PRECISION OF MOOSE DENSITY ESTIMATES DERIVED FROM STRATIFICATION SURVEY DATA

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ABSTRACT: Stratified random block (SRB) surveys are commonly used to monitor moose abundance. However, SRB surveys are expensive and time consuming, hence few areas can be surveyed annually and successive surveys in an area are infrequent. We investigated the potential for using only the stratification portion of the SRB survey technique to monitor moose abundance. Our objective was to determine how precisely moose density could be predicted from stratification data. Densities predicted from stratification data were compared with densities estimated from SRB surveys. A simple regression model demonstrated that moose seen per minute on the stratification surveys explains 81% of the variance in moose density. When applied to new data, the regression model predicted moose density with a 90% confidence interval of $\pm$ 72 moose per 1,000 km^2. Changes in predicted moose density in excess of about 120 moose per 1,000 km^2 are statistically significant ($P < 0.05$). Moose densities predicted from stratification data were not significantly different from SRB estimates in 6 test cases ($P > 0.05$), but fell outside the 90% confidence intervals of the SRB estimates in 4 of the 6 test cases. Management applications for moose density estimates derived from stratification survey data are discussed.

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Moose management often requires precise estimates of moose abundance. While the stratified random block (SRB) survey technique described by Gasaway *et al.* (1986) provides accurate and precise estimates of moose abundance and population composition, it is time consuming and expensive. Hence, in most cases, few areas can be surveyed annually and successive surveys in an area are infrequent. One rapid, inexpensive option for estimating relative abundance of moose is to use only the stratification portion of the SRB technique (Gasaway *et al.* 1986). One major limitation of this approach, however, is that it provides no indication of precision and, as a result, it is impossible to test for statistically significant changes in moose abundance.

Our objective in this study was to determine whether data from previous SRB surveys could be used to quantify the relationship between moose seen on stratification flights and the subsequent SRB survey-derived moose density estimate. We hoped that a strong statistical relationship would allow reasonably precise estimation of moose density using only data collected during stratification surveys. Our specific objectives were to: (1) determine the relationship between the number of moose seen per minute during the stratification portion of SRB surveys and moose density estimated from these surveys; (2) assess the predictive power of this relationship; and (3) develop statistical procedures for testing for significant changes in moose density derived from stratification data.

[3]William C. Gasaway passed away on 15 July 1998 in Stockton, CA, USA.

METHODS

Data Collection

Data collected during 19 SRB surveys conducted throughout southern and central Yukon between 1989 and 1997 (Table 1) were used in the analysis. Moose densities estimated from these surveys ranged between 64 and 381 moose/1,000 km^2.

SRB survey techniques were similar to those described by Gasaway *et al.* (1986) with 2 modifications. First, we used helicopters with a navigator and 2 observers in place of Piper Super Cub or similar aircraft with a single navigator/observer. Second, search intensity during the stratification portion of our surveys ranged between 0.31 and 0.71 minutes per square kilometer (min/km^2), considerably higher than the search intensity of 0.15 - 0.20 min/km^2 recommended by Gasaway *et al.* (1986).

Data Analysis

Gasaway *et al.* (1986) found that the proportion of moose seen during surveys was directly related to search intensity. Variation in search intensity during stratification flights may therefore affect the relationship between the moose seen per minute

Table 1. Yukon moose survey data used in regression model.

Area and Year	Stratification Survey: Number of moose seen	Stratification Survey: Search intensity (min/km^2)	Stratification Survey: Moose seen/minute	SRB Survey: Density (moose/1,000 km^2)
AL 1990	133	0.31	0.12	82.2
AL 1992	64	0.71	0.08	64.1
BS 1993	278	0.54	0.19	195.2
DA 1997	294	0.52	0.22	244.1
DE 1989	318	0.66	0.18	264.6
DW 1989	185	0.43	0.23	167.4
FL 1991	804	0.42	0.50	381.1
FL 1996	814	0.50	0.42	337.7
HJ 1990	250	0.35	0.31	222.6
MO 1993	253	0.66	0.13	122.0
ML 1994	62	0.32	0.21	125.1
NC 1991	408	0.38	0.36	338.9
NC 1996	303	0.33	0.31	277.6
NI 1994	503	0.45	0.25	231.3
OC 1992	223	0.49	0.16	122.5
PL 1995	247	0.44	0.16	197.7
WL 1995	306	0.51	0.14	182.6
WN 1993	195	0.51	0.12	123.0
WS 1995	255	0.51	0.17	149.8

Note: AL= Aishihik Lake, BS = Big Salmon, DA = Dawson, DE = Dawson East, DW= Dawson West, FL = Frances Lake, HJ= Haines Junction, MO = Mayo, ML= Mount Lorne, NC= North Canol, NI = Nisutlin, OC = Onion Creek, PL = Pelly Crossing, WL = Watson Lake, WN= Whitehorse North, WS = Whitehorse South and moose density. We evaluated this possibility using regression analysis of the relationship between proportion of moose seen during stratification and search intensity.

Regression analysis was also used to assess the relationship between moose seen per minute during stratification and moose density estimated using SRB surveys. It is conventional in regression analysis of biological systems to place the independent variable on the X-axis and the dependent variable on the Y-axis (Zar 1984: 261). While strong biological arguments can be made that moose density is the independent variable and moose seen per minute the dependent variable, we chose to reverse the variables on the axes, placing moose seen per minute on the horizontal axis. We selected this approach, referred to as inverse regression by Neter *et al.* (1996: 169), because of the ongoing controversy among statisticians about merits of procedures available for predicting the value of the X-axis variable for an observed Y-axis value (Zar 1984: 276; Neter *et al.* 1996: 167).

We started our assessment of the relationship between moose seen per minute during stratification and estimated moose density using the model: $M_D = a + b * (M_S * S_I)$, where:

M_D = moose density estimate from SRB survey,
a = regression constant,
b = regression coefficient,
M_S = moose seen per minute during stratification, and
S_I = search intensity (min/km^2) during stratification.

Testing the Predictive Model

Data collected during 6 additional SRB surveys conducted in 1988 and 1998 were used to compare moose densities predicted using the resulting regression model with those estimated using standard SRB survey techniques.

RESULTS

Search Intensity and Proportion of Moose Seen

Search intensity during the stratification portion of our SRB surveys varied between 0.31 and 0.71 min/km^2. The proportion of moose seen during stratification ranged between 0.35 and 0.68 ($\bar{x}$ = 0.50) of the total SRB estimated moose population. However, the relationship between search intensity and proportion of moose seen during the surveys was not significant (r^2 = 0.12, P = 0.14; Fig.1).

The Regression Model

Our initial regression model, incorporating search intensity, provided an r^2 = 0.80 (P = 2.3 x 10^{-7}). Because we found no significant relationship between search intensity and proportion of moose seen during stratification, however, we dropped search intensity from the model. This modification resulted in a slightly improved fit (r^2 = 0.81, P = 1.7 x 10^{-7}). We selected this second model, excluding search intensity, for subsequent analysis because it is simpler and fits the data just as well (Fig. 2).

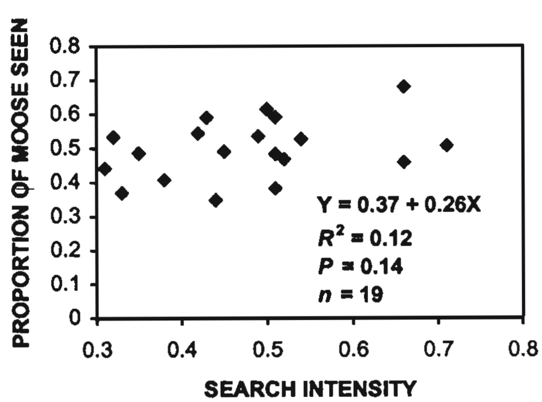

Fig. 1. Relationship between proportion of moose seen during stratification and search intensity (minutes flown per square kilometer).

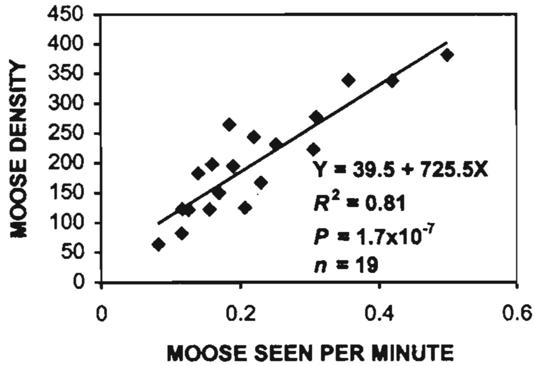

Fig.2. Regression model: moose density estimated using SRB surveys versus moose seen per minute during stratification.

Predicting Moose Density from Stratification Survey Data

Using this model, moose abundance in a new area can be estimated from moose seen per minute during stratification. Taking an example where 0.2 moose were seen per minute during a stratification survey and using $D_{(new)}$ for the predicted moose density gives $D_{(new)} = 39.5 \pm 725.5 * 0.2 = 184.6$. We conclude that moose density in the new area was approximately 185 moose/1,000 km^2.

There are 2 main sources of error that may cause the predicted moose density in the new area to deviate from that which would have been derived had a full SRB survey been conducted. First, there is uncertainty associated with the slope of the regression line. Second, for any given value on the X-axis (moose seen per minute during stratification), there will be variation in actual moose density around the regression line.

Both of these sources of error must be accounted for in the development of a confidence interval (C.I.) for our density estimate. The overall variance associated with the predicted moose density ($S^2_{\{pred\}}$), can be calculated following Neter *et al.* (1996) as:

$$S^2_{\{pred\}} = \text{MSE} * \left[1 + 1/n + \frac{(X_{new} - \overline{X})^2}{\sum (X_i - \overline{X})^2} \right],$$

where:

MSE = mean square error of residuals in the regression model,

n = sample size in the regression model,

X_{new} = moose seen per minute during stratification of the new area,

X_i = X values (moose seen per minute) used in the regression model, and

$\overline{X}$ = mean of X values in regression model.

Following through with our previous example $S^2_{\{pred\}}$ would be:

$$S^2_{\{pred\}} = 1634.76 * \left[1 + (1/19) + \frac{(0.2 - 0.223)^2}{3.296} \right] = 1721.01$$

Having calculated $S^2_{\{pred\}}$, we can establish a C.I. for our newly predicted moose density using $D_{(new)} \pm t_{(1-\alpha/2, n-2)} * S\{pred\}$. For a 90% C.I. where $t_{0.90,17} = 1.740$ the result is: $184.6 \pm 1.740 * \sqrt{1721.01} = 184.6 \pm 72.2$ or $184.6 \pm 39.1\%$.

The C.I. is clearly quite large. In addition, the width of the C.I. remains relatively constant ($\pm$ 72.2 - 73.0 moose/1,000 km^2) across the range of predicted moose densities (Fig. 3). This is because MSE (the distribution of the residuals) contributes a large proportion, (approximately 95%) of the variance of $S^2_{\{pred\}}$. As a consequence, the C.I., as a percentage of the predicted moose density, decreases as X_{new} increases. For example, the C.I. would be approxi-

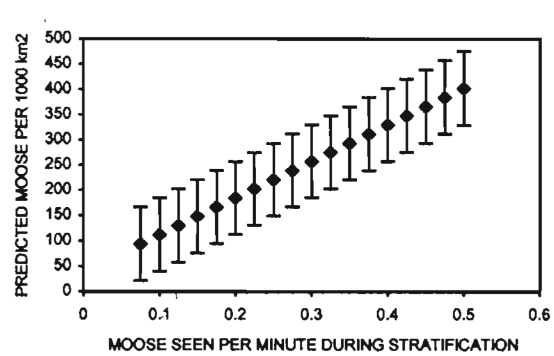

Fig.3. Predicted moose densities and 90% confidence intervals for range of values for moose seen per minute during stratification.

mately $\pm$ 72% when the predicted density is 100 moose/1,000 km^2 and $\pm$ 18% when the predicted density is 400 moose/1,000 km^2.

Testing For Changes in Moose Density

Differences between moose densities predicted from 2 stratification surveys can be tested for using students *t*-test. The $S^2_{\{pred\}}$, calculated previously, is used as the sampling variance in the test. The *t*-value is based on degrees of freedom equal to *n*-2 (*n* = number of samples in the regression model) for each predicted density for a total of 2 * (*n*-2) degrees of freedom (Zar 1984:126). The formula for the *t*-test is:

$$t = (D_{new1} - D_{new2}) / \sqrt{S^2_{\{pred\}1} + S^2_{\{pred\}2}}$$

For example, assume that D_{new1} = 184.6 moose/1,000 km^2 and $S^2_{\{pred\}}$ = 1721.01, represent the results of our first survey. Five years later we conduct a second survey in the same area and observe 0.4 moose per minute of stratification (D_{new2} = 330 moose/1,000 km^2; $S^2_{\{pred\}}$ = 1736.27). We can then test whether a statistically significant change in moose density has occurred ($P < 0.05$, 34 df):

$$t = \frac{330 - 184.6}{\sqrt{1736.27 + 1721.01}}$$

= 2.473

We conclude that there has been a significant increase in moose abundance (since $t_{\alpha=0.05(2),\,34}$ = 2.032).

To estimate how large the increase may have been we estimate the C.I. on the difference between the 2 density estimates using the following formula:

$$(D_{new2} - D_{new1}) \pm t_{(1-\alpha/2)} * \sqrt{S^2_{\{pred\}2} + S^2_{\{pred\}1}}$$

where, the degrees of freedom again equals 2 * (*n*-2) and *n* = number of samples in the regression model. In our example we calculate:

330 - 184.6 $\pm$ 2.032 * 58.8
= 145.4 $\pm$ 119.5

The change in moose density may have been as little as 25.9 moose/1,000 km^2 or as great as 264.9 moose/1,000 km^2. While there would appear to have been a significant change in moose density, there is a high degree of uncertainty about the magnitude of the change.

The magnitude of change in predicted moose densities required to detect a statistically significant difference remains relatively constant across the range of our regression model. Multiple runs using mock data indicated that a change in predicted moose density of about 120 moose/1,000 km^2 was required to detect a significant difference at the $\alpha = 0.05$ level.

Comparison of Observed and Predicted Moose Densities

Densities derived from SRB surveys and those predicted from our regression model were not significantly different ($P >$ 0.05) in our 6 test cases (Table 2). However, in 4 of the 6 cases the density predicted from the regression model fell outside the 90% confidence interval for the SRB density estimate (Table 2). In all cases the precision of the moose density estimates derived from the SRB survey results was higher than that calculated from the stratification regression model.

DISCUSSION

The proportions of moose seen during our stratification flights ($\bar{x}$ = 50%) are somewhat higher than those reported elsewhere. Gasaway *et al.* (1986) observed between 27 - 41% of moose during stratification flights in early winter. On average, Lynch and Schumaker (1995) saw 16% of moose during stratification.

The higher proportion of moose seen during our surveys may be expected given our higher search intensity. Gasaway *et al.* (1986) reported a positive relationship between proportion of moose seen and search intensity. However, we found no similar

Table 2. Moose densities estimated from stratified random block surveys and predicted from our regression model.

Area[1]	Stratification Survey			Moose Density	
	Number of moose seen	Search intensity (min/km^2)	Moose seen/min	SRB Survey	Regression model
AL 1998	285	0.43	0.33	172.8±31.3	278.9±72.3
BS 1998	218	0.55	0.15	195.1±35.0	148.3±72.2
MN 1988	91	0.41	0.10	128.0±32.0	111.3±72.3
MO 1998	277	0.60	0.15	200.0±38.2	148.3±72.2
MS 1988	171	0.38	0.17	147.8±29.6	164.3±72.2
OC 1998	443	0.64	0.20	294.3±61.3	184.6±72.2

Note: AL= Aishihik Lake, BS = Big Salmon, MN = Mayo North, MO = Mayo, MS= Mayo South, OC = Onion Creek,

[1]moose/1,000 km^2 ± 90% C.I.

relationship in our data. This may have been at least partially due to the limited range of search intensities used in our surveys. A positive relationship between search intensity and proportion of moose seen may be apparent over a wider range of search intensities. Factors such as observer ability, weather, terrain, and vegetation can also affect sightability (LeResche and Rausch 1974), and may have masked the relationship within the range of search intensities used in our surveys. Data on these variables were not available for inclusion in the model.

While regression analysis showed a strong relationship between moose seen per minute during stratification and moose density, this could not be translated into precise and reliable predictions of moose density from stratification data. Our 90% C.I.s translate to ± 72% of the predicted density at 100 moose/1,000 km^2 and ± 18% at 400 moose/1,000 km^2.

In contrast, researchers and managers using SRB surveys commonly report population estimates with 90% C.I. of ± 25% or less at all moose densities (Gasaway *et al.* 1986, 1992; Smits *et al.* 1994). This level of precision generally allows for detection of change in population size of approximately 30% or greater (Gasaway *et al.* 1986). Our results suggest that change in population density of less than about 120 moose/1,000 km^2 will not be detectable using stratification surveys.

Throughout much of the Yukon and in many other naturally regulated northern systems moose occur at densities between 100 - 300 moose/1,000 km^2 (Gasaway *et al.* 1992, Ward and Larsen 1994). Changes in density of 120 moose/1,000 km^2 or more are uncommon and would probably be apparent even in the absence of statistical tests. As a result, monitoring changes in moose abundance using stratification survey data will likely be limited to high moose density situations where management is concerned with large changes in moose abundance.

Our test cases suggest that while moose densities estimated from SRB surveys and stratification data are not significantly different, densities predicted from stratification data will frequently fall outside the 90% C.I. associated with a full SRB survey. Use of density estimates derived from stratification data should therefore be limited to situations not requiring accurate and precise measures of moose abundance.

However, in areas where no other information is available, stratification surveys can provide a relatively low cost means of collecting data on moose density and distribution. It is our experience that the cost of a stratification survey is only 10 - 20% of that for a full SRB survey. Savings resulting from conducting only a stratification survey can be used to survey areas more frequently, or to survey additional areas.

Conditions for Application

Several conditions must be met before our moose density prediction model can be considered for use in other areas:

1. Our stratification search intensity was about 0.5 min/km^2. While we found no relationship between search intensity and proportion of moose seen, this may not hold if search intensity is substantially higher or lower than that used on our surveys.
2. It is generally unsafe to extrapolate outside the range of the regression equation (Zar 1984). Our regression model is limited to situations where moose seen per minute during stratification is within a range of about 0.08 - 0.5 (64 - 381 moose/1,000 km^2).
3. Sightability must be similar. This can be affected by a variety of factors including forest cover type and season. Most surveys used in development of our regression model took place in northern boreal forests with relatively open canopies. Sightability in this forest type is likely higher than in more southern boreal forests with denser canopy cover. In addition, our surveys were conducted in early winter. Gasaway *et al.* (1986) found that sightability is substantially lower in late winter.

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