PRECISION AND BIAS OF AERIAL MOOSE SURVEYS IN NORTHEASTERN MINNESOTA

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ABSTRACT: The Minnesota Dept. of Natural Resources (MDNR) has conducted aerial surveys to estimate moose (*Alces alces*) numbers each year since 1960. A modified version of the survey protocol developed in Alaska to estimate moose numbers was adopted in 1982. Moose numbers and age/sex ratios were estimated from transects flown within a random sample of stratified survey plots. Portions of some survey plots were resurveyed more intensively to determine whether moose were missed in the initial survey. Data from the intensive survey were used to calculate a sightability correction factor (SCF). While more robust than earlier protocols used in Minnesota, this methodology had several shortcomings. Precision of the population estimates (90% C.I.) ranged from ±21 to ±125% and annual changes in moose numbers and bull:cow ratios were not statistically significant. Annual changes in the calf:cow ratios were significant, however. Imprecision of survey estimates was usually the result of incorrect stratification. A single mis-stratified plot dramatically reduced precision on several occasions. Regression analyses indicated that starting date and survey length explained a significant proportion of the variation in population estimates. Moose in the boreal forest shift into conifer cover in mid-winter and become more difficult to observe. The regression results reflected the bias caused by this shift and underscore the importance of starting the survey early and completing the survey in a short time interval.

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Aerial surveys have been flown annually by the Minnesota Department of Natural Resources (MDNR) to estimate moose density in northern Minnesota since 1960. Although early estimates varied considerably from year to year, the surveys documented that moose numbers in northern Minnesota could support a hunting season which was re-opened in 1971 with a limited number of permits. Annual surveys are intended to estimate the size of the two disjunct moose populations in northeastern and northwestern Minnesota and to monitor trends (Karns 1982). During some periods, population estimates increased or decreased gradually. Between some years, however, population estimates changed by as much as 63% and it was not clear whether these estimates were biased or these estimates reflected dramatic changes in population numbers.

Harvest quotas in Minnesota have been relatively conservative over the last 26 years, in part because our goal was to increase the number of moose in northern Minnesota. This conservatism also reflected the level of uncertainty in the results of the annual moose survey. My intent in this paper is to evaluate the survey methodology, identify sources of bias, and suggest changes in methodology that may reduce bias and improve precision. "Bias" is a systematic error associated with the methodology that results in an over- or under-estimate of actual moose numbers. Precision represents the random sampling error associated with the population estimate and for this paper will be evaluated in terms of the width of the 90% confidence interval around the estimate. Although aerial surveys are used to estimate moose numbers in both northeastern and northwestern Minnesota, I will focus on the survey of the northeastern population.

METHODS

Beginning in 1982, MDNR adopted a modified version of the stratified random block survey protocol developed in Alaska to estimate moose numbers (Gasaway *et al.* 1986). In the MDNR version of the protocol, moose numbers and age/sex ratios were estimated by flying transects within a stratified random sample of survey plots. Survey plots averaged 38.9 km^2 (4.9 to 95.3 km^2) and their boundaries followed easily recognizable geographic features. In some years, optimal allocation (based on the previous year's results) was used to allocate the number of plots/strata. Survey plots were searched by flying parallel transects 125 to 185 m above the ground, spaced 0.8 km apart, using either a De Havilland Beaver (1982-89) or a Cessna 185 (1990-96) at search intensities that averaged 1.5 min/km^2. If moose were encountered on the transect, the airplane normally circled to allow observers to determine the sex/age class. In the last 13 years of the survey, moose were sexed using the presence of antlers or a vulval patch (Mitchell 1970) and calves were identified on the basis of size. In 6 of the 15 years, portions of some plots were resurveyed by flying overlapping ovals at approximately 4.5 min/km^2 to determine whether moose were missed in the initial survey and these data were used to calculate a sightability correction factor (SCF). Plots were stratified into three levels of expected moose density based on Area Wildlife Managers' knowledge of moose distribution and habitat. The entire survey area was restratified in 1985 and again in 1993. However, individual plots were shifted into different strata in succeeding years if survey flights indicated that plots were misstratified. One flight crew was used to survey moose each year. Although this contributed to consistency among observers, it also lengthened the time period over which survey flights were conducted.

Estimates of moose population size and composition followed Gasaway *et al.* (1986) using a Lotus® template (M. S. Lenarz, MDNR, *unpubl.*). In years when no resurvey flights were flown, the SCF and Var_{SCF} were calculated as the mean of these statistics from 1982-1985 and 1996 (values from 1995 were aberrant and excluded). Multiple linear regression was used to determine whether variation in the estimates of moose numbers, bull/cow and calf/cow ratios, or strata variances could be explained by survey starting date or survey length. A two-tailed t-test was used to determine whether survey estimates differed from the previous year. In all analyses, "uncorrected" refers to estimates not expanded with the SCF. All statistical analyses were conducted using Statistix® (Windows Vers. 1.0, Analytical Software, Tallahassee, FL).

RESULTS

The number of plots surveyed in a year ranged from 24 to 35 ($\bar{x}$ = 28, Table 1). In most years, a set of 24 primary plots were randomly surveyed. Additional plots were surveyed if time and funding were available. Although variable among years, plots/strata averaged 30% low density, 47% medium density, and 24% high density. Both the starting date and survey length varied considerably (Table 1). The total area surveyed each year ranged from 552 to 781 km^2 and represented a sampling fraction of 6.6 to 9.9% of the total survey area (Table 1).

Estimated moose numbers varied from 3,734 to 8,854 and except for the last two years, estimates increased or decreased an

Table 1. Starting date and length of aerial surveys in northeastern Minnesota, 1982-1996.

Year	Plots Surveyed	Starting Date	Survey Length (days)	Proportion of Area Surveyed
1982	33	30 December	26	8.5%
1983	27	12 December	43	7.2%
1984	28	9 January	21	7.9%
1985	35	3 December	35	9.9%
1986	30	11 December	35	8.6%
1987	24	27 December	38	7.2%
1988	29	30 November	29	8.5%
1989	29	18 December	49	9.7%
1990	30	27 December	29	8.5%
1991	30	17 December	29	8.2%
1992	29	28 December	28	7.9%
1993	25	8 December	20	6.7%
1994	32	12 December	46	9.1%
1995	24	2 January	34	6.6%
1996	24	15 December	58	6.8%

average of 19% from the previous year (Fig. 1). The precision of these estimates varied from ±21 to ±49%, except for in 1995 when a late start date (Table 1), snow depths > 75 cm over much of the survey area, and January temperatures averaging as much as 5.7° C colder than normal (NOAA 1996) greatly reduced precision. Estimated moose numbers in adjacent years were not different (P>0.10). Estimates of the bull/cow ratio also were imprecise (Fig. 1) with no difference between adjacent years (P>0.10). In contrast, estimates of the calf/cow ratio were substantially more precise (Fig. 1) and in all years but 1988, 1993, and 1994 were different between adjacent years (P<0.10).

The sampling variance of the "uncorrected" estimate (Var_N) was the largest component of precision in 4 of the 6 years when intensive survey flights were conducted (Fig. 2). Partitioning of the Var_N among the three strata indicated that in most years the low density strata was the most variable strata (Fig. 3). Variance estimates in all three strata were independent of survey starting date and survey length (P>0.10).

Both SCF and its sampling variance (Var_{SCF}) were independent of starting date or survey length ($n = 6$; $F = 0.06$; 2, 3 df; $P = 0.94$ for SCF, $n = 6$; $F = 0.28$; 2, 3 df; $P = 0.94$ for Var_{SCF}). Resurveys were conducted on only 29 to 54% of the plots (Table 2), however, and the Var_{SCF} may have been biased by small sample size.

Regression analysis indicated no significant relationship between "corrected" population estimates ($n = 6$; $F = 0.27$; 2, 3 df; $P = 0.78$) and the starting date or survey length. However, starting date and survey length explained a significant proportion of the variation in the "uncorrected" estimates of moose numbers ($n = 15$; $F = 5.10$; 2, 12

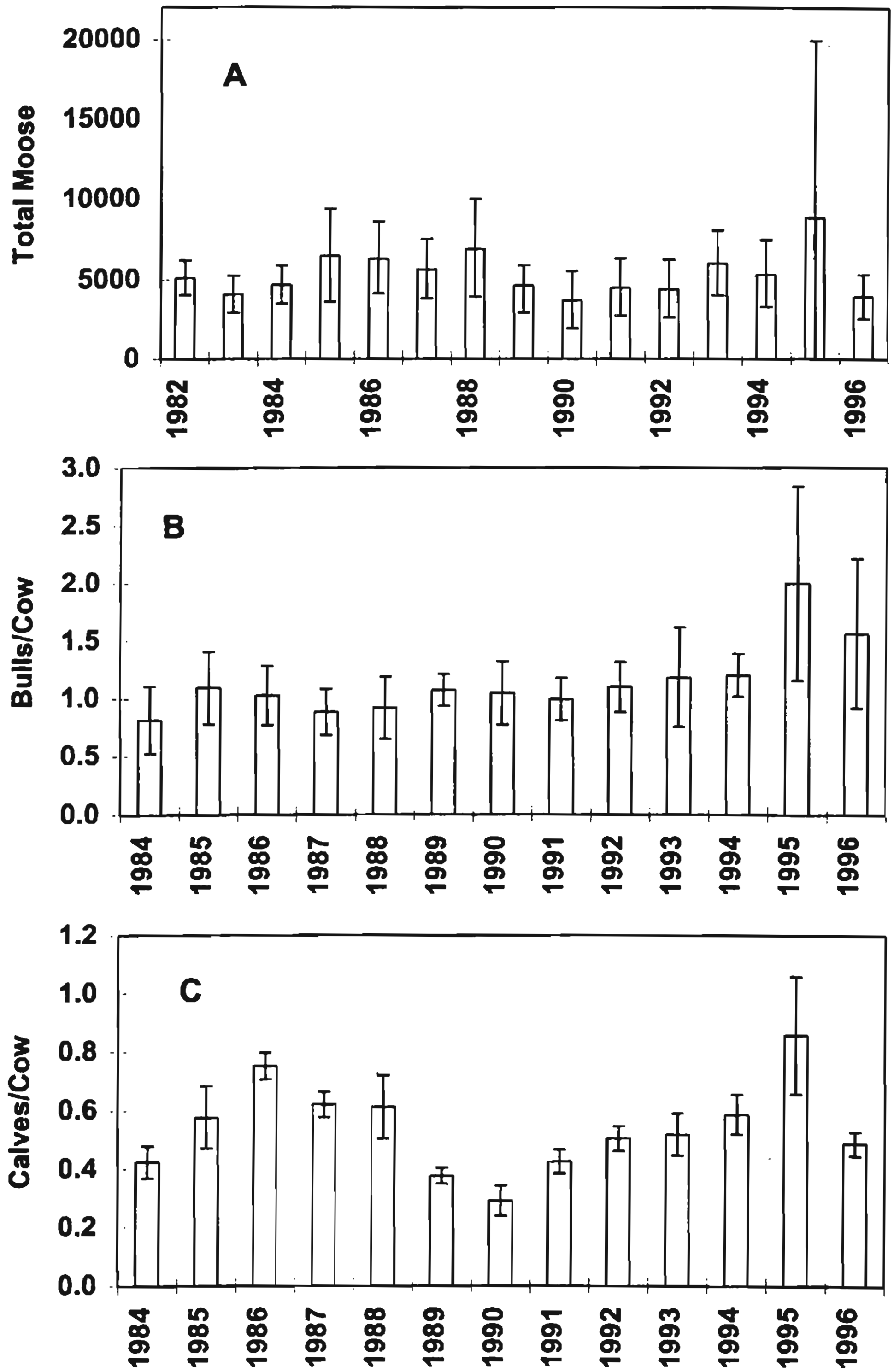

Fig. 1. Estimates of (A) total moose ("corrected"), (B) bull:cow ratios, and (C) calf:cow ratios and their 90% confidence intervals as derived from aerial surveys in northeastern Minnesota, 1982-1996.

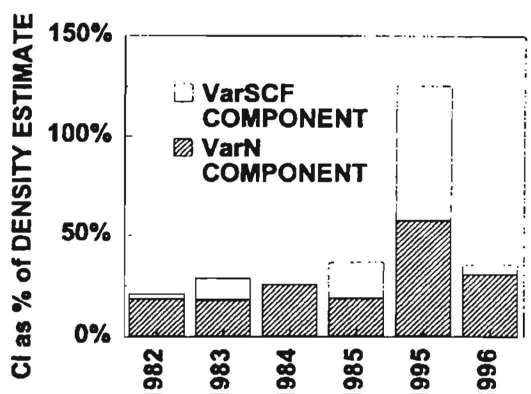

Fig. 2. Confidence interval (CI) of population estimate partitioned into portions contributed by sampling variances of the "uncorrected" estimates (Var_N) and the sightability correction factor (Var_{SCF}).

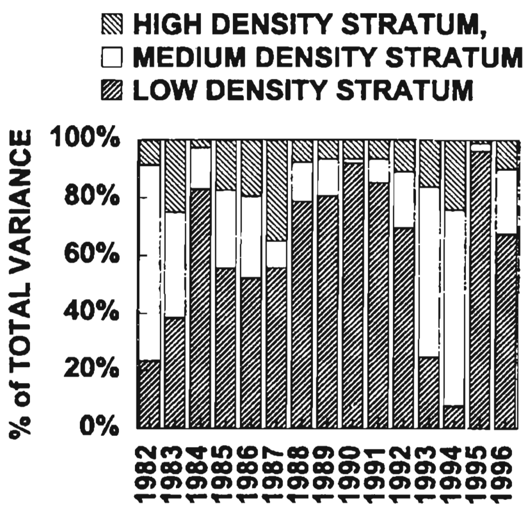

Fig. 3. Relative contributions of strata variance to overall variance in the northeastern Minnesota moose survey, 1982-1996.

df; $P = 0.02$; $R^2 = 0.46$). Coefficients for both covariates were negative ($P = 0.04$ for Survey Length, $P = 0.02$ for First Day). Estimates of bull/cow and the calf/cow ratios were independent of starting date and survey length ($n = 13$; $F = 1.00$; 2, 10 df; $P = 0.40$ for bull:cow, $n = 12$; $F = 0.09$; 2, 10 df; $P = 0.92$ for calf:cow).

Table 2. Annual estimates of the Sightability Correction Factor (SCF) and its variance (Var_{SCF}) in northeastern Minnesota. No SCF is available for 1986-1994 because intensive surveys were not flown in those years.

Year	% Plots Resurveyed	*n*	SCF	Var_{SCF}
1982	30%	10	1.24	0.005
1983	41%	11	1.13	0.018
1984	29%	8	1.00	0.000
1985	26%	9	1.54	0.134
1995	33%	8	2.86	2.728
1996	54%	13	1.14	0.017

DISCUSSION

It was impossible to strictly apply the Gasaway *et al.* (1986) technique because resurvey flights were not conducted between 1986 and 1994. No long term trend was apparent in the "uncorrected" estimates between 1982 and 1996 and it is unlikely a trend would have emerged had we conducted resurveys every year. The SCF attempts to account for moose not observed during the transect flights and therefore, the "corrected" estimates are probably less biased but still provide only an estimate of moose numbers with a wide confidence interval.

For setting harvest quotas, we need to determine whether the population has changed between succeeding years. The results of these surveys imply that moose numbers did not change between 1982 and 1996, but it is also possible that moose numbers did change and the precision of these estimates was too low to detect a change. Gasaway *et al.* (1986) recommended a precision equal to or greater than a 90% CI with a width of less than ±25% of the population estimate. This level of precision was reached in only 1 of the 15 years. The precision of the population estimates needs to be increased before these statistics can play an important role in management decisions in Minnesota.

Estimates of the bull:cow ratio had better precision than the population estimates and attained the recommended threshold (Gasaway *et al.* 1986) in 6 of 13 years. Ratio estimates are not changed by the SCF. It is unlikely that hunting would cause a shift in the bull:cow ratio in Minnesota because only 4 to 6% of the estimated population is removed in the either sex harvests. Unless some sex-specific mortality source shifted the bull:cow ratio dramatically, it would be very difficult to increase precision to a level where changes in this ratio could be documented.

In contrast, estimates of the calf:cow ratio attained the precision threshold (Gasaway *et al.* 1986) in all 13 years and it was possible to document significant changes in this important ratio. Calves are very rarely observed without a cow during the survey (M.S. Lenarz, *pers. obs.*) and hence, there is less chance that this ratio is biased. This statistic may be more important in tracking population change than estimates of moose numbers.

Precision of the population estimates is a function of the sampling variance of both the "uncorrected" estimates (Var_N) and the SCF (Var_{SCF}). Var_N is caused by variability in numbers of moose observed on all plots surveyed while the Var_{SCF} represents variability in the proportion of moose missed during the intensive search (Gasaway *et al.* 1986). The former reflects the correctness of stratification, while the latter reflects the consistency of observers in detecting moose on the plots.

In most years, Var_N contributed more to the width of the CI than Var_{SCF} and in most cases, mis-stratification of plots in the low density strata was responsible for the poor precision. The high variance was generally caused by 1 or 2 plots that contained substantially more moose than expected for that stratification. For example, in 1990, low density plots contained a median of 3 moose but 1 contained 20 moose. This single plot increased the variance of the low density strata by a factor of 10 and nearly doubled the confidence interval. In cases such as this, it is very difficult to minimize the effect of the mis-stratified plot by surveying additional plots. Moreover, additional plots would extend the survey and increase the risk of bias. Although optimal allocation is an important tool in apportioning plots among strata, it has little value in cases such as this where 1 or 2 plots contain substantially more moose than expected.

In 3 of 6 years when resurveys were conducted, more than 35% of the total variance was contributed by the Var_{SCF}. Although these data are limited, they do suggest that Var_{SCF} is important to precision in some years and that additional resurveys each year may improve the overall precision. Although the SCF and Var_{SCF} were independent of survey timing and length, this analysis was based on only 6 years data. The relationship between "uncorrected" population estimates and survey timing, raises the possibility that the SCF might be biased if resurvey flights were clumped at the beginning or end of a long survey period.

Moose shift from deciduous into coniferous habitats sometime in mid-winter and become much more difficult to observe (Lynch 1975, Karns 1982, Peterson and Page 1993). Regression analyses, however, indicated that the "corrected" population estimates were independent of the timing or survey length. Analyses did indicate that starting date and survey length explained a significant proportion of the variation in the "uncorrected" estimates of moose numbers. The analysis indicated that 46% of the year to year variation in the estimates could be explained by the combination of the starting date and the survey length rather than changes in actual moose numbers. That the coefficients in this regression were negative (and significant) implies that "uncorrected" population estimates were biased low in years with a later starting date and/or a prolonged survey interval. Althought the "corrected" estimates were independent of survey timing, they were based on only 6 years of data while 15 years of data were used in analyses of the "uncorrected" estimates. It would be better to correct the conditions that cause the bias by conducting early, short surveys than to rely on the SCF which may only mask the bias.

Despite the imprecision of the estimates, the MDNR has treated the sequential point estimates provided by the survey as representing population trends (Karns 1982) and allocated hunting permits accordingly. In 1991, for example, no moose hunting permits were issued in northeastern Minnesota because the "trend" in moose numbers indicated a 53% decline over 2 years at a time when winter tick infestations (*Dermacentor albipictus*) were particularly common. Aerial surveys indicated that the population decline was not a statistically significant decline. Record low calf:cow ratios in the 2 previous years, however, did represent a significant decline and corroborated other anecdotal information that suggested reduced moose numbers. While harvest quotas in most years are relatively conservative (4-6% of estimated winter population), the point estimates of population numbers would need to be treated with caution when making dramatic changes in harvest quotas. The calf:cow ratios may be a more important index of population trends in northeastern Minnesota until the survey is changed to increase precision of population estimates.

The State of Minnesota is currently in litigation with the Fond du Lac band of Chippewa over their treaty rights to hunt and fish in an area that includes the northeastern moose population. Court settlements in similar cases in the region allow the band to harvest up to 50% of the "harvestable surplus" of species within the treaty boundaries. It will be even more important in future years that we have more precise information on moose numbers and population trends to calculate the harvestable surplus.

MANAGEMENT IMPLICATIONS

The preceding analysis has identified several areas in which MDNR's protocol for surveying moose numbers can be improved. First, the starting date of the survey must be as early as possible and consistent from year to year. In most years, snow cover has been sufficient by 15 December and every effort should be made to begin the survey at this time. Second, the duration of survey must be shortened considerably by using additional survey teams. Even under the best of conditions, it took a single team 20 days (Table 1) to conduct the survey and ideally, this should be reduced to 2-5 days (Timmerman 1993). Third, stratification of plots should be reviewed annually, especially in areas altered by forest fires, spruce budworm or in areas open to logging. Fourth, sampling effort should be reallocated among the strata so as to reduce the Var_N. Optimal allocation can be used in the initial plot selection each year as well as when making decisions regarding additional plots. Finally, the number of resurvey plots should be increased to minimize the Var_{SCF} and thereby increase the precision of the population estimate.

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