further analysis of model specification is probably warranted in future studies. The best model in terms of significance of the F value, incremental increase in total explained variance, and significance of indivdual variables in the model was the 5 variable model, which included cloud cover, time- on-plot, snow crust, snow depth, and aircraft type.

Resurvey data have only been collected in the Northwestern Region. One hundred and twenty-two plots have been resurveyed. Of these 18 plots had no moose and were excluded from the analysis, and an additional three were excluded due to abnormally high residuals, leaving a sample of 101 plots. Surveys in this region use a minimum of five transect lines 500 m apart. The outer lines are placed 250 m inside the plot boundaries so that both observers participate. While this might increase errors at the quadrat edge it also allows more effective coverage of the interior. All observations were made with a crew of four. For these reasons they differ from standard data and may not be representative of the province.

The original surveys were conducted in an average of 30.2 ± 8.14 minutes or 1.2 minutes/km^2 (3.1 minutes/mi^2). Survey times per quadrat ranged from 13 to 56 minutes. Total survey time for the original flight and the resurvey averaged 58.0 ± 17.2 minutes (2.3 min/km^2, 6.0 min/mi^2) per quadrat and ranged from 23 to 110 minutes.

Taken at face value an average of 5.73 ± 5.49 moose were seen per quadrat on the initial survey and 6.84 ± 6.16 moose were seen on the resurveys. An average of 1.11 ± 1.51 moose were missed per plot resulting in an observed sightability of 0.84 ± 0.24%. This sightability is generally greater than many others reported for moose.

The regression model explained 13% of the variation with 5 significant variables (Table 4). Snow depth was the most important factor and explained 7.8% of the variability. Snow depth negatively affect sightability. As snow depth increases moose may move into denser cover, making them more difficult to see (Lynch 1975, Karns 1982, Crete *et al* 1986), or because accumulation of snow on trees decreases visibility. Similar to the standard survey, crust conditions and cloud cover were

Table 4. Partial correlation coefficients (r^2), regression (slope) coefficients, and significance (prob > F) for selected variables associated with resurvey data. The model represents the best 5 variable model. Dependent variable is the arcsine transformation of the percent moose seen per quadrat. N = 101, model R^2=0.13, model prob>F=0.0197.

	Partial r^2	Slope	Prob>F
Intercept		0.9544	0.060
Depth of snow	0.0756	-0.2356	0.053
Snow crust	0.0688	-0.2129	0.024
Time-on-plot	0.0600	0.0183	0.016
Aircraft type	0.0378	0.3170	0.057
Cloud cover	0.0154	0.0483	0.225

associated with fewer missed moose.

Time spent on-plot (during the initial survey), and aircraft type were the other significant factors, accounting for 6 and 4% of the variability, respectively. As more time was spent on-plot during the initial survey, fewer moose were missed. Similar to the standard survey analysis, fixed wing aircraft are associated with better observations.

The estimated multiple regression correction model is:

$$Y' = -0.04829*\mathrm{CLOUD} + 0.01825*\mathrm{TIMECLAS} - 0.21290*\mathrm{CRUST} - 0.23360*\mathrm{DEPTH} + 0.31700*\mathrm{CRAFT} + 0.9544$$

where Y' is defined in equation 2. The corrected number of moose is based on the back-transformation of Y', i.e.,

$$N_c = N_u/\mathrm{sine}\ Y',$$

where N_c and N_u are the corrected and uncorrected estimates, respectively, of moose seen.

When this correction model is applied to data for the Northwestern Region the corrected number of moose per plot is 5.81 ±5.96, up 20.9% from the uncorrected estimate of 4.59 ± 5.96 moose per plot. Using this technique, sightability is estimated at 0.79.

DISCUSSION

The multiple regression analyses of standard and reflight data take conceptually different approaches to understanding the influence of environmental and flight condition factors on sightability. In one respect, the analysis of the standard survey data is weaker than that of the reflight data because we don't have an estimate of the number of moose missed on the ground, and thus cannot derive a linear correction model from this data. In another respect, though, the analysis of the standard data is stronger because of the much larger sample size (13,838 standard plots vs. 104 resurvey plots), and broader range of conditions the data set encompasses; thus it provides a better picture of the conditions associated with more or less moose seen on a plot.

Although sightability can be estimated by resurveying sample units at greater intensity, it can be assumed that some moose are still missed and should optimally be compensated for by an experimentally derived correction factor for a given set of conditions (Gasaway *et al* 1986). Elaborate (and expensive) techniques are available to correct observed estimates more precisely and accurately toward the real population. A number of studies have been done in this regard (Cook and Martin 1974, Cook and Jacobson 1978, Cook and Jacobson 1979, Gasaway *et al* 1986).

Sightability presented in this study considers only sightability relative to the number of moose determined by resurvey. When search effort was doubled a 16% improvement was made in sightability. Theoretically doubling effort would only gain an additional 2.5% improvement. Gasaway *et al* (1986, p.23) present a graph showing improvement in numbers of moose seen with increased search effort. When effort exceeds about 6 min/mi^2 (with a crew of 2) numbers of moose seen become largely asymptotic.

While the techniques for resurvey follow the principles described by Gasaway *et al* (1986), they differ in implementation primarily in that the entire sample unit was resurveyed, not every sample unit in the medium and high stratum were resurveyed, four place aircraft were used and the flight time was not as intense as the 12 min/mi^2 (4.6 min/km^2) recommended. In spite of this, we consider the technique essentially comparable.

Average observed densities in Ontario are normally below 0.39 moose/km^2 (1 moose/mi^2), a point below which Gasaway *et al* (1986) consider it economically unfeasible to resurvey. Because of this and the probability that moose are more uniformly distributed than those in Alaska, our method is more consistent with their recommendations for determining sightability in surveys of low density moose populations. A subsample of survey units was selected and the entire quadrat was resurveyed to reduced the number of zero observations and permit direct comparison of factors which affected sightability during the original survey.

Similarly, because our surveys were undertaken with a crew of four, it did not seem necessary to spend 12 min/mi^2 (4.6 min/km^2) on resurveys. As noted earlier, the size of the survey crew appears to play a significant and relatively important role in sightability. The survey design advocated by Gasaway *et al* (1986) is predicated on a crew with one pilot and one observer and an observation time of 4.6 min/km^2 (12 min/mi^2) over a 5 km^2 (2 mi^2) sample unit. This would equate to 9.2 person min/km^2 of potential observation time if both of the pilot and observer used the entire flight time to look for moose. However, some of this potential time is lost to flying, navigating and recording observations. If, for example, half of one persons time (2.3 min/km^2) was spent on these activities then the actual observation time would be 6.9 person min/mi^2. Our total flight time on resurveyed plots averaged 2.3 min/km^2. This also offered a potential of 9.2 person min/km^2, equal to that recommended by Gasaway *et al* (1986). If half of one persons time (1.2 min/km^2) was spent managing the flight then actual observation time would be 8.0 min/km^2. Even if the entire time of one crew member was not used for observation, actual observation time would, in all probability, still equal that recommended.

Observed sightability was estimated at 0.84 ± 0.24% by simple comparison of initial and resurvey data and 0.79 by the linear correction model. This sightability is generally greater than many others reported for moose. There are several possible reasons for this.

A number of the studies on sightability used single observer aircraft. LeResche and Rausch (1974) reported sightability on the Kenai Peninsula of Alaska in the range of 0.43 to 0.86. Their study was conducted with single observers estimating penned moose populations between 7 to 49 moose/mi^2 (2.7 and 19.1 moose/km^2). The pilot did not generally act as an observer. Except under ideal snow conditions it would be unlikely, at these densities, that tracks could be used to enhance sightability. By including the observations of the pilot the sightability increased by 0.04 to 0.21 (average 0.057). Similarly, Bergerud and Manual (1969) noted that the pilot observed about half the moose. A crew of four should increase sightability even more.

Gasaway *et al* (1978) reported sightability in normal surveys in Alaska at 0.33 to 1.00 with a crew of two flying transects 0.5 mi (800 m) wide to cover the sample unit. Thompson (1979) estimated sightability from a two seat aircraft at between 0.38 and 0.57 on a 500 m wide transect survey in Ontario. He also observed that greater numbers of moose were seen on the right side of the aircraft. Because there is no reason to anticipate that moose are normally distributed in this manner, his observations likely support the conclusion that one observer cannot look out both sides of an aircraft at the same time. This deficiency probably contributes to increased sightability bias in studies using a crew of two.

Thompson (1979) and Dalton (1990) demonstrated the existence of a "blind spot" beneath the aircraft. This phenomenon would be expected to exist with "straight and level" flight, but it should largely disappear when tracks are evident and circling is used to locate animals. A tendency to include animals at the edge of the survey area (Siniff and Skoog 1964) might compensate for those missed, although Thompson (1981) observed that an inexperienced observer consistently recorded moose near the boundary as off the transect.

A number of the studies (LeResche and Rausch 1974, Novak and Gardner 1975, Novak 1981, Gollat 1988) included surveys done in late February and March. This is a time when moose are generally considered to be less visible because they move into dense cover (Lynch 1975, Gasaway *et al* 1978, Novak 1981, Karns 1982, Crete *et al* 1986) and is not recommended for surveys (Karns 1982, Gasaway *et al* 1986). Resurvey flights in our study were completed between December 15 and February 9. This time period corresponds to early winter at this latitude when sightability should be greatest (Gasaway *et al,* 1986).

Spacing of lines for the search pattern may affect sightability. Nearly all reported studies used a search pattern for flights at 500 m or greater and altitudes of 64 m to 200 m above ground. Original flights in this study were conducted at 500 m intervals from an average altitude of 155 m. Changing the pattern to 250 m by addition of lines in the resurvey resulted in more moose being observed. Thompson (1979) observed a decrease in number of moose seen toward the edge of the transect and our experience with resurveys is that many of the missed moose are located midway between the transect lines within quadrats. A more intensive search pattern should be used if a reasonably high level of accuracy is desired. By increasing the intensity of coverage, search time will increase with substantial improvement in sightability.

Several Ontario studies have used the technique of duplicate sampling of the same quadrat. Sightability has been reported at 0.94 and 0.96 (Novak and Gardner 1975), 0.35 - 0.41 (Snider 1984) and 0.44 - 0.78 (Gollat 1988). In these studies the first observation was made by one crew and the second observation was made, usually at some later time, by a different crew often using a helicopter. The studies assume either that one observation is "correct" and the other "biased" (Novak and Gardner 1975, Novak 1981), or that both are biased and that the real population is some combination of the two surveys (Snider 1984, Gollat 1988).

Although there is some theoretical basis behind these types of survey using a Petersen (Marked Recapture) Index (Rice and Harder 1977, Magnusson *et al* 1978,, Pollock and Kendall 1987), such studies may be of limited value because of logistic problems. Determining bias requires that mapping of observations are independent and simultaneous (Pollock and Kendall 1987). While efforts were made by the second crew to track aggregates reported by the first, there is no certainty that animals are either 'marked' or 'recaptured' as required by the technique. Pollock and Kendall (1987, p. 503) conclude that "this method is unlikely to be useful for moving animals because of the impossibility of the exact mapping requirements".

Reported differences in sightability (Novak and Gardner 1975, Snider 1984, Gollat 1988) in Ontario studies may also be attributed to other factors such as differences in observers, aircraft or time-on-quadrat, all of which have previously been demonstrated to significantly affect the number of moose seen. Perhaps of equal importance is the difference in time between the first and second observation. In these surveys, even though the resurvey was attempted as close as possible to the first, they were often separated by hours (about 1 hr for Gollat 1988, "often within 3 hours" for Snider 1984) or days (several at 1 to 2 days for Snider 1984, average 64 hours and 106 hours for Novak and Gardner 1975).

Observer notes associated with our resurvey quadrats record considerable evidence of movement of moose on and off quadrats both during and between survey flights. Unlike the observations of LeResche and Rausch (1974) and Thompson (1979) our experience in Northwestern Ontario suggests that there may be considerable movement of animals and break up of aggregates (except cow/calf groups) when disturbed by surveys.

Resurveys by the same crews using tracks and current knowledge of the animals, their locations and movements do not support the assumption used by Snider (1984) and Gollat (1988) that different crews were seeing different groups of moose. If that assumption was invalid, the observed sightability in Snider's and Gollat's studies would be in the order of 0.77 and 0.90. These values are consistent with ours, although the design is not strictly comparable because of the delay between surveys.

Summary

The results of over fifteen years of moose aerial surveys are presented and analyzed using multiple regression techniques. While conclusive interpretation requires a more rigorous experimental design, some probable relationships are discussed, and an initial correction model derived. Depth of snow, snow crust, time spent on plot, aircraft type, and cloud cover are the significant variables in the linear correction model.

This model provides a valid statistical framework to correct survey data for visibility factors. Based on the recorded sightability factors, each individual plot can be corrected for visibility bias. Although useable in its present form, clearly three areas of additional research are required for refinement: i) more detailed analysis of the model specification, ii) a more extensive, and controlled study to better determine the number of missed moose (e.g., radio-tagging), and iii) analysis of the influence of habitat factors on moose visibility. This latter may be the most important factor, but likely requires radio-tagged animals for a valid analysis. With the advent of geographic information systems, and statistical models as those described here, habitat-related visibility factors could readily be calculated to further decrease the bias in moose-survey population-estimates.

REFERENCES

BERGERUD, A. T., and F. MANUAL. 1969. Aerial census of moose in central Newfoundland. J. Wildl. Manage. 33:910-916

BISSET, A. R. 1991. Standards and guidelines for moose aerial inventory in Ontario. Ont. Min. Nat. Res., Wildl. Brl, Toronto. 37pp.

CAUGHLEY, G. 1974. Bias in aerial survey. J. Wildl. Manage. 38:921- 933.

_______, R. SINCLAIR, and D. SCOTT-KEMMIS. 1976. Experiments in aerial survey. J. Wildl. Manage. 40:290-300.

COOK, R., and J.O. JACOBSON. 1978. A visibility biased model for aerial surveys of moose on the AOSERP study area. Alberta Oil Sands Environmental Research Program. unpubl. rep. 25pp.

_______, and J. O. JACOBSON. 1979. A design for estimating visibility bias in aerial surveys. Biometrics 35:735-742.

_______, and F. B. MARTIN. 1974. A model for quadrat sampling with "visibility bias." J. Am. Stat. Assoc. 69:345-349.

CRETE, M., L.-P. RIVEST, H. JOLICOEUR, J. BRASSARD and F. MESSIER. 1986. Predicting and correcting helicopter counts of moose with observations made from fixed-wing aircraft in southern Quebec. J. Appl. Ecol. 23:751-761.

DALTON, W.J. 1990. Moose density estimation with line transect survey. Alces:26: 129-141.

GASAWAY, W. C., S. D. DUBOIS, S. J. HARBO, and D. G. KELLYHOUSE. 1978. Preliminary report on sightability of moose during aerial surveys. Alces 14:32-55.

_______, S. D. DUBOIS, S. J. HARBO, and D. J. REED. 1986. Estimating moose population parameters from aerial surveys. Biological Papers. Univ. of Alaska. 22:108pp.

GOLLAT, R. 1988. Investigations into the suitability of the Bell 206L and deHavilland Turbo Beaver for aerial moose censuses. Ontario Ministry of Natural Resources. unpubl. rep. 42pp.

KARNS, P.D. 1982. Twenty-plus years of moose survey in Minnesota. Alces 18:186-196.

LERESCHE, R. E., and R. A. RAUSCH. 1974. Accuracy and precision of aerial moose censusing. J. Wildl. Manage. 38:175-182.

LYNCH, G. 1975. Best timing for moose

LYNCH, G. 1975. Best timing for moose surveys in Alberta. Alces 11:141-153.

MAGNUSSON, W. E., G. J. CAUGHLEY, and G. C. GRIGG. 1978. A double-survey estimate of population size from incomplete counts. J. Wildl. Manage. 42(1):174-176.

NORTON-GRIFFITHS, M. 1976. Further aspects of bias in aerial census of large mammals. J. Wildl. Manage. 40(2):368-371.

NOVAK, M. 1981. The value of aerial inventories in managing moose populations. Alces 17:282-315.

_______, and J. GARDNER. 1975. Accuracy of moose aerial surveys. Alces 11:154-180.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1975. Guidelines for Moose aerial inventory. Ontario Moose Council. unpubl. rep. 4pp. typescript.

POLLOCK, K. H., and W. L. KENDALL. 1987. Visibility bias in aerial surveys. J. Wildl. Manage. 51(2):502-510.

RICE, W. R., and J. D. HARDER. 1977. Application of multiple aerial sampling to a mark-recapture census of white-tailed deer. J. Wildl. Manage. 41(2):197-206.

SINIFF, D. B., and R. O. SKOOG. 1966. Aerial censusing of caribou using stratified random sampling. J. Wildl. Manage. 28(2):391-401.

SNIDER, J. B. 1984. Aerial moose census accuracy determined in a comparison of an intensive helicopter search and standard turbo beaver search. Ontario Ministry of Natural Resources. unpubl. rep. 14pp.

THOMPSON, I. D. 1979. A method of correcting population and age and sex estimates from aerial transect surveys of moose. Alces 15:148-168.

_______. 1981. Comparison of navigating and recording systems for aerial surveys. J. Wildl. Manage 45(3):738-740

ZAR, J.H. 1984. Biostatistical analysis. Prentice-Hall Inc., Englewood Cliffs, NJ 718pp.