# A MODIFICATION OF A MOOSE POPULATION ESTIMATOR

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ABSTRACT: The enumeration of moose (*Alces alces*) populations to obtain estimates of moose density, and bull:cow, and calf:cow ratios are important to successful management of moose populations. Aerial surveys using the Gasaway-DuBois-Reed-Harbo method, GDRH, (Gasaway *et al.* 1986) assume that sightability is identical for all strata. The GDRH method uses a stratified double sample design, and as a result, sightability must be calculated and applied within strata to be statistically valid. We also present data suggesting sightability is not identical for all strata. We present a modification to the GDRH method that allows sightability to vary between strata and offer software that includes these modifications.

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In boreal forest and the subalpine zone, the Gasaway-DuBois-Reed-Harbo (GDRH) sampling method (Gasaway *et al.* 1986) has been used to estimate the size of moose populations in Alaska (Gasaway *et al.* 1983, Ballard *et al.* 1987, Ballard *et al.* 1991, Schwartz and Franzmann 1989) and Canada (Larsen 1982). This method represents a major improvement in estimation of moose population size. The GDRH estimator uses a stratified double sampling design to estimate moose population size. The basic technique is to divide a study area into primary sample units approximately 28-34 km$^2$ in size, classify the units into strata based upon estimated moose densities, select a simple random sample (SRS) of units within each strata to be sampled, search the selected units at 1.5-2.4 min per km$^2$, and record the number of bulls, cows and calves observed. In addition, a subsample of searched primary sample units are selected and partitioned into 2.6-5.2 km$^2$ secondary sample units. These secondary units are randomly selected and searched, at 4.6 min./km$^2$, immediately after the regular search in that sample unit. Thus the number of moose observed during the regular survey can be accurately compared with the number of moose present during the intensive search. A sightability correction factor (SCF) can then be computed as follows:

$$\frac{\text{No. of moose seen during the intensive search}}{\text{No. of moose seen during the standard search}} + \text{Correction for small sample bias.}$$

The GDRH method advocates that a random sample of the non-low strata primary sample units be selected for sub-sampling to obtain SCF information. Gasaway *et al.* (p31, 1986) argue that it is not practical or economical to sample low strata sample units (≤0.39 moose/km$^2$) to obtain SCF information. The SCF information is pooled over all strata and applied to strata estimates of standard search moose density estimates to obtain intensive search density estimates. By pooling over strata, the GDRH method assumes equal sightability for all strata.

## METHODS

Moose population estimates and SCF data was collected using the GDRH method (Gasaway *et al.* 1986) for Game Management Units (GMU) 14B and 16B-middle in southern Alaska, and GMU 16A-north and 12 in interior Alaska. During December of 1987, C. Grauvogel and W. Taylor collected moose data in GMU 14B, which consists of the western Talkeetna Mountains and the eastern Susitna River Valley between the Talkeetna

River and Willow-Peters Creeks. In November 1990, R. Modaferri and M. Masteller collected the moose data in GMU 16A-north, which consists of the area north of the Petersville road to the Alaska Range, between the Kahiltna and Chulitna Rivers. During December 1990, W. Taylor and M. McDonald collected the moose data in GMU 16B-middle, which consists of the area north of the Beluga River, east of the Alaska Range, west of the Yetna and Susitna rivers and south of and including the Skwentna River drainage. Data for a portion GMU 12, consisting of the Tanana River drainage between the Robertson River and Tetlin Junction, was collected by D. Kelleyhouse and D. Haggstrom in March 1989.

A nonpooled t-test was used to test for differences in SCF and the degrees of freedom (df) were approximated using Satterthwaite's method (Ostle and Mensing, 1982). The t-statistic was adjusted by a Bonferroni multiple comparison procedure (Neter and Wasserman 1974) to ensure that the experiment-wise error rate did not exceed 0.20. Statistical significance was evaluated at $P = 0.2/3 = 0.0667$ (Bonferroni), where 3 denotes the number of comparisons being made. The power of each t-test was computed. Power denotes the probability of determining that the observed difference in SCF was significant.

## RESULTS

### Argument for SCF Modification

It is not statistically valid to pool secondary sample data across strata (Cochran 1977). The GDRH analytical approach for using sightability data implicitly assumes that secondary sample units are selected as a SRS from all primary sample units independent of strata designation. In practice, selection of secondary sample units is restricted by the sampling proportions of primary sample units within strata and no secondary units in the low strata are usually sampled, so the surveyed secondary units are not a SRS of possible secondary units, and cannot be assumed to approximate a SRS. The GDRH analytical approach is not consistent with the data collection procedures, so biased estimates of the standard error (SE), degrees of freedom (df) and confidence interval for SCF and expanded population estimate ($\hat{T}_e$) are produced. The point estimates of SCF and $\hat{T}_e$ are also biased, unless sightability is identical across all strata. In order to produce unbiased statistics, SCF must be estimated for each stratum and the SCF adjustments made within stratum.

The estimated bias of the SE of SCF, as calculated by the GDRH method, ranged from -62.8% to 53.6% in GMU 14B (Table 1) and -83.8% to -3.5% in GMU 12 (Table 2). Esti-

Table 1. Sightability correction factors (SCF) by strata for moose in Game Management Unit 14B, which consists of the western portion of the Talkeetna Mountains and the eastern Susitna River Valley of Alaska, between the Talkeetna River and Willow-Peters Creek, during December 1987.

| | GDRH | | Actual | | % Bias | |
|---|---|---|---|---|---|---|
| Strata | SCF1[a] | SE | SFC2[b] | SE | GDRH SE | n |
| Super High | 1.268 | 0.106 | 1.080 | 0.069 | +53.6 | 4 |
| High | 1.268 | 0.106 | 1.526 | 0.285 | -62.8 | 6 |
| Medium | 1.268 | 0.106 | 1.287 | 0.159 | -33.3 | 11 |
| Low | 1.268 | 0.106 | 1.000 | 0.000 | NA | 3 |

[a]SCF1 denotes the sightability correction factor calculated using the formula in section 3.6.5.3 of Gasaway *et al.* (1986).

[b]SCF2 denotes the sightability correction factor calculated using the formula presented in this paper.

Table 2. Sightability correction factors (SCF) by strata for moose in Alaska Game Management Unit 12, consisting of the Tanana River drainage between the Roberston River and Tetlin Junction, during March 1989.

| | GDRH | | Actual | | % Bias | |
|---|---|---|---|---|---|---|
| Strata | SCF1[a] | SE | SFC2[b] | SE | GDRH SE | n |
| High | 1.253 | 0.082 | 1.121 | 0.085 | -3.5 | 8 |
| Medium | 1.253 | 0.082 | 1.374 | 0.139 | -41.0 | 17 |
| Low | 1.253 | 0.082 | 1.344 | 0.507 | -83.8 | 8 |

[a]SCF1 denotes the sightability correction factor calculated using the formula in section 3.6.5.3 of Gasaway *et al.* (1986).

[b]SCF2 denotes the sightability correction factor calculated using the formula presented in this paper.

mated relative biases in point estimates of $\hat{T}_e$ were on the order of 2% or less but biases in estimates of precision of $\hat{T}_e$, as indicated by confidence intervals, were more variable and pronounced (Table 3). The GDRH approach overstated the relative precision of the GMU 16B-middle population estimate by 24% (relative 80% C.I. of ±8.2% vs. ±10.8%) and understated the relative precision of the GMU 16A-north population estimate by 2%.

Large differences in SCF exists in some areas of Alaska. Estimated strata SCF differed by 0.446 between the high and super high strata of the moose survey in GMU 14B (Table 4) and by 0.253 between the medium and high strata of the moose survey in GMU 12 (Table 5). These large differences were not significant, however, the power of the tests was poor (0.253 and 0.354 respectively). While these data are inconclusive statistically, they indicate that caution should be exercised when considering whether sightability should be assumed to be identical across strata. In the authors' experience, habitat type and canopy cover can vary significantly between strata, which is a strong practical argument against this assumption. Even if sightability is identical across strata, resulting in unbiased point estimates of SCF and $\hat{T}_e$ with the GDRH method, the estimate of SE, df, and confidence interval for SCF and $\hat{T}_e$ using the GDRH method will be biased.

## Modified Formulae

We will use the notation and numbering system used in specified sections (e.g., Sec-

Table 3. Moose estimates by Alaska Game Management Unit (GMU) using the GDRH (Gasaway *et al.* 1986) and Modified formulas.

| (GMU) | Estimator | Te | SE(Te) | df | 80%C.I. | +/-% |
|---|---|---|---|---|---|---|
| 12 | GDRH | 792.8 | 75.5 | 18 | 692-893 | 12.7 |
| " | Modified | 789.5 | 82.8 | 25 | 680-899 | 13.8 |
| 16A-north | GDRH | 1467.9 | 140.3 | 18 | 1281-1655 | 12.7 |
| " | Modified | 1436.6 | 134.1 | 19 | 1258-1615 | 12.4 |
| 16B-middle | GDRH | 3824.9 | 236.9 | 21 | 3511-4138 | 8.2 |
| " | Modified | 3752.2 | 299.9 | 12 | 3345-4159 | 10.8 |

Table 4. Differences in moose sightability correction factors (SCF2, Table 1) between strata for Alaska GMU 14B during December 1987.

| Comparison | Difference | *t* | df | *P* | Power |
|---|---|---|---|---|---|
| Medium - S.High | 0.2069 | 1.194 | 9.97 | 0.2603 | 0.2084 |
| Medium - High | -0.2389 | -0.733 | 7.32 | 0.4866 | 0.1098 |
| High - S.High | 0.4458 | 1.521 | 5.385 | 0.1804 | 0.2526 |

Table 5. Differences in moose sightability correction factor (SCF2, Table 2) between strata for Alaska GMU 12 during March 1989.

| Comparison | Difference | *t* | df | *P* | Power |
|---|---|---|---|---|---|
| Low - High | 0.223 | 0.433 | 7.39 | 0.6771 | 0.0813 |
| Low - Medium | -0.030 | -0.058 | 7.50 | 0.9555 | 0.0670 |
| Medium - High | 0.253 | 1.550 | 21.13 | 0.1359 | 0.3537 |

tion 3.6.5.3) of Gasaway *et al.* (1986). Since $SCF_o$ will now be calculated on a within strata basis, the new $SCF_{io}$ formulae (3.6.5.3) is as follows:

$$\hat{SCF}_{io} = (\Sigma_k u_{ik}/\Sigma_k v_{ik}) + [n_{io} s^2_{iuv}/(\Sigma_k v_{ik})^2] - [n_{io} s^2_{iv} \Sigma_k u_{ik}/(\Sigma_k v_{ik})^3],$$

where:

$n_{io}$ = the number of 5.2-km² (2-mi²) plots surveyed with an intensive search in the $i^{th}$ stratum;

$u_{ik}$ = the number of moose seen during the intensive search in the $k^{th}$ sightability plot of the $i^{th}$ stratum, $k = 1,2,\ldots,n_{io}$;

$v_{ik}$ = the number of moose seen during the standard search in the $k^{th}$ sightability plot of the $i^{th}$ stratum, $k = 1,2,\ldots,n_{io}$;

$s^2_{iuv} = [\Sigma_k u_{ik} v_{ik}/(n_{io}-1)] - \{(\Sigma_k u_{ik} \Sigma_k v_{ik})/[n_{io}(n_{io}-1)]\}$; and

$s^2_{iv} = (\Sigma_k v^2_{ik}/(n_{io}-1)) - \{[(\Sigma_k v_{ik})^2]/[n_{io}(n_{io}-1)]\}$.

The sampling variance of the $\hat{SCF}_{io}$ is

$V(SCF_{io}) = (n_{io}\, s^2_{qs})/((\Sigma_k v_{ik})^2)$, where :

$s^2_{qs} = (\Sigma_k u^2_{ik} - 2\hat{SCF}_i \Sigma_k u_{ik} v_{ik} + \hat{SCF}_{io}{}^2 \Sigma_k v^2_{ik})/(n_{io}-1)$.

An estimate of the total population (Section 3.7.3.2) is $T_e = \Sigma_i T_i \cdot SCF_{io}$, where $T_i$ denotes the estimate of observable moose in the $i^{th}$ stratum and is calculated using the formula in section 3.7.1.2. Using product variance formula (Goodman 1960), the variance of the population estimate (Section 3.7.3.3) is:

$$V(\hat{T}_e) = \Sigma\{_i \hat{SCF}_{io}{}^2[V(T_i)] + \hat{T}_i^2[V(\hat{SCF}_{io})] - V(\hat{SCF}_{io})[V(\hat{T}_i)]\},$$

where $V(\hat{T}_i)$ denotes the variance of the estimate of observable moose in the $i^{th}$ stratum and is calculated using the formula in section 3.7.1.3. The degrees of freedom for total moose (3.7.3.4) are:

$$\nu_o = [V(\hat{T}_e)]^2/\{\sum_i([V(\hat{T}_{ei})]^2/n_{io}-1))\}, \text{ where:}$$

$$V(\hat{T}_{ei}) = \hat{SCF}_{io}{}^2[V(T_i)\hat{]} + T_i^2[\hat{V}(SCF_{io})] - V(\hat{SCF}_{io})[V(\hat{T}_i)].$$

Optimal sample allocation (Section 3.10.3) is calculated using a forward stepwise approach to minimize the width of the confidence interval about the estimated population total for a fixed amount of sampling effort, measured in monetary terms. The optimization algorithm uses sampling costs for both the primary and secondary sample units as well as the constraints that units can only be sampled once and only 1 secondary sample unit can be selected per primary unit.

The bull:cow and calf:cow ratios (Section 5.5) are:

$$\hat{p} = \sum_i \hat{SCF}_{io} \cdot \hat{W}_{im} / \sum_i \hat{SCF}_{io} \cdot \hat{W}_{id}, \text{ where:}$$

$\hat{W}_{in}$ = estimated observable bulls or calves, depending on which ratio is being computed, in the $i^{th}$ stratum and can be calculated using the formula in section 5.2.2.

$\hat{W}_{id}$ = estimated observable cows in the $i^{th}$ stratum and can be calculated using the formula in section 5.2.2.

Using a first order Taylor series approximation on the above ratio and the assumptions that $cov(W_{in},SCF_{io})=0$ and $cov(W_{id},SCF_{io})=0$, the variance is calculated as:

$$V(\hat{p}) = (\sum_i \hat{S}CF_{io}{}^2 V(\hat{W}_{in})/[\sum_i \hat{S}FC_{io}\cdot\hat{W}_{id}]^2)$$
$$+ ([\sum_i \hat{S}FC_{io}\cdot\hat{W}_{in}]^2 \sum_i \hat{S}CF_{io} V(\hat{W}_{id})/[\sum_i \hat{S}FC_{io}\cdot\hat{W}_{id}]^2)$$
$$+ ((\sum_i[\hat{W}_{in}(\sum_i \hat{S}FC_{io}\cdot\hat{W}_{id})-\hat{W}_{id}(\sum_i \hat{S}FC_{io}\cdot\hat{W}_{in})]^2 V(\hat{S}CF_{io}))/[\sum_i \hat{S}FC_{io}\cdot\hat{W}_{id}]^4)$$
$$- (2(\sum_i \hat{S}FC_{io}\cdot\hat{W}_{in})\sum_i \hat{S}CF_{io} Cov(\hat{W}_{in},\hat{W}_{id}))/[\sum_i \hat{S}FC_{io}\cdot\hat{W}_{id}]^3).$$

Where $Cov(\hat{W}_{in},\hat{W}_{id})$ is calculated using the formula in section 5.5 of Gasaway *et al.* (1986). The degrees of freedom for the sex ratio is:

$\nu_p$ = minimum $[\nu_{wn},\nu_{wd}]$, where:

$$\nu_{wn} = [V(\hat{W}_{en})]^2/\{\sum_i([V(\hat{W}_{in})]^2/n_{io}-1)\};$$

$$V(\hat{W}_{en}) = \sum_i \hat{S}CF_{io}{}^2[V(\hat{W}_{in})] + \hat{W}_{in}{}^2[V(\hat{S}CF_{io})] - V(\hat{S}CF_{io})[V(\hat{W}_{in})];$$

$V(\hat{W}_{in})$ = the estimated variance for total observable age class in the numerator of the ratio, and is calculated using the formula in section 5.22;

$$\nu_{wd} = [V(\hat{W}_{ed})]^2/\{\sum_i([V(\hat{W}_{id})]^2/n_{io}-1)\};$$

$$V(\hat{W}_{en}) = \sum_i \hat{S}CF_{io}{}^2[V(\hat{W}_{id})] + \hat{W}_{id}{}^2[V(\hat{S}CF_{io})] - V(\hat{S}CF_{io})[V(\hat{W}_{id})];\text{ and}$$

$V(\hat{W}_{in})$ = the estimated variance for total observable age class in the denominator of the ratio, and is calculated using the formula in section 5.22.

## DISCUSSION

By pooling SCF data across strata, as in the GDRH approach, the variance of the population estimate is calculated incorrectly and the population estimate itself may be biased. Steinhorst and Samuel (1989) use a modified Horvitz-Thompson estimator to incorporate sightability correction into a population estimate of moose. For most applications, radio collared animals would be used to estimate sighting probabilities. If heterogeneous sightability exists, they feel that the population will be underestimated. In addition they recommend computation of sightability in predefined or postdefined strata to obtain improvements in accuracy.

In order to increase the power of the t-tests, an $\alpha$ of 0.20 was used. The use of Bonferroni comparisons to maintain an overall experiment-wise error rate of 0.20 further reduced the power of the tests. Even though large differences in SCF between strata were present in both GMU 14B and GMU 12, the power of the tests was poor.

Gasaway *et al.* (1986) state that, based on their experience, "...it is not economically feasible to estimate sightability where moose density is less than 1.0 moose/mi$^2$ (0.39 moose/km$^2$) nor is it feasible to estimate a SCF for each stratum...". Further experience with the GDRH sampling procedures has demonstrated that it is possible to estimate sightability by stratum and that sightability data can be obtained for strata with moose densities less than 0.39 moose/km$^2$. The estimated moose densities for the low, medium, and high strata associated with the SCF estimates for GMU 12 (Table 2) were 0.10, 0.29, and 0.46 moose/km$^2$ respectively (ADF&G unpublished data). The GDRH analytical procedure of pooling observations across strata was offered as a compromise solution to a perceived practical problem. Application of our modified procedures should be considered relative to the practical considerations raised by Gasaway *et al.* (1986).

We agree that it is difficult to learn much about sightability using GDRH sampling procedures where moose are scarce. Unfortunately, it is also impossible to learn anything about sightability if an attempt is not made to collect the data. Many practitioners of the GDRH method have trouble believing that seeing 0 moose during an intensive search after seeing 0 moose during the regular search is real data. This is indeed real data, and contributes 1 df to the SCF estimate, because it informs the observer that no moose were missed in that secondary sample unit during the regular search. Of the 8 secondary sample units surveyed to estimate SCF in the low stratum in GMU 12 (Table 2), 5 observations had no moose during the regular search. Of these 5, no moose were detected during the intensive search in 4 of the secondary sample units, however 2 moose were detected in one that were not seen during the regular search. Of the 17 secondary sample units surveyed in the medium strata, 9 had no moose during the regular search. Moose were discovered in 4 of these 9 secondary sample units during the intensive search. Obtaining unbiased estimates of SCF and its SE is preferable to biased estimates because the former are necessary to calculate unbiased estimates of $\hat{T}_e$ and its SE.

A situation may occur, when attempting to estimate sightability in low density strata, that SCF is not estimable because no moose are seen in any secondary sample units during the regular search. When no moose are seen during the intensive searches, the estimate of SCF is undefined mathematically, as was the case for the low density stratum in GMU 14B (Table 1). If moose are seen during the intensive searches with no moose during the regular searches, the estimate of SCF and its SE are infinity. We suggest 2 possible compromises for the practitioner faced with this type of data. One approach is to assume SCF is 1.0, with a SE of 0.0. The second approach is to evaluate the overall sightability conditions in the remaining strata, and use the estimate of SCF and its SE from the stratum most comparable to the strata with the insufficient SCF data. Either approach introduces bias into the expanded estimate of size ($\hat{T}_e$). We recommend the second compromise because it is likely to produce the most accurate estimate of ($\hat{T}_e$) and its SE. The approach introduces biases in point estimates and SE's of similar nature to those of the GDRH pooling approach. The biases are less severe than those of the GDRH approach because they will be introduced on a smaller scale and only when the compromise is necessary.

In the situation where only 1 secondary sample unit, of a given strata, had moose observed in it during the regular and intensive survey, the SCF point estimate and its SE will be unbiased. The SE of such an estimate will be 0 because only 1 sample unit had moose observed in it. In order to maintain unbiased estimates of $\hat{T}_e$ and its confidence interval, these estimates should be used in the modified formulas we have presented. Some practitioners will be tempted to use the second compromise presented above, however, to do so will lead to biased estimates. An additional solution to this problem is to sample more secondary sample units in this stratum and perhaps even enlarge the size of these units.

The Alaska Department of Fish and Game is in the process of implementing these modifications on future moose surveys. In future moose surveys, enough SCF data will be collected in the low stratum to ensure that the modified approach can be applied to all strata. A program has been developed to calculate modified GDRH moose population estimates using the formulas reported in this paper. The program requires an IBM compatible personal computer and is available from Dan Reed.

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