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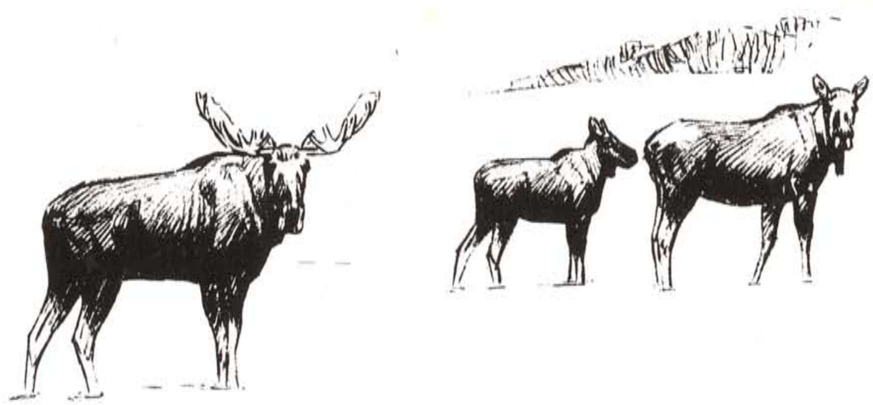
# Estimating moose population parameters from aerial surveys

*William C. Gasaway, Stephen D. DuBois,*
*Daniel J. Reed, and Samuel J. Harbo*



NUMBER 22

DECEMBER 1986

INSTITUTE OF ARCTIC BIOLOGY

ISSN 0568-8604

# *BIOLOGICAL PAPERS OF THE UNIVERSITY OF ALASKA*



**The Cover Illustration:** Moose group sketched in the Alaska Range by the late William D. Berry. Sketch provided for this publication by Elizabeth Berry, with the cooperation of the Rasmuson Library, Alaska and Polar Regional Collection, University of Alaska, Fairbanks.

*Financial and in-kind support for this issue were provided by:*
Alaska Department of Fish and Game, Division of Game, Juneau and Fairbanks
U.S. Fish and Wildlife Service, Office of Information Transfer

***Second Printing, December 1987***
**Courtesy of the** U.S. **Fish and** Wildlife Service, Division of Federal Aid, Region 7, Anchorage.

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Library of Congress Cataloging-in-Publication Data

Estimating moose population parameters from aerial surveys / by William C. Gasaway . . . [et al.]

(Biological Papers of the University of Alaska; no. 22)

1. Moose—Alaska. 2. Mammal population—Alaska. I. Gasaway, William C. II. Series.

QH1.A258 no. 22



Printed in the United States of America
by the U.S. Government Printing Office, Denver CO

**Second Printing, December 1987**

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# ESTIMATING MOOSE POPULATION PARAMETERS FROM AERIAL SURVEYS

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Number 22

ISSN 0568-8604

December 1986
**Second Printing, December 1987**

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# PREFACE

Successful moose management depends on knowledge of population dynamics. The principal population parameters required are size, rate of change, recruitment, sex composition, and mortality. Moose management in Alaska has been severely hampered by the lack of good estimates of these parameters, and unfortunately, this lack contributed to the decline of many Alaskan moose populations during the 1970s (e.g., Gasaway et al. 1983). The problems were: (1) population size was not adequately estimated, (2) rapid rates of decline were not acknowledged until populations were low, (3) meaningful recruitment rates were not available in the absence of good population estimates, and (4) calf and adult mortality rates were grossly underestimated.

Frustration of moose managers working with inadequate data led to the development of aerial survey procedures that yield minimally biased, sufficiently precise estimates of population parameters for most Alaskan moose management and research. This manual describes these procedures.

Development of these procedures would have been impossible without the inspiration, support, advice, and criticism of many colleagues. We thank these colleagues for their contributions. Dale Haggstrom and Dave Kelleyhouse helped develop flight patterns, tested and improved early sampling designs, and as moose managers, put these procedures into routine use. Pilots Bill Lentsch and Pete Haggland were instrumental in developing and testing aerial survey techniques. Their interest in and dedication to improving moose management made them valuable allies. Statisticians Dana Thomas of the University of Alaska and W. Scott Overton of Oregon State University provided advice on variance approximations for the population estimator. Warren Ballard, Sterling Miller, SuzAnne Miller, Doug Larsen, and Wayne Kale tested procedures and provided valuable criticisms and suggestions. Jim Raymond initially programmed a portable calculator to make lengthy calculations simple, fast, and error-free. Angie Babcock, Lisa Ingalls, Vicky Leffingwell, and Laura McManus patiently typed several versions of this manual. John Coady and Oliver Burris provided continuous moral and financial support for a 3-year project that lasted 6 years. Joann Barnett, Rodney Boertje, Steven Peterson, and Wayne Regelin of the Alaska Department of Fish and Game provided helpful editorial suggestions on previous drafts. Finally, we thank referees David Anderson of the Utah Cooperative Wildlife Research Unit, Vincent Schultz of Washington State University, and James Peek, E. "Oz" Garton, and Mike Samuel of the University of Idaho whose comments and suggestions improved this manual. This project was funded by the Alaska Department of Fish and Game through Federal Aid in Wildlife Restoration Projects W-17-9 through W-22-1.

# 1. INTRODUCTION

This is an instruction manual and field guide for estimating population parameters for moose in the circumpolar northern boreal forest, the subalpine zone, and the north-coastal shrub zone. Depending on the density of forest canopies in other areas, these methods may require some modifications or may not be usable. The manual is detailed and designed for field personnel. We describe one set of the many ways to estimate moose population parameters. We do not argue the pros and cons of the various methods available; however, we considered many options while developing the procedures in this manual and selected the ones best suited for our purposes. For alternatives to these techniques, we refer you to some of the many manuals and publications on estimating population parameters (e.g., Bergerud and Manuel 1969; Jolly 1969; Caughley and Goddard 1972; Caughley 1974, 1977; Croskery 1975; Caughley et al. 1976; Eberhardt 1978; Norton-Griffiths 1978; Cook and Jacobson 1979; Crête 1979; Thompson 1979; Burnham et al. 1980; Seber 1982; White et al. 1982; Gasaway and DuBois 1987).

Moose population parameters discussed in this manual are: (1) size; (2) rate of change; (3) sex and age composition and recruitment; and (4) distribution, i.e., spatial relative abundance. Mortality, the remaining important population parameter, is not addressed here, but it can be estimated indirectly from the four discussed parameters (Bergerud 1978, 1980). Population size is the most difficult of the four parameters to estimate. Given the method for estimating population size, methods for estimating other parameters follow easily. Therefore, estimating population size is a central part of this manual. For brevity, we use the term population estimate to specify an estimate of population size, i.e., number of moose in the population.

Estimating moose population size has always been a problem (Timmermann 1974), yet good estimates are essential for managers to understand population dynamics. In our view, methods for estimating population size must meet five criteria: (1) be unbiased, i.e., on the average not over- or underestimating actual population size; (2) provide an adequate level of precision (as indicated by the width of the confidence interval) based on realistic measures of major sampling errors; (3) be suitable for flat, hilly, and mountainous terrain; (4) not require special maps or aerial photos for sampling; and (5) be affordable.

Our method of estimating population size, based on a stratified random sampling design modified from Siniff and Skoog (1964) and Evans et al. (1966), satisfies these five criteria as follows: (1) bias is minimized by using flight patterns and search efforts that provide high sightability (percentage animals seen) of moose and by estimating a good sightability correction factor (SCF) for moose not seen, (2) estimates of precision combine both sampling variance of estimated observable moose and sampling variance of the estimated SCF, (3) suitability in all types of terrain is achieved by using irregularly shaped sample units (SU) and varying search patterns, and (4) special maps or photos are avoided by using natural terrain features on conventional topographic maps for SU boundaries.

Estimates of the remaining population parameters rely on data obtained from either surveys to estimate population size or separate application of portions of that survey method. Rate of population increase or decline is determined from a comparison of population estimates separated by one or more years. Estimates of sex composition and recruitment, obtained during population estimation surveys, contain little bias because of high sightability of moose and random sampling. Distribution, i.e., spatial relative abundance, is obtained by using the stratification process of the population estimation survey.

When precise and nearly unbiased methods for estimating population parameters become routine, new horizons will open for wildlife biologists. The effects of new management programs, habitat changes, severe winter weather, and predator-prey relationships can be evaluated with estimates of rate of population change. Harvest quotas and numbers of moose killed by hunters and predators can be more easily interpreted with good estimates of numbers of moose in sex-age classes. Numbers of moose killed can be compared to standing stock in sex-age classes, and rates of harvest can be estimated subsequently. Recruitment can be weighed against independent estimates of mortality to achieve a rapid assessment of population status and likely population trend. With a better grasp of the dynamics of a moose population, management options become more apparent. Portions of this manual are specific to estimating moose population parameters, e.g., population size; however, the concepts used can be applied to other species. Other estimation procedures in this manual, e.g., rate of population change, are more general and apply directly to many species.

Many of the formulas presented in this manual will be new to the reader. A statistician adept at sampling theory and methods will note that some are not quite appropriate theoretically due to violations of assumptions and that many formulas have a form of computation bias known as small-sample bias. We have been aware of these problems. Unfortunately, sampling theory offers no reliable, unbiased, computationally efficient formulas for many of the parameter estimates that we needed. In the statistical sense, the formulas we recommend are approximations. The formulas have been tested using computer simulation techniques and are reliable if the recommendations on methodology are followed.

This manual is a step-by-step field guide for conducting surveys and estimating population parameters. Although the manual is intended to be self-explanatory, we recommend that prior to conducting a population estimation survey all participants attend a workshop conducted by a person experienced with the technique. Examples of calculations are given to ensure correct treatment of data. To expedite calculations and reduce errors, programs have been written for the Hewlett-Packard 97 calculator (HP 97) to calculate optimal allocation of sampling effort, estimates of moose abundance, estimates of sex and age composition, and confidence intervals for all estimates. Upon request, we will supply copies of the programs on magnetic cards, or you may program the HP 97 directly from the program listings in Appendix 1. With minor changes, these programs can be adapted for the Hewlett-Packard 41C calculator. At the time of this printing, a program to perform these calculations is in development for IBM PC and compatible computers. Contact the authors for availability of the program. Sample forms are provided for recording observations and storing results. These forms may be photo-copied and used directly or modified to meet individual needs. The glossary defines abbreviations used in this manual.

Suggested reading in this manual varies with a person's involvement in estimating population parameters. Field staff involved only in aerial surveys should read Sections 2, 3.1 to 3.4, 3.5.2, 3.6.1 to 3.6.5.2, 3.6.6, and 6. Persons in charge of surveys and who calculate estimates of population parameters with a preprogrammed HP 97 should read all Sections except 3.8, 5.3, and 5.6. Persons in charge of surveys, but who calculate estimates of population parameters without a preprogrammed calculator, should read all Sections except 3.9, 3.11, 5.4, and 5.7.

Finally, if our descriptions of methods are unclear, feel free to contact us for clarification. Our phone numbers are (907) 456-5156 or 452-1531, and our address is ADF&G, 1300 College Road, Fairbanks, Alaska 99701.

## 2. REVIEW OF SAMPLING ERROR AND PRECISION

A review of sampling error and precision of estimates will be helpful before describing the methods of estimating population parameters. First, we define some commonly used terms. A population is a collection or set of individuals or objects whose properties are to be analyzed, e.g., all SUs in a survey area or moose in an area. A parameter is a numerical characteristic of an entire population. A sample is a subset of a population, and, typically, a random sample is one in which every element in the population has an equal probability of being chosen as part of the sample. For additional reading on sampling and precision estimation see White et al. (1982), Simpson et al. (1960), Stuart (1984), and Scheaffer et al. (1979).

A population parameter (e.g., density of moose) estimated from a random sample usually differs from the actual population parameter. This difference is a result of each SU differing in density from that of the overall density in the survey area; therefore, mean density in a sample of *n* SUs is a function of which SUs were selected. The mean of a second random sample would be expected to differ from the first as well as from the actual parameter by a random amount. The difference between the estimated value from one set of observations and the actual value is the sampling error.

We can use a general formula for calculating moose population size to demonstrate where sampling error enters population estimates. The actual number of moose is calculated as

$$\text{actual number of moose} = \text{actual density} \times \text{area}.$$

Although actual density cannot be determined, it can be estimated as

$$\begin{matrix}\text{estimated}\\\text{moose}\\\text{density}\end{matrix} = \begin{matrix}\text{estimated}\\\text{observable}\\\text{moose density}\end{matrix} \times \begin{matrix}\text{estimated}\\\text{correction factor}\\\text{for missed moose.}\end{matrix}$$

The correction factor for missed moose corrects for sightability bias. Substituting estimated density for actual density in the above formula, we get

$$\begin{matrix}\text{estimated}\\\text{number of}\\\text{moose}\end{matrix} = \begin{matrix}\text{estimated}\\\text{observable}\\\text{moose density}\end{matrix} \times \begin{matrix}\text{estimated}\\\text{correction factor}\\\text{for missed moose}\end{matrix} \times \text{area.}$$

Because each estimate has a random sampling error associated with it, the above formula can be rewritten to include these sampling errors, where area is measured without error.

$$\begin{matrix}\text{Actual}\\\text{number}\\\text{of moose}\end{matrix} = \begin{matrix}\text{estimated}\\\text{number of}\\\text{moose} + \epsilon_1\end{matrix} = \begin{matrix}\text{estimated}\\\text{observable}\\\text{moose}\\\text{density}\\+ \epsilon_2\end{matrix} \times \begin{matrix}\text{estimated}\\\text{correction}\\\text{factor for}\\\text{moose missed}\\+ \epsilon_3\end{matrix} \times \text{area}$$

where $\epsilon_i$ = the random sampling error for the *ith* estimate (i = 1, 2, 3). In this formula, the sampling error of the estimated number of moose, $\epsilon_1$ is affected by sampling errors associated with both density and missed moose, $\epsilon_2$ and $\epsilon_3$, respectively.

Now, let us look at an example of how variation in sampling error associated with moose density estimates affects population estimates. For the time being, assume 100% of the moose were seen in each SU searched, so that the estimate of missed moose drops out of the density equation. Figure 1 shows the fictitious Square Mountain survey area

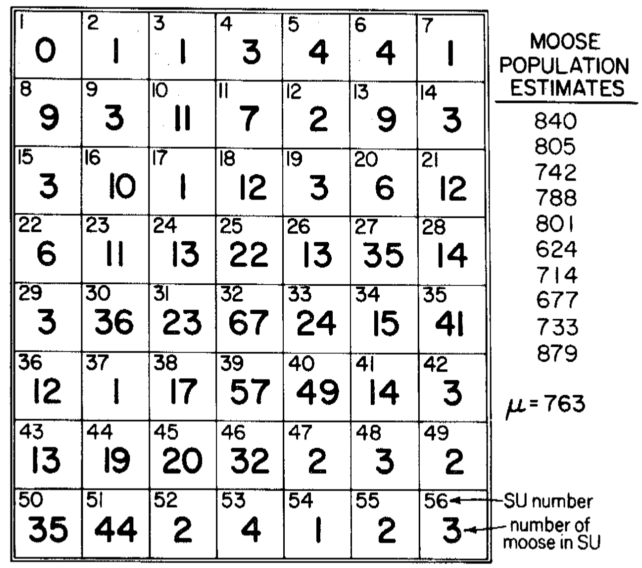


**Figure 1.** The fictitious Square Mountain survey area has 56 sample units (SUs) of 12 mi$^2$ each and has 763 moose. Ten sets of 32 SUs each were randomly selected and used to calculate 10 estimates. The estimator of population size = (no. of moose observed in surveyed SUs/ area of surveyed SUs) × total area.

from which 10 simple random samples of 32 SUs each were selected and surveyed. Two important points are demonstrated from results of the 10 surveys. First, population estimates are generally different (10 estimates ranged from 624 to 879 moose) and do not equal the actual number because of sampling error. Second, because sampling error is a random variable, it is impossible to tell how much an individual estimate differs from the actual value, i.e., how large the sampling error is for a particular sample, because the actual value is unknown.

Let us carry the idea of a sampling error of unknown size a little further. If a large number of random samples were taken from the Square Mountain population, the population estimates would form a distribution around the actual population size ($\mu$) (Fig. 2). However, during an actual survey, you do not have the option of calculating a large number of estimates. Generally only one sample of *n* SUs is selected and searched for moose. Therefore, only one of the many

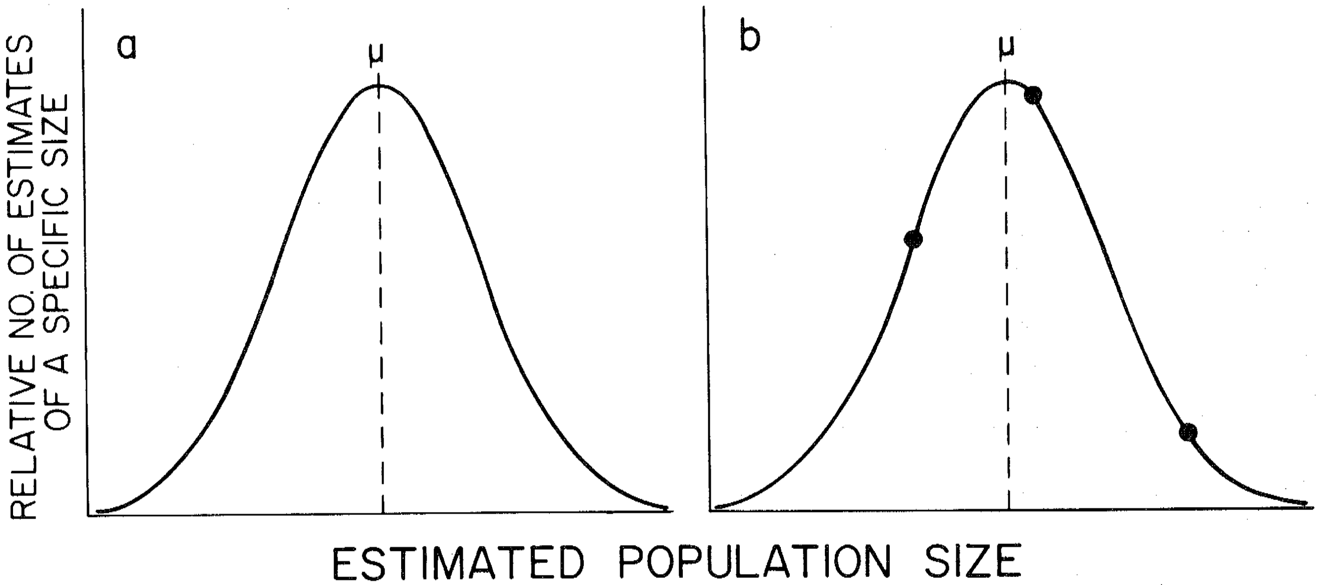


**Figure 2.** Frequency distribution of a large number of moose population estimates from the fictitious Square Mountain survey area. The actual population size equals *m*.

possible estimates of $\mu$ is obtained, and you cannot determine its location in the distribution of possible population estimates. The estimate may be very close to or far from $\mu$.

Sampling error also occurs when estimating sightability. This sampling error has an effect on population estimates similar to that described above for density estimates. Therefore, the final error component for the population estimate is a combination of the two sampling errors. Without a measure of the potential size of these errors, we have no way of knowing how much faith to put into the population estimate.

Fortunately, there is information within a sample that allows the potential size of the sampling error to be estimated. This information is the variation among SU measurements—the greater the variation, the greater the potential sample error. A calculated measure of variation is called the variance. A formula for the sample variance of a simple random sample of x's is

$$\text{sample variance of x} = \frac{\sum_j (x_j - \bar{x})^2}{n-1}$$

where $x_j$ is the measurement in the *jth* SU; $\bar{x}$ is the mean of measurements in the sample of SUs, $x_1 \ldots x_n$; *n* is the sample size ($n - 1$ is the degrees of freedom); and $\Sigma_j$ indicates the summation of the values for each $x_j$. Conceptually, sample variance is the average squared difference between individual SU measurements and the mean measurement of all SUs. The sample variance is a measure of the variation in the population being sampled and is used to calculate the sampling variance of the sample mean $\bar{x}$. The sampling variance is an indication of the potential size of the sampling error and is calculated as

$$\text{sampling variance of } \bar{x} = \frac{\text{sample variance of x}}{n}$$

Variance is used in part to measure the precision (repeatability) of estimates for density, sightability, and population size. Estimates of these parameters are of limited value unless precision of the estimates can be clearly specified. Although it is impossible to know the actual value of a parameter (e.g., number of moose), it is possible to describe a range of values, or interval, that is likely to include the actual value. This interval is the confidence interval (CI), and the specification of the CI is as important as the estimate itself (Simpson et al. 1960). For example, to have a population estimate of 1,000 moose for a study area is of little interest unless one has some idea how close it may be to the actual number.

A CI gives you a known probability ($1 - \alpha$) that the actual value of a parameter will be included within the CI. Another way of describing this concept is that, with repeated estimates, the CIs should include the actual population size a known percentage of the time. The probability of error ($\alpha$) is the proportion of CIs, from all possible samples and their estimates, that would not include the actual value. The probability of successfully including the actual value in a CI is specified when calculating the CI, e.g., 0.9, which is equal to $1 - \alpha$ where the probability of an error ($\alpha$) equals 0.1. The CI for an estimate has a specified probability of including the actual value, but you do not know for sure

Table 1. Population estimates and 90% confidence limits (CL) for 10 replicate surveys of 32 sample units from the fictitious Square Mountain survey area. The actual population is 763 moose.

| | Survey number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Population estimate | 840 | 805 | 742 | 788 | 801 | 624[a] | 714 | 677 | 733 | 879 |
| Upper CL | 1,024 | 973 | 905 | 974 | 968 | 761 | 870 | 824 | 895 | 1,048 |
| Lower CL | 656 | 637 | 575 | 601 | 635 | 487 | 558 | 530 | 572 | 709 |

[a] Confidence interval for this estimate does not contain the actual population size.

that $\mu$ is within the CI or where $\mu$ is relative to each estimate of $\mu$. To illustrate this concept, we calculated CIs for the 10 population estimates listed in Figure 1 for the fictitious Square Mountain survey area (Table 1). Each CI in Table 1 has a 0.90 probability of including $\mu$, and as expected, 9 out of 10 CIs included $\mu$. However, under actual survey conditions with only one estimate of $\mu$, you will not know if your CI is one of those that includes $\mu$; the probability simply tells you the odds of that CI including $\mu$. Now compare the 10 estimates of $\mu$ with the real $\mu$. Some estimates are close to $\mu$ whereas others are well above or below $\mu$; additionally, no two estimates are the same. Because you will make only one population estimate for an area, the estimate will also be some unknown amount above or below $\mu$. Therefore, you must depend on the CI to show the range in which the actual number may lie, and within that range, be prepared to accept the fact that $\mu$ may be near one of the CI limits or, infrequently, beyond a limit.

A general formula for a CI around an estimate ($\bar{x}$) of $\mu$ is

$$CI = \bar{x} \pm t_{\alpha,\nu}\sqrt{\text{sampling variance of } \bar{x}}$$

where $\bar{x}$ is the estimate based on the mean value in SUs, and and $t_{\alpha,\nu}$ is the critical $t$-value for the degrees of freedom ($\nu$) and the probability ($\alpha$) from our level of confidence ($1 - \alpha$). The formula clarifies how the variance of the estimate is used to calculate the CI.

The two major factors determining CI width are the sampling variance of the estimate and the specified degree of confidence you desire, $1 - \alpha$. As variance increases, the CI width for a specified $\alpha$ increases and precision decreases. The CI width is also altered by the degree of confidence you specify for the estimate. Unfortunately, as you decrease the degree of confidence ($1 - \alpha$) to narrow the CI, the probability that the actual value is within that range also decreases. You must decide if it is better to be nearly sure that the number of moose lies within a wide range, or to be less sure that it lies in a narrower range. It is solely up to you to choose the level of confidence for each case.

We recommend striving for precision equal to or greater than a 90% CI with a width less than ±25% of the population estimate. Ideally, one wants a CI with a high probability of containing the actual number of animals but that is also narrow in width, e.g., 95% CI with a width of ±5% of the estimated number of moose. However, wildlife biologists cannot expect to obtain a 95% CI that narrow because the large sampling effort required makes it prohibitively expensive. Therefore, a reasonable compromise must be sought for moose population estimates.

# 3. ESTIMATING POPULATION SIZE

## 3.1 INTRODUCTION

Procedures for a survey to estimate population size may seem complex at first; however, they are less formidable when viewed as six steps.

1. Define the population of interest and select a survey area.
2. Delineate all possible SUs on a topographic map of the survey area.
3. Stratify the survey area by conducting a preliminary aerial survey to determine relative moose densities.
4. Select a random sample of SUs from each stratum.
5. Fly surveys of selected SUs and recount some areas using a more intensive search pattern to estimate the percentage of moose that were missed.
6. Calculate an estimate of population size and CI around the estimate.

## 3.2 SELECTING THE SURVEY AREA

### 3.2.1 Survey Area Boundaries

The choice of survey area boundaries is determined by your needs. Managers often want to estimate the number of moose in a natural population. Thus, physiographic features such as major river drainages and ridges are selected as boundaries. In other instances, the population estimate is for a site-specific management problem; here more arbitrary boundaries of game management areas, study areas, refuges, parks, or proposed industrial sites become appropriate.

### 3.2.2 Size of Survey Area

The size of the survey area will influence the success or failure of a population estimation survey. Survey areas may range from 300 to 4,000 mi$^2$; smaller survey areas can usually be searched in their entirety, and larger survey areas will usually be impractical due to time constraints. Size of survey areas is dictated by the following variables:

1. *Precision desired.*—A survey area must decrease in size as precision of the estimate is increased, assuming a fixed cost. Precision is directly related to cost (see Section 3.11).

2. *Weather.*—Size of a manageable survey area is influenced by dominant weather patterns. Approximately 3 and 8 days of good flying weather are necessary to complete surveys of 300 and 4,000 mi$^2$, respectively. Large survey areas are practical only if long periods of good flying weather and snow conditions are predictable. When acceptable weather conditions last only a few consecutive days, small areas should be selected or large areas partitioned into several smaller areas. The important point is that a survey should be completed as rapidly as possible. If bad weather halts the operation long enough for moose distribution to shift substantially, you may be forced to start over.

3. *Manpower.*—Survey area size should be adjusted to the available manpower. At least three experienced pilot-observer teams are required to complete a survey rapidly. Large survey areas (3,000 to 4,000 mi$^2$) should not be attempted with less than four teams; five teams are preferred.

4. *Logistics.*—Considerations of cost and time available are important when selecting the size of the survey area. Surveys in remote areas increase fuel and lodging costs and may take longer to complete than surveys in less remote areas.

5. *Moose movements.*—If moose are expected to move extensively during the survey, select a small survey area or reschedule the survey.

## 3.3 SAMPLE UNITS

### 3.3.1 Defining Sample Units

A SU is the smallest delineated portion of the survey area that has a probability of being selected and searched in its entirety for moose. All moose habitat in the survey area is divided into SUs. Only that habitat which is clearly not suitable for moose is excluded. Generally, excluded habitat includes only glaciers, large lakes, and high portions of mountains; define these areas on a map prior to delineating SUs.

### 3.3.2 Drawing Sample Units

SUs are the foundation for the entire survey and must be drawn with a great deal of forethought. SUs should be drawn in pencil on maps of approximately 1:63,360 scale. A master survey area map should be hung on a wall in survey headquarters for logistical purposes. Consider the following factors when drawing each SU: (1) proper size and shape, (2) identifiable boundaries, and (3) habitat and moose distribution.

#### 3.3.2.1 Sample unit size and shape

SU size should range from 11 to 13 mi$^2$, although some may be out of this range because of lack of sufficient natural boundaries. Avoid making SUs smaller than 9 mi$^2$ or larger than 15 mi$^2$. Consistency in SU size improves precision of population estimates using our estimators because variation in SU size increases variance of the population estimate. The shape of SUs should be conducive to aerial searching. Avoid drawing SUs with narrow extensions protruding from the main body of the SU. After drawing each SU, visually estimate its size to confirm that it is 11 to 13 mi$^2$. A clear plastic template equaling 12 mi$^2$ (3 × 4 mi) on the map can be used to quickly check SU area.

Our SUs are large compared to SUs in most other sampling methods used to estimate numbers of moose. The reasons are: (1) easily identified natural physiographic features used to define SUs on maps do not occur with sufficient regularity to consistently describe small SUs; (2) fewer SUs are required if they are large than if they are small; therefore, the cost of flying between SUs and locating boundaries is reduced; and (3) for a fixed sum of money, sampling variance and CI width can be reduced by using large SUs, particularly in low-density moose populations.

### 3.3.2.2 Sample unit boundaries

Boundaries must be identifiable from the air; therefore, persons drawing SUs should be familiar with the survey area, survey procedures, and using topographic maps in flight. You will find SUs easiest to draw in hills and mountains and most difficult on flat, uniform terrain. Boundaries of SUs are generally trails, roads, lakes, gullies, creeks, rivers, ridges, and contour lines defining the upper limit of moose habitat; however, straight lines between two identifiable points are used when good topographic features are not available. Forks or bends in creeks, lakes, and peaks on ridges are convenient starting or ending points for straight boundary lines (Fig. 3). Straight line boundaries are difficult to define precisely from the air. For this reason, these vague boundaries should be placed in areas of very low moose density to minimize numbers of moose that may occur on or near the boundary. For example, dense spruce forest may have a very low moose density, hence a poorly defined boundary through it presents little problem because few moose will be encountered. A compass or visual heading is flown along the boundary while observations are made from only one side of the aircraft. This flight path establishes the boundary; subsequent flight lines are made toward the interior of the SU.

### 3.3.2.3 Habitat and moose distribution in sample units

Attempt to draw SUs that have uniform moose distribution and have boundaries that avoid habitat where moose are likely to concentrate. A uniform moose distribution within SUs speeds and improves the accuracy of stratification, which results in a more precise estimate of population size. Figure 4 shows a SU along a river drainage where moose concentrate near or above timberline. SU1 (Fig. 4) was drawn to include the alpine from the upper limit of moose habitat (4,000-ft contour) on the north side of the drainage, through the lowlands, and up to the limits of moose habitat on the south side of the drainage. SU1 contains a mixture of habitats with moose densities ranging from high on the upper side hills to low in the lowlands. This area can be redrawn into two more appropriate SUs, each having more

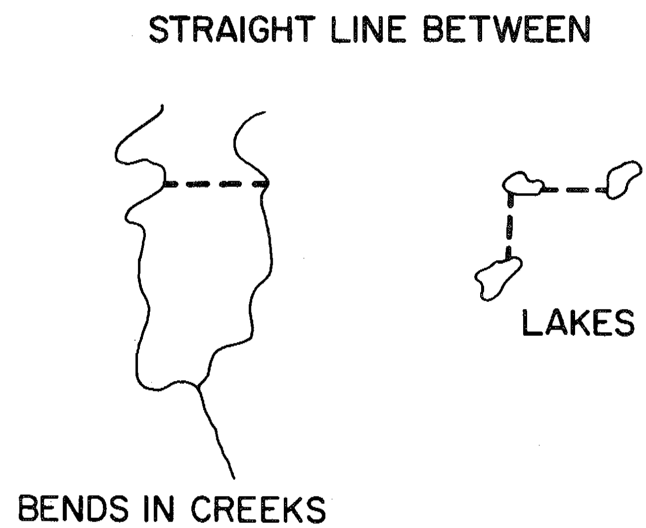


**Figure 3.** Straight line boundaries between topographic references are used to define sample unit boundaries when more prominent features are not available.

uniform habitat and moose density, e.g., SU2 and SU3 (Fig. 5). SU2 is drawn to enclose mainly subalpine and alpine habitat where moose densities are anticipated to be high, whereas SU3 (Fig. 5) contains mostly lowland habitat. SU2 and SU3 have a more uniform moose distribution than SU1. By drawing a new boundary on the 2,500 ft contour (Fig. 5), we have created a boundary that is impossible to locate exactly. However, in this drainage, moose are infrequently found in forested habitat near 2,500 ft elevation. Therefore, the imprecise boundary will cause few problems.

### 3.3.2.4 Numbering sample units

Give each SU a unique number for easy identification. Numbers are color coded for rapid relocation on the master survey area map. Blocks of approximately 50 contiguous SUs should each have a unique color.

### 3.3.2.5 Example: sample unit boundaries

Figure 6 illustrates SUs in mountainous and flat terrain. Each SU is between 11 and 13 mi$^2$ and can be easily distinguished when viewed from an airplane. Follow the boundaries of each SU noting the landmarks. Moose in the mountainous SUs of this area are commonly found in riparian willow along small creeks and gullies; therefore, most boundaries follow ridges. Creeks and gullies are avoided except in a few cases. In the lowland SUs, moose are distributed along the major river bottom; therefore, rivers are rarely used as a boundary. Straight line boundaries pass through black spruce forest where few moose are encountered.

## 3.4 STRATIFYING

To improve precision of the population estimate, one can either increase the number of SUs surveyed or use a sam-

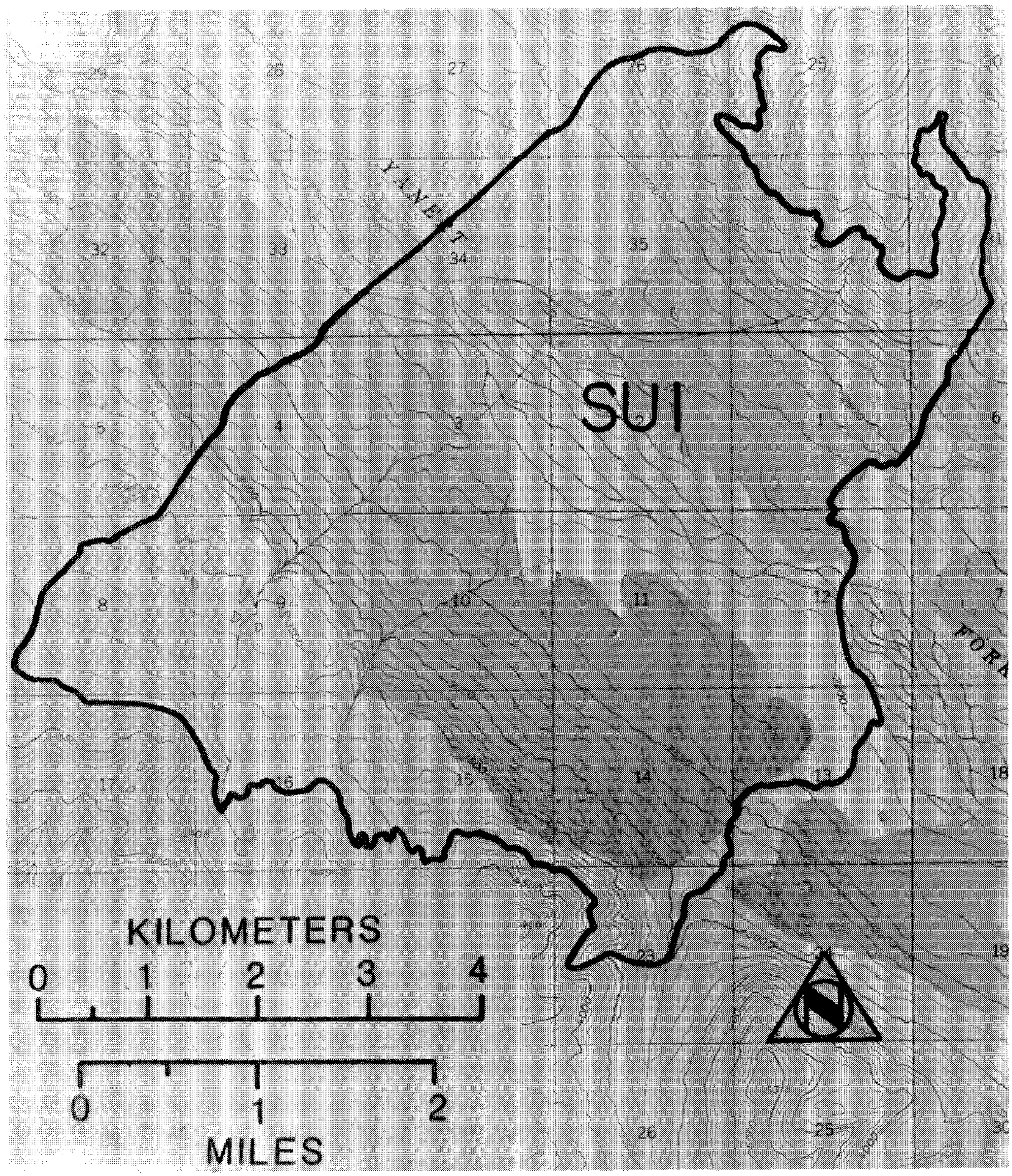


**Figure 4.** Sample unit 1 (SU1) includes upland and lowland moose habitat. During early winter, high moose densities exist in uplands and low densities exist in lowlands.

pling design that reduces variance. The stratified sampling design is a method that reduces variance. It is used to pool SUs into strata of differing moose density, thereby assigning as much total variance as possible to differences among strata. Variation among strata estimates does not contribute to the sampling variance of the population estimate. In this

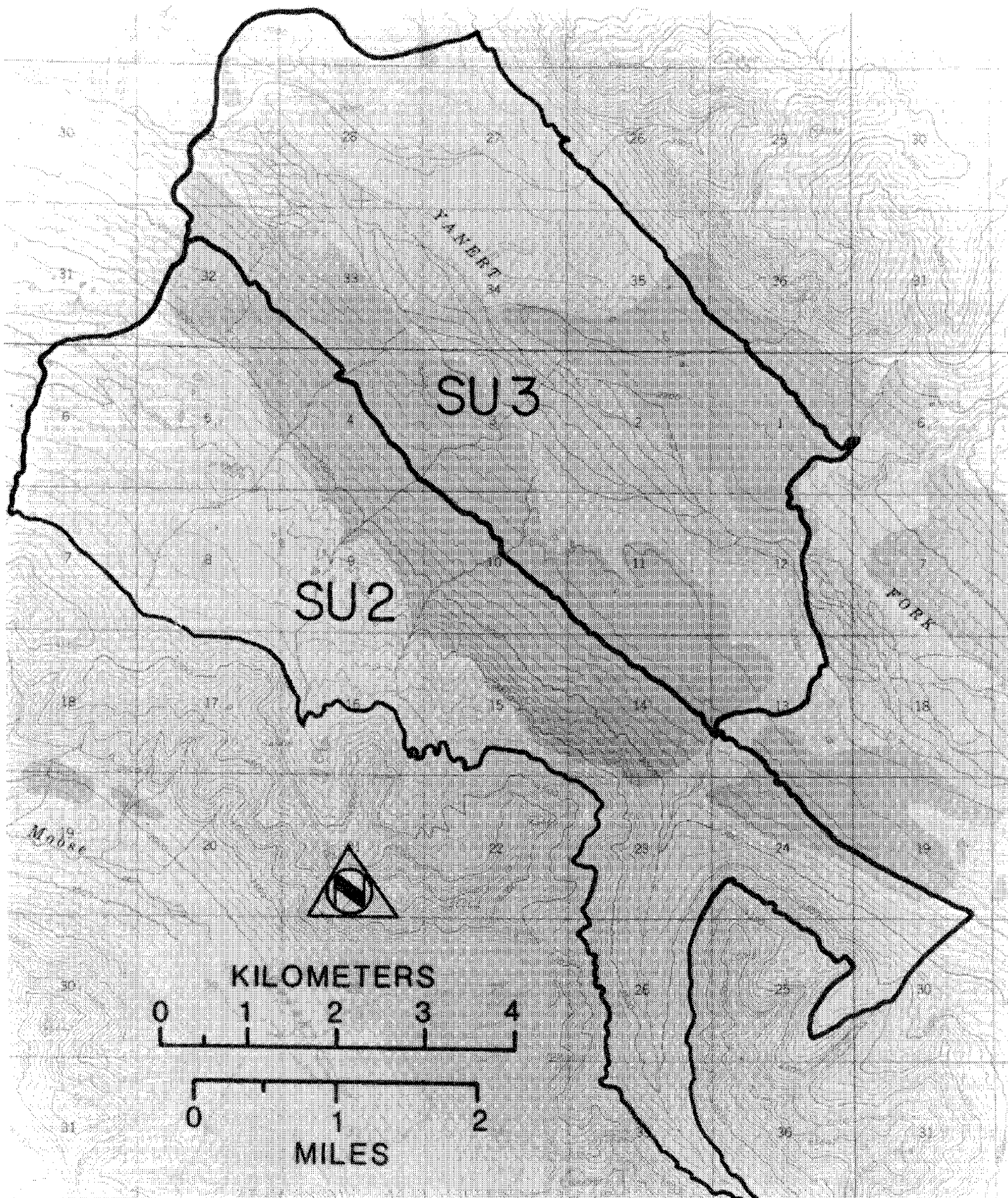


**Figure 5.** Sample unit 1 (SU1) in Figure 4 is redrawn into two new SUs, each having a more uniform moose distribution. Sample unit 2 (SU2) is upland habitat, and sample unit 3 (SU3) is lowland habitat. During early winter, moose concentrate in upland habitat.

way, the variance within strata is kept small, and this variance is used to estimate the precision of the population estimate.

In addition to increasing precision, stratification allows one optimally to allocate sampling effort among strata, thereby getting the most precision for your dollars (see Sec-

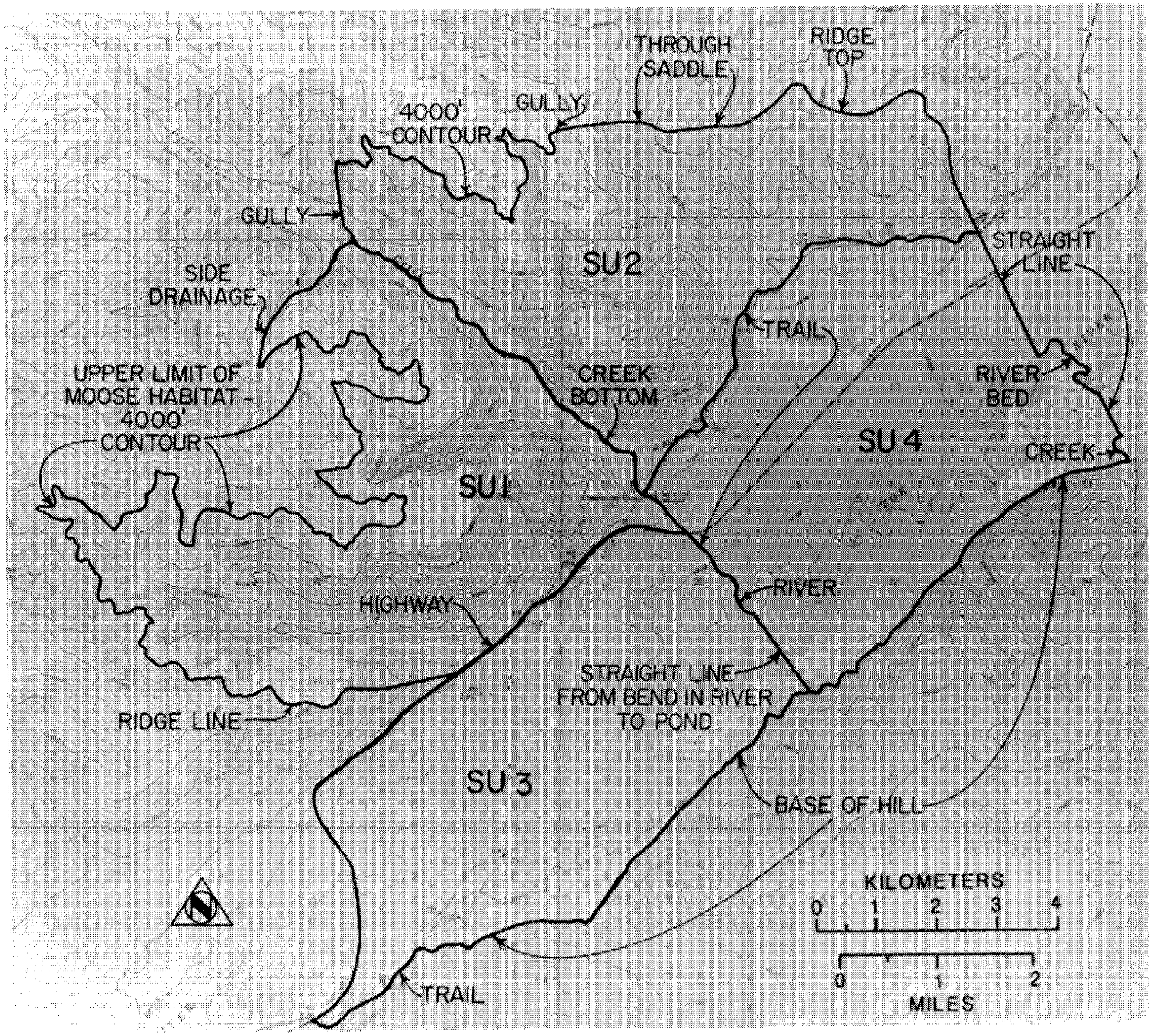


**Figure 6.** Example of sample units (SUs) in mountainous and lowland terrain. SU boundaries are creeks, gullies, ridges, rivers, straight lines between two points, and other features.

tion 3.8). In our experience, high-density strata generally have the greatest variance and, therefore, require the most sampling effort.

Stratification of the survey area is one of the most important aspects of estimating moose population size. The field procedure for stratifying involves classifying each SU into one of several relative moose density categories during a preliminary survey. Without a reliable stratification, it may be financially impossible to obtain a precise estimate. If stratification is done improperly, SUs will not be segregated into groups of relatively uniform density, causing increased variance, sample sizes, and costs. However, even a poor stratification will likely improve precision compared to unstratified random sampling.

### 3.4.1 Stratification Process

#### 3.4.1.1 Number of strata in a survey area

The number of strata within a survey area is based on your ability to identify areas having relatively homogeneous densities of moose. Generally, only three strata can be identified accurately. Suggested designations are high, medium, and low density. Occasionally, a fourth stratum will be found that consists of very high or very low density. This additional stratum usually has only a few SUs and therefore is surveyed in its entirety.

Moose densities within a stratum are relative values for that particular survey. For example, a high-density stratum may contain 1.8 moose/mi$^2$ in one survey area, and 3.2 moose/mi$^2$ in another.

### 3.4.1.2 Personnel and aircraft requirements

Stratification is most efficient with one crew consisting of three observers and a pilot. The observer sitting adjacent to the pilot navigates and records observations. The other two observers sit in backseats and search for moose and moose tracks and evaluate habitat. Only one crew is used to ensure consistent stratum classification among SUs. Stratifying SUs is subjective; therefore, two independent crews have difficulty maintaining continuity of classification. In our experience, savings in time with two crews were offset by larger variances resulting from inconsistent classification of SUs. Stratify using aircraft that fly 120 to 160 mph and carry three observers, e.g., a Helio Courier or Cessna 185, 206, or 207. Slow-flying aircraft such as Super Cubs should be used only when faster aircraft are not available. However, if a slow-flying 2-place airplane is used, flying at cruising speed is best. The pilot and observer must perform all the functions of a 4-person crew.

It can be advantageous to use a second plane for stratifying when only a few SUs remain to be stratified. Specifically, a Super Cub may be used to finish the stratification, thereby freeing two observers to begin searching SUs. The observer in the Cub should be a member of the original stratification crew.

### 3.4.1.3 In-flight procedures

Begin stratifying in those areas that you think have the highest and lowest densities. This allows the crew to observe and discuss the likely extremes in density.

Although the crew members must strive for accuracy, they must do so while stratifying at an average of 140 mi$^2$/hour (12 to 13 SUs/hour). The following factors necessitate this rate of speed.

1. Stratification is expensive. A Cessna 185 rented for approximately $185/hour in 1985, which totaled approximately $1,000 for a typical day's flying.

2. Surveying SUs cannot begin in full force until stratifying is complete. Delays increase the chance that bad weather will interrupt the survey.

3. Moose distribution is continually changing; therefore, the stratification becomes less accurate as time elapses between stratifying and surveying. Precision of the population estimate declines as the quality of the stratification deteriorates.

Flight time must be used efficiently for stratification to progress rapidly. Be prepared, use a fast airplane, and work long days. The navigator must locate SU boundaries on maps; therefore, have an accomplished map reader navigate so flight time is not wasted finding your location. A full day of map reading is exhausting when flying at 140 mph and 200 to 400 feet above the ground, so it helps to have two "mappers" in the crew. Increase the height of the aircraft above ground as the forest canopy becomes taller. The increased height improves the sightability of moose and moose tracks in tall timber.

Maximizing the efficiency of your flight path through each SU speeds stratification. An efficient flight path is illustrated in Figure 7*a*; this involves one pass along the side

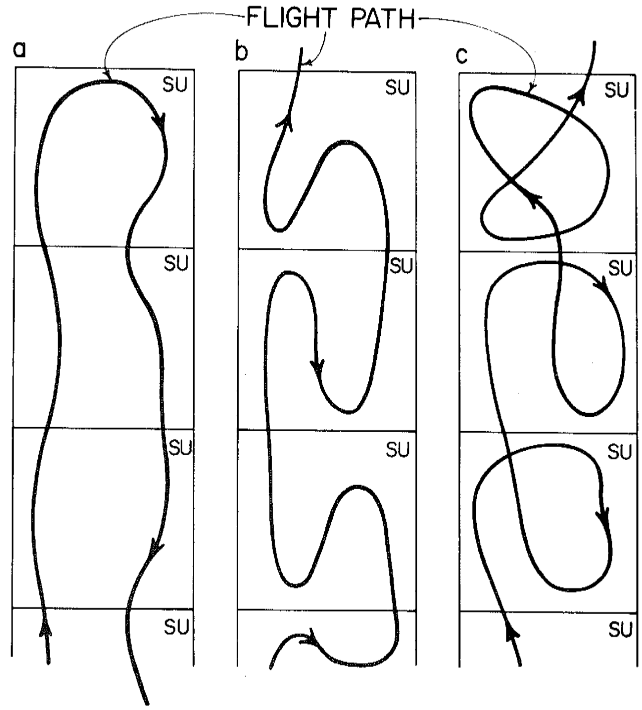


**Figure 7.** Examples of stratification flight path through sample units (SUs). (a) Recommended flight path that maximizes efficiency of flight time. (b) Flight path is too long for routine use but may be useful in SUs that are difficult to stratify. (c) Flight path is extremely long and rarely should be used.

of several SUs and then doubling back through the SUs. This flight path requires careful navigation and note-taking for each SU. The flight path in Figure 7*b* is 1.3 × longer than the flight path in Figure 7*a*; it may be useful when a little extra search effort is required in a SU. Because each SU must be stratified, there is a tendency to look at one SU at a time (Fig. 7*c*). This method invariably results in an excessive amount of search effort per SU and is approximately 1.6 × the length of the path in Figure 7*a*.

Spend the most time stratifying those SUs that are difficult to classify and the least time in easy SUs. Remember, the stratification flight is a superficial survey.

Stratification is based on a subjective evaluation of moose density, so use all clues that might indicate relative density. The following clues are helpful:

1. *Prior knowledge of moose distribution.*—This knowledge is based on previous surveys and habitat

use. Previous surveys are most useful if they have flight routes and locations of moose recorded. If the area was stratified previously, a copy of that stratification map will be useful.

2. *Relative number and distribution of moose seen during stratification.*—This is the most useful clue for stratification. Remember, however, that on the average 50 to 75% of the moose will be overlooked during stratification.

3. *Moose tracks.*—Track abundance is useful if major movements have not occurred since the last snowfall.

4. *Habitat type.*—Habitat type and moose density are often correlated. However, SUs should rarely be stratified solely on habitat. Ecotones often signal changes in moose density.

The only time stratification of SUs can be based solely on habitat is in large, homogeneous expanses of poor-quality habitat. A portion of a habitat block is stratified using direct clues of moose density, while the remainder of the block is stratified based only on habitat. For example, a 120-$mi^2$ block of muskeg and black spruce forest may be subdivided into 10 SUs. You may fly over three of the SUs noting the poor quality of habitat and absence of moose or moose tracks. You then place the three SUs in the low-density stratum and suspect the remaining seven SUs also have a comparable low density. To help confirm this, you check the SUs adjacent to better habitat and find no moose. Now satisfied, you classify all 10 SUs as low density, even though you did not fly over all of them. Some SUs would have been stratified based solely on habitat rather than on observed moose density. SUs stratified solely on habitat should be noted because this criterion becomes important if you restratify during the survey.

Recording the flight path, observations of moose and tracks, dominant habitat, and the stratum designation for each SU is mandatory during the stratification flight. This requires good communication among observers via a 4-way intercom. Portable units can be used in any plane. The backseat observers and pilot simply call out the number of moose or moose tracks seen to the navigator-recorder who marks the flight route and observations on the map. Each SU is placed into a stratum immediately after the SU is searched. If changes in SU boundaries or stratum classification are made later (but before sampling), the notes on moose, tracks, habitat, and flight lines will be invaluable.

### 3.4.1.4 Example: stratifying an area

Section 3 of this manual presents summary data on 10 population estimates in the fictitious Square Mountain survey area (Fig. 1). The estimates were based on a random selection of 32 SUs from an unstratified population of 763 moose. If the Square Mountain survey area were stratified based on moose density, a more precise population estimate should be produced with reduced sampling effort. Let us return to Square Mountain, stratify the survey area, and calculate 10 new population estimates.

Suppose you are in the stratification crew, and you just flew through SU27 collecting the following information:

1. 10 moose were seen.
2. Moderate number of tracks were present.
3. Habitat was generally good.
4. SU27 was surrounded by SUs already classified as medium density.
5. You expect high-density SUs to have at least 20 moose.
6. You expect medium-density SUs to have less than 20 moose.

While flying into the next SU, assimilate the facts and consider the following questions pertaining to SU27:

1. You saw 10 moose. Did you see sufficient tracks to indicate enough additional moose to make it a high-density SU? If there were not enough tracks to indicate equal to or greater than 10 additional moose, perhaps you saw a high percentage of the moose in this SU.
2. Should the SU be classified medium density? It is surrounded by medium-density SUs.
3. Is habitat quality the type associated with high densities?

You decide to classify SU27 as a high-density SU, and you stratify the remaining SUs using the same approach. There is some overlap in the range of densities within each stratum because stratification is not perfect.

Now that the stratification is completed, let us calculate 10 population estimates from stratified, random samples of 20 SUs each. Each sample was optimally allocated among three strata to minimize variance (see Section 3.8 for optimum allocation). The results of these estimates ranged from 698 to 849 moose, and precision of the estimates (90% CI) ranged from ±7 to 12% (Table 2). In comparison, population estimates from the simple random samples of Square Mountain SUs ranged from 624 to 879 and the 90% CI ranged from ±19 to 24% (Fig. 1, Table 2). Therefore, even with reduced sampling effort (20 versus 32 SUs), the estimates using stratification were more precise than those without stratification.

The stratified sampling technique produced estimates that had CIs averaging ±10% of the population estimate. However, if this level of precision were not needed, you could have sampled less than 20 SUs and still had better precision than that of the unstratified survey, resulting in saving time and money.

Table 2. Ten population estimates based on simple random samples of 32 sample units and stratified samples of 20 sample units from the fictitious Square Mountain survey area. The actual population is 763 moose.

| Survey no. | Simple random sample | | | Stratified sample | | |
|---|---|---|---|---|---|---|
| | Estimate | Variance | 90%CI (% of estimate) | Estimate | Variance | 90% CI (% of estimate) |
| 1 | 840 | 11,727 | 22 | 763 | 1,700 | 9 |
| 2 | 805 | 9,846 | 21 | 849 | 1,596 | 8 |
| 3 | 742 | 9,245 | 22 | 733 | 2,533 | 12 |
| 4 | 788 | 12,090 | 24 | 755 | 2,619 | 12 |
| 5 | 801 | 9,694 | 21 | 775 | 1,947 | 10 |
| 6 | 624 | 6,736 | 22 | 759 | 2,418 | 12 |
| 7 | 714 | 8,457 | 22 | 782 | 2,315 | 12 |
| 8 | 677 | 7,512 | 22 | 819 | 1,075 | 7 |
| 9 | 733 | 9,046 | 22 | 717 | 2,003 | 11 |
| 10 | 879 | 10,008 | 19 | 698 | 1,165 | 10 |
| Mean | 760 | | 22 | 765 | | 10 |

### 3.4.1.5 Redrawing sample unit boundaries before surveying

Some SU boundaries will need to be redrawn during and after the stratification flight but before being surveyed. The two situations that require redrawing of SU boundaries are:

1. *Highly variable moose densities occurring within a SU.*—Despite the initial attempt to make density uniform, some SUs may have both high- and low-density portions. If this makes it difficult to assign a SU to a stratum, redraw the boundaries of it and adjacent SUs as described in Section 3.3.2.

2. *Concentrations of moose on or near strata boundaries.*—Localized movement of moose may occur between adjacent SUs after stratification. The problem is most critical when moose move into lower density strata. Local movements generally increase the variance in the lower stratum more than the variance in the higher stratum.

A solution to the problem of moose moving between strata is to redraw the SU to include some lower density area within the perimeter of a high-density SU. This low-density strip helps ensure that moose within an adjacent medium- or high-density SU will be in the SU when it is later surveyed. For example, imagine a burned area subdivided into SUs. Each SU is stratified as high density and surrounded by black spruce forest that was classified as low density. A large number of moose may wander between the burn and the margins of the spruce. Therefore, the best SU boundary is within the spruce forest rather than at the edge of the burn. A subjective judgment must be made to determine where the influence of the edge grades into actual low moose density. We recommend extending the higher density SU 0.25 mi or more into the lower density area (Fig. 8).

Even though some SUs will be redrawn after the stratification, drawing SUs prior to stratification helps stratification flights proceed rapidly.

Sometimes the absence of topographic features precludes moving SU and stratum boundaries that pass through areas where moose concentrate. In this case, the new strata boundary is moved a specified distance from the existing boundary. An example is where SUs from the low and medium strata are separated by a creek with no other usable boundary for miles. Because moose tend to concentrate along riparian willow, many moose associated with the medium SU could be on either side of the creek. To ensure these moose are counted in the medium SU, the entire riparian willow strip should be included in the medium SU. Remember, the decision to include the entire riparian strip must be made before searching the SU, thereby holding bias to a minimum.

To indicate this special boundary situation, color the outside of the new medium-density SU boundary with a transparent colored marker. The colored mark indicates a predesignated boundary situation, e.g., the entire riparian strip, or a 100-yard strip beyond the creek. Adjusted SU boundaries are transferred to a master survey area map.

### 3.4.1.6 Changes in stratification during the survey

Restratifying during the survey may occasionally be legitimate. Areas incorrectly stratified might be identified while flying to and from SUs or while surveying adjacent SUs.

When the initial stratification was based on observed moose density (i.e., abundance of tracks or numbers of moose seen), incorrect stratification may be the result of moose movements during the survey, errors in track identification during stratification, or poor choices of SU boundaries. If errors are gross, it may be worthwhile to do another stratification flight for the SUs in question.

Table 3. Random numbers from 1 to 440. Numbers were generated on the Hewlett-Packard 97 calculator.

| Row | Column 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 384 | 225 | 54 | 142 | 257 | 104 | 269 | 92 | 414 | 170 | 60 | 155 | 209 | 363 | 272 | 295 | 414 | 135 |
| 2 | 337 | 29 | 186 | 228 | 167 | 57 | 138 | 275 | 331 | 61 | 138 | 38 | 284 | 47 | 79 | 234 | 145 | 135 |
| 3 | 45 | 136 | 437 | 427 | 26 | 146 | 124 | 393 | 7 | 92 | 231 | 257 | 403 | 414 | 384 | 373 | 48 | 305 |
| 4 | 143 | 297 | 420 | 362 | 252 | 265 | 284 | 427 | 150 | 150 | 334 | 301 | 67 | 361 | 153 | 259 | 276 | 60 |
| 5 | 13 | 269 | 244 | 68 | 131 | 299 | 414 | 190 | 220 | 79 | 182 | 64 | 143 | 122 | 243 | 81 | 248 | 327 |
| 6 | 432 | 158 | 160 | 71 | 207 | 384 | 353 | 165 | 255 | 198 | 59 | 394 | 348 | 267 | 160 | 310 | 279 | 341 |
| 7 | 160 | 271 | 419 | 132 | 429 | 99 | 437 | 156 | 121 | 324 | 210 | 424 | 252 | 249 | 289 | 357 | 150 | 34 |
| 8 | 401 | 407 | 157 | 288 | 67 | 121 | 184 | 348 | 396 | 419 | 223 | 39 | 290 | 47 | 125 | 152 | 132 | 291 |
| 9 | 133 | 326 | 54 | 326 | 15 | 276 | 80 | 429 | 195 | 58 | 401 | 169 | 51 | 307 | 339 | 431 | 148 | 224 |
| 10 | 64 | 134 | 226 | 178 | 14 | 301 | 149 | 74 | 389 | 393 | 273 | 41 | 178 | 373 | 18 | 15 | 130 | 320 |
| 11 | 272 | 271 | 253 | 16 | 238 | 404 | 323 | 353 | 95 | 209 | 400 | 149 | 211 | 419 | 202 | 5 | 134 | 286 |
| 12 | 154 | 312 | 139 | 314 | 68 | 351 | 206 | 31 | 224 | 78 | 400 | 398 | 295 | 344 | 89 | 331 | 422 | 420 |
| 13 | 439 | 152 | 223 | 408 | 347 | 83 | 56 | 145 | 136 | 425 | 408 | 176 | 143 | 302 | 102 | 249 | 41 | 57 |
| 14 | 370 | 358 | 264 | 91 | 283 | 118 | 136 | 205 | 285 | 27 | 161 | 180 | 407 | 325 | 125 | 279 | 410 | 25 |
| 15 | 196 | 184 | 332 | 401 | 349 | 132 | 210 | 193 | 350 | 122 | 113 | 157 | 361 | 268 | 223 | 298 | 64 | 419 |
| 16 | 263 | 434 | 298 | 140 | 157 | 276 | 217 | 361 | 401 | 89 | 118 | 145 | 422 | 130 | 221 | 46 | 354 | 335 |
| 17 | 281 | 249 | 29 | 36 | 189 | 340 | 308 | 361 | 428 | 209 | 245 | 152 | 34 | 3 | 433 | 298 | 150 | 94 |
| 18 | 353 | 335 | 177 | 64 | 192 | 250 | 256 | 357 | 72 | 211 | 369 | 89 | 41 | 2 | 290 | 36 | 282 | 440 |
| 19 | 159 | 350 | 45 | 440 | 354 | 303 | 262 | 122 | 113 | 396 | 194 | 20 | 286 | 367 | 376 | 215 | 252 | 35 |
| 20 | 1 | 391 | 382 | 124 | 153 | 39 | 181 | 262 | 106 | 8 | 214 | 332 | 426 | 89 | 435 | 73 | 260 | 426 |
| 21 | 72 | 260 | 247 | 137 | 158 | 149 | 330 | 352 | 374 | 328 | 131 | 91 | 364 | 347 | 196 | 217 | 322 | 72 |
| 22 | 29 | 75 | 49 | 79 | 224 | 208 | 313 | 109 | 14 | 260 | 350 | 285 | 135 | 58 | 416 | 405 | 216 | 322 |
| 23 | 16 | 20 | 404 | 127 | 121 | 114 | 302 | 362 | 101 | 1 | 127 | 62 | 250 | 129 | 80 | 328 | 266 | 403 |
| 24 | 221 | 248 | 121 | 60 | 344 | 37 | 73 | 366 | 350 | 65 | 90 | 224 | 5 | 159 | 320 | 225 | 99 | 397 |
| 25 | 323 | 21 | 167 | 37 | 253 | 225 | 48 | 328 | 54 | 213 | 18 | 329 | 171 | 86 | 396 | 336 | 440 | 264 |
| 26 | 32 | 63 | 374 | 204 | 25 | 185 | 172 | 312 | 248 | 220 | 409 | 135 | 238 | 270 | 383 | 264 | 246 | 107 |
| 27 | 311 | 115 | 185 | 21 | 188 | 297 | 257 | 397 | 111 | 193 | 28 | 126 | 226 | 46 | 120 | 244 | 231 | 277 |
| 28 | 109 | 247 | 347 | 97 | 101 | 31 | 40 | 331 | 291 | 76 | 128 | 361 | 28 | 145 | 396 | 276 | 331 | 52 |
| 29 | 405 | 87 | 355 | 15 | 206 | 424 | 120 | 265 | 351 | 125 | 261 | 276 | 73 | 386 | 233 | 115 | 136 | 225 |
| 30 | 141 | 7 | 289 | 65 | 213 | 208 | 34 | 93 | 184 | 138 | 261 | 5 | 101 | 150 | 175 | 152 | 253 | 228 |
| 31 | 247 | 380 | 296 | 170 | 249 | 141 | 403 | 28 | 46 | 135 | 74 | 176 | 349 | 272 | 312 | 198 | 338 | 146 |
| 32 | 98 | 361 | 343 | 64 | 203 | 375 | 258 | 104 | 379 | 187 | 75 | 139 | 91 | 145 | 392 | 21 | 397 | 350 |
| 33 | 368 | 259 | 126 | 303 | 68 | 71 | 190 | 201 | 103 | 310 | 8 | 308 | 316 | 387 | 292 | 36 | 169 | 258 |
| 34 | 329 | 44 | 266 | 274 | 11 | 392 | 58 | 31 | 163 | 250 | 340 | 178 | 401 | 245 | 11 | 370 | 130 | 317 |
| 35 | 46 | 209 | 33 | 374 | 4 | 283 | 438 | 97 | 378 | 66 | 205 | 181 | 364 | 210 | 264 | 11 | 291 | 325 |
| 36 | 252 | 350 | 62 | 153 | 222 | 210 | 230 | 406 | 16 | 110 | 273 | 311 | 96 | 368 | 129 | 430 | 119 | 310 |
| 37 | 334 | 211 | 252 | 398 | 59 | 114 | 297 | 210 | 213 | 412 | 10 | 158 | 150 | 233 | 176 | 331 | 102 | 189 |
| 38 | 415 | 110 | 217 | 350 | 276 | 87 | 195 | 218 | 331 | 8 | 291 | 415 | 388 | 413 | 330 | 322 | 84 | 119 |
| 39 | 172 | 126 | 153 | 29 | 245 | 426 | 256 | 187 | 150 | 334 | 164 | 175 | 3 | 34 | 429 | 318 | 156 | 63 |
| 40 | 127 | 371 | 208 | 215 | 328 | 243 | 111 | 68 | 198 | 405 | 205 | 304 | 95 | 202 | 105 | 191 | 179 | 313 |
| 41 | 48 | 25 | 276 | 290 | 107 | 235 | 365 | 220 | 201 | 303 | 192 | 66 | 335 | 337 | 50 | 247 | 51 | 14 |
| 42 | 51 | 77 | 119 | 200 | 353 | 151 | 63 | 433 | 228 | 103 | 142 | 256 | 286 | 430 | 85 | 236 | 368 | 396 |
| 43 | 59 | 414 | 375 | 333 | 181 | 432 | 108 | 354 | 104 | 239 | 109 | 64 | 22 | 87 | 326 | 280 | 124 | 303 |
| 44 | 84 | 362 | 271 | 102 | 341 | 55 | 276 | 20 | 319 | 440 | 433 | 407 | 324 | 194 | 438 | 426 | 276 | 61 |
| 45 | 154 | 383 | 271 | 12 | 130 | 151 | 435 | 36 | 203 | 62 | 347 | 93 | 426 | 40 | 347 | 286 | 147 | 406 |
| 46 | 63 | 292 | 126 | 98 | 71 | 390 | 413 | 321 | 385 | 263 | 436 | 367 | 431 | 47 | 169 | 163 | 229 | 266 |
| 47 | 226 | 234 | 235 | 64 | 424 | 367 | 10 | 221 | 100 | 427 | 176 | 255 | 229 | 403 | 137 | 67 | 343 | 354 |
| 48 | 365 | 270 | 82 | 412 | 176 | 101 | 44 | 161 | 246 | 281 | 146 | 420 | 45 | 166 | 398 | 169 | 125 | 92 |
| 49 | 340 | 235 | 144 | 125 | 70 | 370 | 209 | 250 | 299 | 2 | 215 | 298 | 423 | 240 | 24 | 243 | 23 | 78 |
| 50 | 1 | 364 | 262 | 52 | 70 | 207 | 122 | 193 | 200 | 83 | 436 | 216 | 52 | 293 | 35 | 262 | 186 | 161 |
| 51 | 75 | 145 | 245 | 331 | 394 | 290 | 96 | 78 | 128 | 382 | 41 | 323 | 341 | 128 | 210 | 34 | 281 | 355 |
| 52 | 423 | 172 | 282 | 426 | 16 | 409 | 202 | 205 | 346 | 33 | 363 | 161 | 101 | 27 | 255 | 397 | 424 | 190 |

Table 3. Continued.

| Row | Column 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53 | 345 | 417 | 322 | 56 | 45 | 380 | 120 | 130 | 400 | 8 | 213 | 259 | 207 | 14 | 41 | 297 | 321 | 322 |
| 54 | 153 | 294 | 351 | 335 | 332 | 142 | 113 | 225 | 79 | 44 | 349 | 145 | 316 | 283 | 63 | 151 | 265 | 34 |
| 55 | 82 | 97 | 381 | 236 | 216 | 352 | 283 | 148 | 144 | 257 | 184 | 262 | 355 | 315 | 284 | 78 | 334 | 237 |
| 56 | 249 | 163 | 56 | 342 | 371 | 158 | 88 | 286 | 44 | 370 | 28 | 366 | 96 | 272 | 142 | 97 | 184 | 341 |
| 57 | 307 | 177 | 324 | 44 | 230 | 117 | 218 | 80 | 197 | 79 | 304 | 201 | 106 | 10 | 128 | 1 | 159 | 397 |
| 58 | 287 | 226 | 389 | 59 | 241 | 232 | 74 | 120 | 220 | 330 | 92 | 344 | 124 | 302 | 181 | 54 | 329 | 382 |
| 59 | 362 | 348 | 206 | 154 | 15 | 270 | 123 | 103 | 143 | 338 | 399 | 16 | 159 | 17 | 259 | 147 | 16 | 426 |
| 60 | 145 | 315 | 198 | 403 | 319 | 266 | 291 | 135 | 148 | 345 | 84 | 66 | 82 | 428 | 185 | 121 | 40 | 332 |
| 61 | 27 | 282 | 329 | 12 | 54 | 207 | 243 | 373 | 4 | 293 | 374 | 388 | 139 | 287 | 136 | 163 | 258 | 77 |
| 62 | 112 | 76 | 50 | 154 | 350 | 175 | 9 | 164 | 409 | 125 | 373 | 124 | 42 | 330 | 93 | 429 | 328 | 264 |
| 63 | 167 | 121 | 371 | 19 | 314 | 399 | 258 | 46 | 320 | 212 | 307 | 211 | 399 | 319 | 426 | 321 | 361 | 72 |
| 64 | 262 | 36 | 439 | 245 | 145 | 155 | 82 | 297 | 123 | 127 | 241 | 52 | 438 | 392 | 201 | 256 | 370 | 60 |
| 65 | 191 | 101 | 151 | 260 | 401 | 59 | 49 | 425 | 220 | 319 | 437 | 342 | 38 | 271 | 13 | 27 | 271 | 102 |
| 66 | 253 | 338 | 30 | 261 | 378 | 80 | 106 | 358 | 294 | 381 | 155 | 161 | 91 | 80 | 27 | 45 | 59 | 235 |
| 67 | 381 | 191 | 39 | 211 | 314 | 128 | 138 | 24 | 406 | 290 | 167 | 297 | 104 | 186 | 211 | 172 | 131 | 300 |
| 68 | 350 | 365 | 401 | 144 | 419 | 118 | 135 | 158 | 86 | 152 | 113 | 126 | 213 | 139 | 58 | 336 | 132 | 371 |
| 69 | 18 | 108 | 417 | 384 | 134 | 298 | 7 | 142 | 316 | 218 | 277 | 50 | 317 | 98 | 48 | 158 | 75 | 359 |
| 70 | 268 | 130 | 10 | 1 | 394 | 317 | 320 | 47 | 325 | 364 | 350 | 366 | 16 | 279 | 349 | 197 | 282 | 350 |
| 71 | 399 | 428 | 50 | 274 | 107 | 88 | 104 | 339 | 139 | 18 | 135 | 250 | 306 | 60 | 68 | 318 | 262 | 365 |
| 72 | 196 | 404 | 427 | 199 | 26 | 192 | 216 | 360 | 223 | 315 | 247 | 200 | 438 | 2 | 194 | 48 | 440 | 286 |
| 73 | 348 | 56 | 397 | 136 | 409 | 335 | 419 | 68 | 431 | 377 | 67 | 158 | 241 | 242 | 243 | 318 | 164 | 119 |
| 74 | 217 | 351 | 267 | 50 | 52 | 163 | 46 | 438 | 346 | 283 | 268 | 363 | 212 | 359 | 82 | 326 | 71 | 387 |
| 75 | 108 | 24 | 206 | 244 | 349 | 15 | 225 | 145 | 315 | 387 | 114 | 262 | 135 | 408 | 197 | 44 | 243 | 51 |
| 76 | 158 | 140 | 188 | 157 | 160 | 36 | 230 | 396 | 361 | 108 | 248 | 180 | 84 | 422 | 381 | 314 | 428 | 380 |
| 77 | 218 | 127 | 11 | 20 | 132 | 109 | 429 | 435 | 26 | 14 | 336 | 120 | 303 | 22 | 153 | 202 | 25 | 297 |
| 78 | 225 | 93 | 309 | 39 | 138 | 264 | 45 | 360 | 92 | 403 | 148 | 381 | 55 | 295 | 185 | 188 | 70 | 111 |
| 79 | 162 | 19 | 127 | 102 | 375 | 366 | 411 | 364 | 332 | 98 | 101 | 210 | 284 | 364 | 341 | 138 | 406 | 427 |
| 80 | 78 | 225 | 218 | 250 | 171 | 103 | 439 | 82 | 177 | 374 | 28 | 421 | 421 | 81 | 58 | 61 | 86 | 255 |
| 81 | 137 | 379 | 367 | 236 | 110 | 117 | 434 | 426 | 220 | 206 | 409 | 136 | 395 | 80 | 17 | 220 | 337 | 11 |
| 82 | 235 | 91 | 74 | 439 | 296 | 190 | 136 | 408 | 375 | 288 | 263 | 423 | 142 | 243 | 2 | 245 | 387 | 313 |
| 83 | 269 | 313 | 297 | 220 | 340 | 298 | 378 | 146 | 244 | 142 | 433 | 267 | 433 | 268 | 330 | 222 | 98 | 304 |
| 84 | 97 | 265 | 11 | 281 | 424 | 137 | 218 | 81 | 93 | 33 | 193 | 60 | 431 | 227 | 28 | 331 | 41 | 130 |
| 85 | 173 | 337 | 376 | 266 | 132 | 68 | 22 | 397 | 196 | 338 | 259 | 207 | 380 | 186 | 100 | 30 | 361 | 148 |
| 86 | 300 | 373 | 57 | 166 | 152 | 182 | 144 | 377 | 403 | 217 | 60 | 135 | 255 | 418 | 53 | 343 | 4 | 343 |
| 87 | 369 | 335 | 220 | 179 | 3 | 423 | 198 | 247 | 132 | 6 | 102 | 89 | 55 | 2 | 344 | 87 | 359 | 129 |
| 88 | 310 | 189 | 411 | 261 | 70 | 102 | 246 | 287 | 207 | 224 | 189 | 337 | 420 | 381 | 146 | 121 | 141 | 166 |
| 89 | 340 | 326 | 244 | 8 | 366 | 90 | 223 | 208 | 135 | 335 | 211 | 424 | 409 | 305 | 232 | 292 | 189 | 387 |
| 90 | 78 | 9 | 11 | 432 | 213 | 363 | 305 | 60 | 285 | 294 | 284 | 167 | 299 | 189 | 320 | 425 | 123 | 302 |
| 91 | 263 | 326 | 100 | 140 | 328 | 323 | 311 | 145 | 5 | 362 | 232 | 242 | 132 | 139 | 428 | 135 | 3 | 280 |
| 92 | 203 | 215 | 99 | 157 | 104 | 330 | 418 | 322 | 46 | 315 | 427 | 59 | 136 | 265 | 394 | 240 | 89 | 54 |
| 93 | 205 | 331 | 312 | 138 | 99 | 111 | 284 | 94 | 82 | 356 | 44 | 16 | 359 | 342 | 5 | 350 | 387 | 209 |
| 94 | 344 | 207 | 243 | 382 | 146 | 106 | 36 | 119 | 284 | 337 | 221 | 66 | 352 | 404 | 148 | 371 | 343 | 107 |
| 95 | 118 | 4 | 424 | 437 | 56 | 255 | 419 | 88 | 314 | 427 | 129 | 337 | 111 | 83 | 296 | 113 | 47 | 305 |
| 96 | 350 | 362 | 231 | 345 | 178 | 250 | 99 | 260 | 222 | 19 | 20 | 427 | 262 | 172 | 286 | 317 | 328 | 79 |
| 97 | 58 | 56 | 282 | 69 | 161 | 401 | 105 | 379 | 365 | 141 | 180 | 440 | 361 | 358 | 153 | 382 | 195 | 284 |
| 98 | 293 | 175 | 365 | 101 | 67 | 12 | 90 | 395 | 307 | 160 | 355 | 313 | 340 | 49 | 227 | 178 | 370 | 318 |
| 99 | 330 | 210 | 303 | 341 | 29 | 241 | 83 | 100 | 21 | 207 | 199 | 413 | 368 | 149 | 340 | 289 | 196 | 89 |
| 100 | 85 | 172 | 175 | 26 | 342 | 162 | 271 | 440 | 409 | 195 | 344 | 147 | 16 | 369 | 278 | 281 | 235 | 204 |
| 101 | 138 | 339 | 216 | 271 | 12 | 412 | 144 | 155 | 223 | 285 | 356 | 30 | 355 | 43 | 411 | 161 | 420 | 81 |
| 102 | 427 | 329 | 394 | 47 | 319 | 306 | 102 | 126 | 121 | 303 | 294 | 134 | 146 | 181 | 333 | 421 | 222 | 245 |
| 103 | 13 | 217 | 381 | 284 | 139 | 94 | 20 | 139 | 124 | 272 | 410 | 291 | 175 | 25 | 24 | 273 | 412 | 64 |
| 104 | 361 | 183 | 79 | 148 | 104 | 30 | 21 | 178 | 85 | 432 | 115 | 265 | 344 | 337 | 151 | 20 | 318 | 86 |
| 105 | 317 | 136 | 189 | 187 | 381 | 84 | 397 | 346 | 377 | 86 | 295 | 270 | 124 | 212 | 63 | 259 | 136 | 428 |

Table 3. Continued.

| Row | Column 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 106 | 426 | 156 | 311 | 309 | 151 | 280 | 169 | 46 | 180 | 110 | 332 | 91 | 73 | 199 | 128 | 249 | 319 | 177 |
| 107 | 318 | 187 | 437 | 306 | 160 | 151 | 200 | 177 | 254 | 279 | 325 | 251 | 232 | 357 | 200 | 207 | 74 | 150 |
| 108 | 246 | 260 | 87 | 151 | 103 | 189 | 391 | 378 | 236 | 174 | 189 | 190 | 432 | 177 | 34 | 184 | 198 | 357 |
| 109 | 226 | 94 | 133 | 59 | 435 | 343 | 48 | 208 | 305 | 257 | 81 | 353 | 287 | 137 | 177 | 155 | 18 | 298 |
| 110 | 327 | 243 | 403 | 294 | 164 | 418 | 343 | 14 | 30 | 401 | 354 | 153 | 292 | 95 | 382 | 246 | 129 | 100 |
| 111 | 285 | 238 | 63 | 404 | 23 | 367 | 229 | 127 | 188 | 67 | 223 | 295 | 415 | 403 | 58 | 164 | 320 | 92 |
| 112 | 253 | 425 | 260 | 76 | 130 | 147 | 215 | 31 | 335 | 257 | 364 | 150 | 314 | 295 | 235 | 361 | 332 | 221 |
| 113 | 57 | 151 | 370 | 99 | 130 | 311 | 83 | 16 | 200 | 263 | 154 | 268 | 313 | 319 | 162 | 299 | 322 | 176 |
| 114 | 295 | 384 | 315 | 24 | 226 | 127 | 122 | 199 | 437 | 105 | 203 | 415 | 61 | 180 | 163 | 38 | 282 | 35 |
| 115 | 240 | 159 | 90 | 193 | 10 | 278 | 40 | 370 | 339 | 176 | 14 | 126 | 34 | 313 | 180 | 170 | 97 | 61 |
| 116 | 214 | 53 | 303 | 84 | 327 | 300 | 343 | 237 | 295 | 51 | 378 | 85 | 326 | 403 | 388 | 349 | 436 | 176 |
| 117 | 247 | 230 | 257 | 343 | 238 | 3 | 294 | 281 | 279 | 319 | 417 | 219 | 227 | 177 | 285 | 184 | 2 | 33 |
| 118 | 377 | 233 | 295 | 184 | 103 | 276 | 151 | 193 | 410 | 231 | 20 | 77 | 433 | 317 | 413 | 9 | 332 | 101 |
| 119 | 6 | 52 | 208 | 360 | 112 | 136 | 159 | 367 | 40 | 41 | 399 | 395 | 376 | 76 | 20 | 334 | 81 | 87 |
| 120 | 1 | 164 | 238 | 14 | 316 | 237 | 253 | 209 | 420 | 212 | 60 | 134 | 53 | 316 | 78 | 174 | 45 | 329 |
| 121 | 412 | 425 | 46 | 39 | 111 | 28 | 304 | 130 | 341 | 265 | 170 | 323 | 11 | 192 | 356 | 283 | 88 | 316 |
| 122 | 424 | 205 | 384 | 185 | 328 | 43 | 369 | 320 | 122 | 63 | 223 | 80 | 58 | 155 | 251 | 20 | 164 | 159 |
| 123 | 64 | 223 | 258 | 308 | 256 | 307 | 369 | 290 | 302 | 192 | 179 | 125 | 216 | 331 | 121 | 154 | 59 | 55 |
| 124 | 189 | 10 | 411 | 366 | 417 | 233 | 315 | 348 | 234 | 74 | 370 | 125 | 201 | 26 | 17 | 335 | 100 | 430 |
| 125 | 62 | 203 | 206 | 421 | 231 | 285 | 68 | 38 | 12 | 350 | 246 | 267 | 73 | 359 | 113 | 43 | 50 | 77 |
| 126 | 324 | 174 | 376 | 133 | 429 | 278 | 211 | 189 | 170 | 386 | 14 | 396 | 172 | 355 | 238 | 360 | 312 | 348 |
| 127 | 230 | 46 | 110 | 64 | 423 | 56 | 332 | 241 | 92 | 258 | 263 | 245 | 284 | 294 | 294 | 104 | 120 | 420 |
| 128 | 211 | 394 | 167 | 68 | 261 | 277 | 417 | 93 | 213 | 343 | 210 | 113 | 15 | 176 | 135 | 248 | 221 | 396 |
| 129 | 357 | 329 | 362 | 321 | 86 | 82 | 57 | 155 | 73 | 246 | 131 | 110 | 267 | 174 | 135 | 80 | 384 | 184 |
| 130 | 148 | 201 | 196 | 127 | 392 | 219 | 30 | 305 | 122 | 232 | 426 | 246 | 53 | 276 | 322 | 12 | 241 | 152 |
| 131 | 241 | 392 | 282 | 145 | 265 | 214 | 193 | 405 | 72 | 351 | 262 | 356 | 255 | 67 | 223 | 135 | 389 | 32 |
| 132 | 33 | 403 | 367 | 99 | 432 | 4 | 233 | 265 | 175 | 51 | 377 | 366 | 400 | 209 | 40 | 141 | 26 | 87 |
| 133 | 34 | 279 | 279 | 329 | 314 | 54 | 56 | 405 | 385 | 63 | 202 | 197 | 354 | 35 | 89 | 4 | 403 | 342 |
| 134 | 14 | 410 | 55 | 317 | 153 | 372 | 437 | 237 | 10 | 71 | 240 | 374 | 152 | 429 | 198 | 406 | 107 | 125 |
| 135 | 24 | 166 | 17 | 380 | 112 | 56 | 355 | 285 | 207 | 44 | 331 | 168 | 172 | 414 | 403 | 68 | 388 | 263 |
| 136 | 157 | 181 | 424 | 257 | 197 | 87 | 156 | 358 | 123 | 92 | 324 | 241 | 130 | 424 | 260 | 85 | 66 | 438 |
| 137 | 253 | 368 | 320 | 132 | 44 | 311 | 285 | 107 | 367 | 220 | 266 | 94 | 33 | 133 | 420 | 238 | 344 | 317 |
| 138 | 152 | 224 | 305 | 301 | 385 | 20 | 88 | 54 | 397 | 146 | 165 | 338 | 229 | 376 | 17 | 256 | 207 | 315 |
| 139 | 351 | 222 | 129 | 340 | 190 | 226 | 137 | 247 | 201 | 52 | 137 | 408 | 440 | 266 | 281 | 69 | 171 | 337 |
| 140 | 187 | 107 | 408 | 165 | 139 | 224 | 138 | 267 | 75 | 166 | 128 | 380 | 374 | 358 | 319 | 416 | 92 | 34 |
| 141 | 426 | 326 | 234 | 185 | 183 | 259 | 6 | 272 | 293 | 221 | 179 | 43 | 70 | 432 | 264 | 85 | 225 | 339 |
| 142 | 11 | 300 | 83 | 283 | 288 | 246 | 401 | 96 | 231 | 197 | 224 | 86 | 94 | 154 | 309 | 439 | 44 | 110 |
| 143 | 247 | 440 | 406 | 383 | 74 | 159 | 73 | 360 | 292 | 286 | 84 | 126 | 191 | 170 | 273 | 32 | 328 | 169 |
| 144 | 208 | 243 | 63 | 411 | 354 | 385 | 177 | 54 | 67 | 248 | 170 | 326 | 375 | 184 | 142 | 136 | 359 | 109 |
| 145 | 216 | 172 | 42 | 437 | 387 | 49 | 258 | 116 | 376 | 183 | 132 | 199 | 68 | 348 | 36 | 232 | 267 | 270 |
| 146 | 251 | 429 | 158 | 234 | 96 | 43 | 123 | 412 | 285 | 414 | 34 | 123 | 4 | 10 | 291 | 335 | 172 | 383 |
| 147 | 234 | 146 | 31 | 294 | 124 | 3 | 304 | 190 | 8 | 42 | 440 | 376 | 93 | 203 | 115 | 406 | 13 | 410 |
| 148 | 68 | 255 | 187 | 91 | 94 | 322 | 64 | 254 | 133 | 189 | 121 | 120 | 250 | 161 | 276 | 100 | 20 | 19 |
| 149 | 201 | 166 | 119 | 340 | 89 | 341 | 375 | 317 | 186 | 362 | 108 | 138 | 143 | 163 | 192 | 159 | 430 | 319 |
| 150 | 55 | 307 | 207 | 144 | 385 | 254 | 52 | 17 | 188 | 231 | 402 | 118 | 194 | 229 | 363 | 371 | 438 | 247 |
| 151 | 244 | 36 | 312 | 428 | 370 | 235 | 417 | 363 | 1 | 125 | 378 | 276 | 400 | 389 | 369 | 309 | 289 | 287 |
| 152 | 16 | 265 | 54 | 396 | 61 | 30 | 103 | 304 | 162 | 246 | 271 | 212 | 153 | 189 | 220 | 89 | 405 | 253 |
| 153 | 70 | 157 | 221 | 369 | 130 | 327 | 388 | 382 | 426 | 316 | 297 | 363 | 422 | 37 | 122 | 163 | 360 | 212 |
| 154 | 21 | 77 | 108 | 169 | 94 | 183 | 393 | 250 | 177 | 81 | 187 | 320 | 256 | 4 | 403 | 187 | 52 | 83 |
| 155 | 40 | 201 | 136 | 299 | 45 | 29 | 356 | 223 | 260 | 393 | 391 | 51 | 38 | 172 | 395 | 411 | 281 | 169 |
| 156 | 123 | 384 | 80 | 207 | 204 | 306 | 37 | 243 | 288 | 226 | 97 | 303 | 328 | 393 | 150 | 364 | 417 | 243 |
| 157 | 276 | 82 | 43 | 330 | 272 | 203 | 251 | 170 | 203 | 429 | 9 | 38 | 72 | 355 | 234 | 394 | 331 | 298 |
| 158 | 221 | 316 | 257 | 137 | 259 | 233 | 313 | 427 | 360 | 298 | 53 | 106 | 399 | 135 | 209 | 173 | 7 | 9 |

Table 3. Continued.

| Row | Column 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 159 | 243 | 351 | 36 | 109 | 348 | 46 | 272 | 58 | 391 | 331 | 421 | 232 | 182 | 23 | 396 | 341 | 225 | 198 |
| 160 | 20 | 434 | 417 | 158 | 257 | 237 | 367 | 351 | 432 | 278 | 380 | 26 | 382 | 204 | 324 | 75 | 115 | 425 |
| 161 | 1 | 204 | 177 | 121 | 413 | 13 | 99 | 167 | 368 | 339 | 400 | 385 | 114 | 375 | 118 | 341 | 98 | 391 |
| 162 | 80 | 248 | 337 | 360 | 271 | 403 | 163 | 406 | 246 | 330 | 133 | 186 | 421 | 321 | 26 | 314 | 67 | 163 |
| 163 | 275 | 348 | 56 | 115 | 316 | 83 | 26 | 176 | 414 | 265 | 51 | 47 | 18 | 39 | 268 | 303 | 291 | 327 |
| 164 | 296 | 130 | 230 | 86 | 336 | 227 | 320 | 226 | 287 | 108 | 254 | 238 | 333 | 192 | 76 | 291 | 295 | 415 |
| 165 | 354 | 120 | 234 | 155 | 363 | 387 | 220 | 30 | 14 | 221 | 156 | 281 | 18 | 279 | 236 | 214 | 171 | 437 |
| 166 | 271 | 9 | 242 | 172 | 187 | 347 | 262 | 45 | 9 | 113 | 383 | 364 | 300 | 193 | 95 | 422 | 190 | 331 |
| 167 | 266 | 170 | 257 | 37 | 395 | 327 | 258 | 87 | 265 | 85 | 122 | 293 | 254 | 169 | 184 | 112 | 316 | 18 |
| 168 | 74 | 86 | 145 | 55 | 347 | 244 | 65 | 302 | 241 | 163 | 335 | 190 | 359 | 293 | 95 | 372 | 309 | 166 |
| 169 | 334 | 241 | 72 | 321 | 14 | 39 | 368 | 349 | 337 | 206 | 344 | 127 | 2 | 11 | 400 | 419 | 188 | 180 |
| 170 | 210 | 234 | 191 | 419 | 281 | 280 | 333 | 242 | 212 | 152 | 104 | 86 | 345 | 266 | 95 | 49 | 178 | 193 |
| 171 | 375 | 178 | 311 | 8 | 73 | 156 | 160 | 317 | 337 | 119 | 115 | 312 | 298 | 392 | 232 | 344 | 357 | 34 |
| 172 | 379 | 162 | 229 | 276 | 142 | 153 | 69 | 131 | 285 | 7 | 369 | 328 | 114 | 322 | 245 | 151 | 284 | 424 |
| 173 | 129 | 137 | 279 | 209 | 104 | 36 | 351 | 56 | 397 | 329 | 194 | 305 | 101 | 230 | 167 | 414 | 154 | 342 |
| 174 | 377 | 223 | 410 | 432 | 218 | 270 | 429 | 185 | 112 | 306 | 81 | 243 | 72 | 20 | 279 | 226 | 278 | 350 |
| 175 | 72 | 310 | 420 | 58 | 15 | 149 | 207 | 41 | 161 | 369 | 200 | 373 | 108 | 47 | 259 | 93 | 313 | 398 |
| 176 | 250 | 399 | 160 | 347 | 157 | 159 | 70 | 427 | 9 | 151 | 54 | 393 | 361 | 231 | 167 | 404 | 217 | 50 |
| 177 | 431 | 89 | 11 | 247 | 111 | 123 | 198 | 433 | 227 | 197 | 169 | 234 | 285 | 237 | 345 | 224 | 168 | 87 |
| 178 | 314 | 234 | 385 | 103 | 250 | 116 | 416 | 209 | 83 | 256 | 168 | 174 | 175 | 24 | 257 | 313 | 418 | 132 |
| 179 | 175 | 272 | 2 | 183 | 393 | 417 | 251 | 326 | 404 | 107 | 59 | 291 | 109 | 48 | 335 | 291 | 235 | 306 |
| 180 | 382 | 135 | 278 | 41 | 267 | 294 | 7 | 412 | 104 | 201 | 116 | 135 | 130 | 87 | 105 | 288 | 247 | 347 |
| 181 | 228 | 76 | 410 | 342 | 288 | 186 | 306 | 30 | 16 | 419 | 202 | 92 | 363 | 100 | 284 | 168 | 17 | 370 |
| 182 | 82 | 86 | 256 | 234 | 435 | 276 | 175 | 235 | 124 | 63 | 109 | 97 | 131 | 321 | 382 | 375 | 247 | 422 |
| 183 | 395 | 71 | 352 | 264 | 46 | 366 | 148 | 404 | 296 | 325 | 281 | 9 | 61 | 125 | 309 | 230 | 366 | 71 |
| 184 | 252 | 220 | 366 | 440 | 407 | 152 | 237 | 204 | 225 | 209 | 210 | 63 | 373 | 119 | 361 | 34 | 154 | 379 |
| 185 | 278 | 377 | 326 | 113 | 247 | 47 | 16 | 79 | 429 | 205 | 356 | 364 | 62 | 123 | 214 | 158 | 331 | 171 |
| 186 | 204 | 85 | 295 | 385 | 400 | 158 | 327 | 381 | 64 | 44 | 296 | 94 | 352 | 436 | 53 | 377 | 376 | 98 |
| 187 | 396 | 140 | 116 | 26 | 402 | 88 | 49 | 107 | 429 | 415 | 143 | 395 | 201 | 133 | 129 | 200 | 87 | 221 |
| 188 | 99 | 421 | 161 | 51 | 324 | 334 | 149 | 223 | 240 | 39 | 341 | 238 | 305 | 69 | 9 | 228 | 347 | 386 |
| 189 | 366 | 310 | 308 | 161 | 216 | 277 | 304 | 68 | 62 | 253 | 379 | 342 | 88 | 404 | 353 | 264 | 224 | 139 |
| 190 | 164 | 29 | 54 | 255 | 378 | 426 | 261 | 84 | 35 | 73 | 376 | 287 | 58 | 124 | 243 | 438 | 265 | 394 |
| 191 | 357 | 84 | 242 | 52 | 146 | 166 | 235 | 305 | 110 | 215 | 141 | 326 | 52 | 430 | 58 | 304 | 102 | 136 |
| 192 | 165 | 35 | 103 | 299 | 204 | 42 | 180 | 243 | 313 | 365 | 80 | 287 | 103 | 209 | 320 | 346 | 36 | 63 |
| 193 | 8 | 388 | 332 | 105 | 295 | 14 | 369 | 110 | 24 | 386 | 394 | 146 | 282 | 253 | 165 | 408 | 115 | 436 |
| 194 | 384 | 245 | 438 | 256 | 230 | 343 | 18 | 388 | 433 | 213 | 372 | 367 | 302 | 301 | 101 | 71 | 267 | 24 |
| 195 | 190 | 223 | 108 | 269 | 430 | 88 | 124 | 180 | 13 | 286 | 207 | 234 | 96 | 371 | 268 | 43 | 251 | 186 |
| 196 | 126 | 158 | 181 | 133 | 30 | 231 | 136 | 218 | 391 | 118 | 384 | 213 | 224 | 129 | 227 | 207 | 293 | 238 |
| 197 | 63 | 250 | 200 | 136 | 309 | 406 | 336 | 260 | 217 | 317 | 287 | 416 | 266 | 424 | 380 | 305 | 22 | 144 |
| 198 | 194 | 140 | 257 | 386 | 190 | 138 | 364 | 251 | 209 | 354 | 420 | 311 | 91 | 244 | 361 | 400 | 108 | 267 |
| 199 | 278 | 331 | 408 | 126 | 91 | 304 | 367 | 139 | 377 | 347 | 363 | 251 | 345 | 437 | 159 | 110 | 76 | 60 |
| 200 | 219 | 291 | 242 | 72 | 29 | 216 | 48 | 38 | 101 | 91 | 150 | 73 | 359 | 419 | 282 | 396 | 181 | 401 |
| 201 | 379 | 156 | 42 | 50 | 369 | 356 | 103 | 229 | 148 | 71 | 40 | 350 | 49 | 366 | 240 | 74 | 416 | 43 |
| 202 | 416 | 363 | 10 | 62 | 200 | 36 | 152 | 274 | 8 | 222 | 299 | 74 | 354 | 381 | 85 | 115 | 56 | 232 |
| 203 | 356 | 403 | 307 | 271 | 39 | 61 | 43 | 231 | 307 | 252 | 288 | 337 | 5 | 293 | 304 | 342 | 105 | 439 |
| 204 | 276 | 391 | 161 | 321 | 112 | 116 | 27 | 82 | 117 | 264 | 286 | 334 | 336 | 44 | 200 | 106 | 19 | 64 |
| 205 | 41 | 330 | 103 | 366 | 80 | 277 | 71 | 97 | 102 | 219 | 221 | 186 | 258 | 234 | 225 | 127 | 132 | 136 |
| 206 | 101 | 360 | 323 | 191 | 90 | 284 | 285 | 204 | 355 | 83 | 167 | 324 | 2 | 235 | 181 | 3 | 53 | 227 |
| 207 | 224 | 258 | 298 | 320 | 16 | 139 | 68 | 418 | 82 | 266 | 115 | 402 | 36 | 37 | 202 | 155 | 173 | 112 |
| 208 | 228 | 7 | 363 | 307 | 440 | 54 | 47 | 365 | 120 | 43 | 171 | 193 | 301 | 193 | 85 | 15 | 369 | 100 |
| 209 | 39 | 201 | 427 | 56 | 436 | 437 | 432 | 437 | 355 | 145 | 362 | 201 | 154 | 77 | 218 | 227 | 127 | 301 |
| 210 | 374 | | | | | | | | | | | | | | | | | |

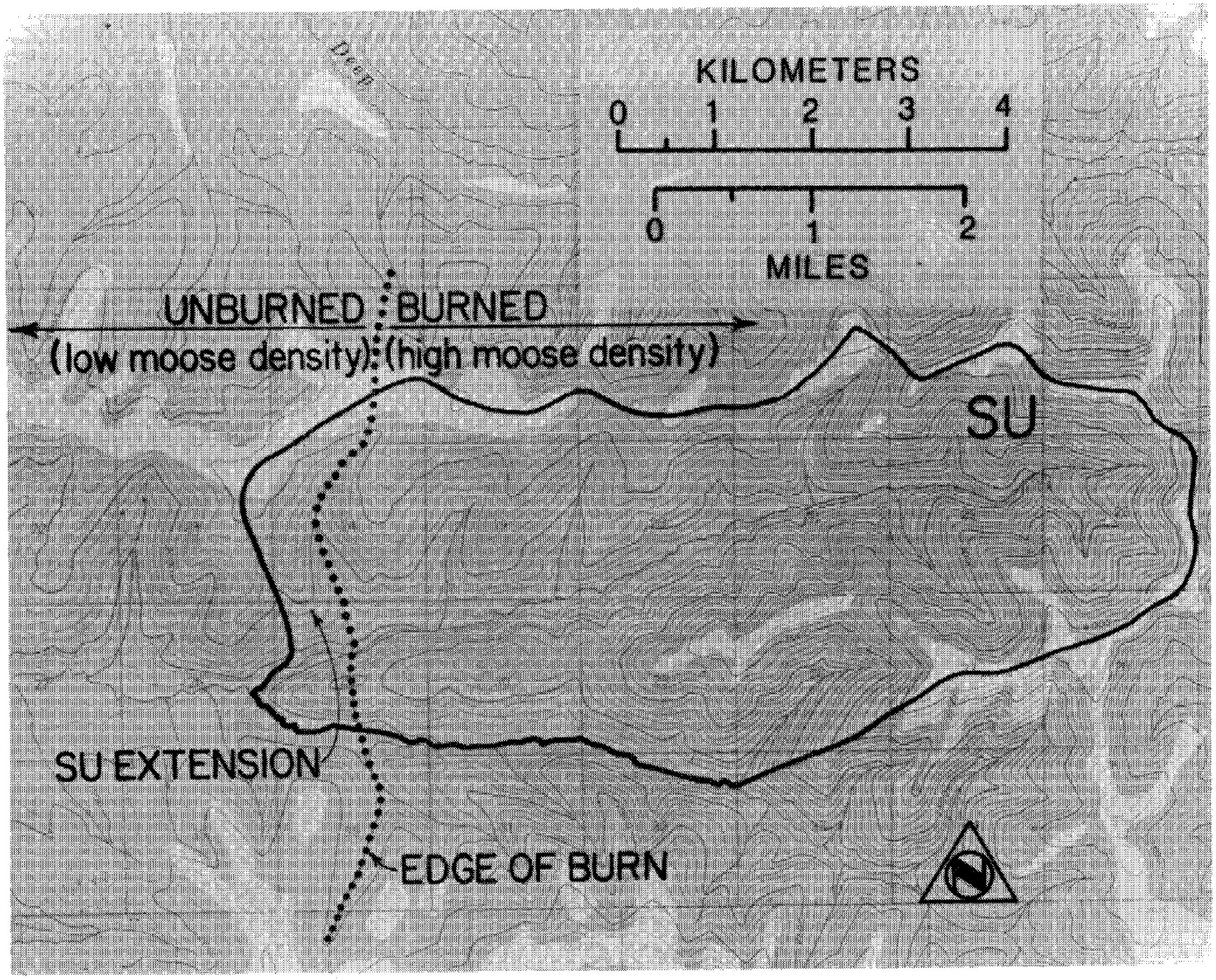


**Figure 8.** Example of strata and sample unit (SU) boundaries that accommodate moose movements between adjacent good and poor habitats. Instead of using the edge of the burn as the western boundary of this SU, the boundary was moved into the unburned area about 0.5 mi to the next identifiable topographic feature. Now moose that wander short distances into the poor habitat will be included in the high density SU.

When the initial stratification was based on factors other than observed moose density, e.g., habitat type, reassignment of strata for the SUs in question may be accomplished by assigning a different relative density to the habitat type in question or be based on the direct observations that initially caused you to question the stratification. A restratification flight may also be necessary.

If restratification is attempted, SUs that have been counted prior to the decision to restratify must stay in the initial stratum category. The SUs that have not been surveyed may be changed to a new stratum and sampled at the intensity of the new stratum.

Restratification of SUs should occur rarely and should be made judiciously. Restratification is reserved for a gross oversight or small areas where, for example, weather prevented a good initial stratification. Restratification privileges can be abused easily. Legitimate restratifying is done to improve precision, but if abused, the result is a false level of precision.

Restratification invariably detracts from the true randomness of a random sampling scheme, which results in bias in the estimates and questions about the trueness of confidence intervals around the estimates. Because you cannot reclassify SUs that have been searched, the improvements in precision resulting from restratification may not be worth the effort required to restratify. Proceed with caution.

### 3.4.1.7 Timing of stratification

Stratification should be conducted just prior to the survey of SUs. Wait for proper conditions (adequate snow, little or no wind, and good light) and then rapidly stratify the area.

Timing of many moose population estimation surveys coincides with routine trend and composition surveys during

October-December. Unfortunately, the number of good flying days is limited, and biologists are tempted to conduct other surveys and stratification flights simultaneously. However, each type of survey is unique, and they should not be flown simultaneously. If both types of surveys are scheduled for nearly the same time, mapping groups of moose and flight routes during composition or trend surveys will speed stratification for that area.

## 3.5 SELECTING SAMPLE UNITS

### 3.5.1 Selection Process

A simple random sample of SUs is selected from each stratum using a table of random numbers (Table 3). Be sure to vary the starting point in the random number table with each survey so that the same sequence of numbers is not continually reused. Sampling is without replacement, i.e., a SU can be selected only once. Vertically list SUs in the order of selection on Form 1 (see Appendix 2 for blank form). Cross SUs off the list after their first appearance. Select 80% or more of the SUs in each stratum so that you will not have to return to the random number list. Indicate the stratum classification of each SU by placing a symbol (L, M, H) beside each SU number. On Form 2, list all SUs by stratum in the order of selection from Form 1 (see Appendix 2 for blank form).

### 3.5.2 Ensuring A Random Sample

The order in which selected SUs are searched is important to ensure randomness. The first five SUs selected in each stratum can be searched in the most efficient order. However, after the first five (or a greater predetermined minimum number), SUs should be searched in nearly the order of selection. By doing so, the survey can be terminated whenever adequate precision of the population estimate is attained and randomness will be assured.

Practically speaking, a SU that was selected may be skipped because of localized hazardous flying weather on the last day of the survey or because of poor snow cover. Omissions such as these should be rare. Simply replace a SU with the next one on the random number list from that stratum. Do not omit SUs for other reasons, e.g., long distances from airports. Subjective omission of SUs destroys the random selection process.

## 3.6 SURVEY METHODS AND ESTIMATING SIGHTABILITY

### 3.6.1 Timing of Surveys

Estimating moose population size in early winter (Oct-Dec) is preferable to late winter because sightability is greater in early winter. This, of course, is dependent on good snow cover in early winter, a condition that often does not occur in southern portions of North American moose range. Sightability is higher during early winter because moose form larger groups (Peek et al. 1974, Mytton and Keith 1981, Novak 1981) and have stronger preferences for vegetation with low, open canopies (Lynch 1975, Peek et al. 1976, Mytton and Keith 1981). However, regardless of time of year, there are some habitat types that are too dense to see an adequate proportion of the moose during any type of survey, e.g., coastal spruce-hemlock forest in Canada and Alaska.

Table 4. Classification of snow conditions for sightability of moose during aerial surveys.

| Age of snow classification | Coverage | Snow ranking |
|---|---|---|
| Fresh | Complete | Good |
| | Some low vegetation showing | Moderate |
| | Bare ground or herbaceous vegetation showing | Poor |
| Moderate | Complete | Good |
| | Some low vegetation showing | Moderate |
| | Bare ground or herbaceous vegetation showing | Poor |
| Old | Complete | Moderate |
| | Some low vegetation showing | Poor |
| | Bare ground or herbaceous vegetation showing | Poor |

Survey methods in this manual were primarily designed and tested in early winter. If surveys cannot be conducted until late winter, alterations in the methods must be made. We have made recommendations for this period, but they are largely untested (Section 3.6.4). Recommendations are based on two late winter surveys in southwest Alaska, our late winter sightability experiments using radio-collared moose, experiments using penned moose on the Kenai Peninsula, Alaska (LeResche and Rausch 1974), and experiences in Canada (Novak and Gardner 1975, Thompson 1979).

### 3.6.2 Required Snow Conditions

Ensure satisfactory snow conditions exist throughout the survey area (good and moderate by our ranking in Table 4) before starting a survey, because snow conditions have a major influence on moose sightability. To help track changing snow conditions during the survey, snow conditions in each SU should be ranked good, moderate, or poor based on subjective evaluations of snow age and snow cover. Rankings are recorded on Form 3 at the time the SU is surveyed (see Appendix 2 for blank form). Subjective snow age and cover categories used in Table 4 are defined below.

Form 1. Simple random sample of sample unit numbers drawn from a random number table. List numbers in the order of selection within columns. Place L, M, or H after each number to indicate the assigned stratum.

Survey Area Fictitious Square Mountain

Game Management Unit(s) 1 Subunit(s) A

Date Nov 1983 Range of SU Numbers 1-56

Column

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 55L | | | | | | | | | | | |
| 56L | | | | | | | | | | | |
| 48L | | | | | | | | | | | |
| 40H | | | | | | | | | | | |
| 34M | | | | | | | | | | | |
| 10M | | | | | | | | | | | |
| 7L | | | | | | | | | | | |
| 14L | | | | | | | | | | | |
| 30H | | | | | | | | | | | |
| 6M | | | | | | | | | | | |
| 11M | | | | | | | | | | | |
| 46M | | | | | | | | | | | |
| 31H | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
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| | | | | | | | | | | | |

Form 2. Stratified random sample of sample units by stratum. Numbers are listed in order of selection within strata.

Survey Area Fictitious Square Mountain

Game Management Unit(s) 1 Subunit(s) A

Date Nov 1983 Range of SU numbers 1-56

Stratum

| Low | Medium | High | Other |
|---|---|---|---|
| 55 | 34 | 40 | |
| 56 | 10 | 30 | |
| 48 | 6 | 31 | |
| 7 | 11 | | |
| 14 | 46 | | |

Form 3. Moose survey data gathered during standard or intensive searches of sample units.

SU no. 38 Date Nov 4 1983 Page 1 of 2

Survey area Fictitious Square Mountain

Pilot/obs. Gasaway/DuBois Est. area 12.0 mi$^2$

Type of search: Standard (e.g., 4-6 min/mi$^2$) ☑
Intensive (e.g., 12 min/mi$^2$) ☐

Dominant habitat Low shrub-dominated burn

STANDARD SEARCH DATA SUMMARY

Strata H ☑, M ☐, L ☐, O ☐
Total moose seen 17
Min. searched 66
Measured area (mi$^2$) 12.0
Search effort (min/mi$^2$) 5.5
Obs. density (moose/mi$^2$) 1.4

INTENSIVE SEARCH DATA SUMMARY

No. moose std. search 2
No. moose int. search 2
Int. search time (min) 30

| WEATHER: | Clouds | Precipitation | Temperature | Wind | Turbulence |
|---|---|---|---|---|---|
| | overcast | none | -12° F | 0-5 mph | none |

LIGHT
TYPE: Bright ☐ Flat ☑
INTENSITY: High ☐ Med. ☑ Low ☐

SNOW AGE AND COVER
Fresh ☑ Moderate ☐ Old ☐
Complete ☑ Some low veg. showing ☐ Bare ground showing ☐

SEARCH TIME
Stop time 11:37
Start time 10:31

REMARKS

| In SCF plot (√) | Group no. | Bulls/Activ. Yrlg | Med | Lge | Cows and calves/Activ. ♀ | ♀/1 calf | ♀/2 calf | Lone calf | Unk. sex-age | Total moose | Habitat moose are in |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | | 3/L | | | | | 3 | H LS TS D SS S L |
| | 2 | | | | | 1/L | | | | 2 | H LS TS D SS S L |
| | 3 | | | | | 1/L | | | | 2 | H LS TS D SS S L |
| ✓ | 4 | | | | | 1/L | | | | 2 | H LS TS D SS S L |
| | 5 | 1/L | | | | | 1/S | | | 4 | H LS TS D SS S L |
| | 6 | | 1/L | | 1/S | | | | | 2 | H LS TS D SS S L |
| | 7 | | | | | 1/♀L Ca S | | | | 2 | H LS TS D SS S L |
| | 8 | | | | | | | | | | H LS TS D SS S L |
| | 9 | | | | | | | | | | H LS TS D SS S L |
| | 10 | | | | | | | | | | H LS TS D SS S L |
| | 11 | | | | | | | | | | H LS TS D SS S L |
| | 12 | | | | | | | | | | H LS TS D SS S L |
| | 13 | | | | | | | | | | H LS TS D SS S L |
| | 14 | | | | | | | | | | H LS TS D SS S L |
| Sex-age totals | | Y= 1 | M= 1 | L= | ♀= 4 | ♀= 4 Ca= 4 | ♀= 1 Ca= 2 | Ca= | U= | 17 | = Total Moose |

Table 5. The influence of habitat selection and search intensity on the sightability of moose during aerial surveys with good, moderate, and poor snow conditions. Data for early and late winter are combined.

| | Percent radio-collared moose seen during standard search (4-6 min/$mi^2$) | | |
|---|---|---|---|
| Habitat selected | Good snow | Moderate snow | Poor snow |
| Non-spruce[a] | 87 | 83 | 68 |
| Spruce[b] | 60 | 30 | 0 |

[a] Includes herbaceous, low shrub, tall shrub, deciduous forest, and larch forest.

[b] Includes spruce forest and sparse spruce forest.

Snow Age

1. *Fresh*.—Generally less than or equal to 1 week since snowfall of greater than 3 inches. Old tracks are covered.

2. *Moderate*.—Generally greater than 1 and less than or equal to 2 weeks since fresh snow conditions. Newly fallen snow of less than 3 inches often is inadequate to renew the snow surface so that it appears smooth and disturbance-free; therefore, shallow new snow may be classed as moderate-aged based on appearance.

3. *Old*.—Generally greater than 2 weeks since fresh snow conditions. However, newly fallen snow subjected to melting conditions can rapidly appear like old snow, i.e., depressions around trees and shrubs, irregular surface, and enlarged animal tracks. Therefore, new snow may be classed as old after only 2 to 3 days.

Snow Cover

1. *Complete*.—Low vegetation covered. Generally 6 to 12 inches of snow are required.

2. *Some low vegetation showing*.—Tops of some grasses, forbs, or very low shrubs protruding through snow. Snow cover has a brownish cast.

3. *Distracting amounts of bare ground or herbaceous vegetation showing*.—Distinct brown patches exist that reduce observer efficiency. Stumps and fallen trees in burns have the same effect if not snow covered.

Snow conditions may deteriorate during a survey, so be sure that SUs have satisfactory snow conditions when searched so that high sightability is maintained throughout the survey. Sightability decreases as snow conditions deteriorate (Table 5).

Occasionally, surveys are started when a few SUs contain poor snow. Waiting for good or moderate snow throughout large areas is often impractical. For example, localized wind-scouring of snow may routinely cause poor sightability in some mountainous SUs. If a SU with poor snow conditions is selected for searching, increase the search effort, or if need be, omit it and move to the next randomly selected SU.

### 3.6.3 Early Winter Surveys (Oct-Dec)

#### 3.6.3.1 Search effort

Search effort (min of search/$mi^2$) largely determines sightability. High sightability in the open canopy forests of Alaska is assured by maintaining a high minimum search effort that compensates for variation in survey conditions among SUs and from day-to-day. The observer must ensure adequate search time is put into each SU. In interior Alaska, search effort of 4 to 5 min/$mi^2$ was required to see most moose during early winter (Fig. 9). The minimum acceptable time in interior Alaska is 4 min/$mi^2$, and sometimes 6 to 8 min/$mi^2$ will be required if unusual circumstances occur, e.g., deep snow, which encourages moose to select spruce forest more frequently, or high moose density (greater than 4 moose/$mi^2$ in a SU), which requires substantial time to fly circles around each group of moose. Sightability will vary among areas of North America, and corresponding adjustments in search effort will be required. Search time must increase as the canopy increases in height and density. Examples of habitat found in interior Alaska are included (Figs. 10-14) for use in comparing habitats of other areas.

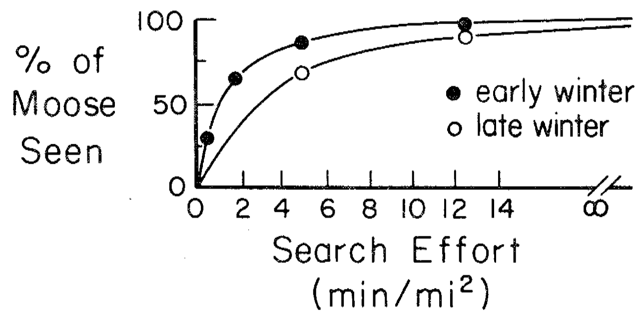


**Figure 9.** The influence of search effort (min/$mi^2$) on sightability of moose during early winter (Oct-Dec) and late winter (Jan-Apr) aerial surveys.

Appropriate search time per SU is calculated by estimating area in $mi^2$ from a map and multiplying by 4.5 min/$mi^2$ (or a greater value if required) plus 1 min of circling per group expected in the SU. Therefore, a 12 $mi^2$ low-density SU where no moose were expected would require 54 min to search at 4.5 min/$mi^2$. A 12 $mi^2$ high-density SU with eight groups of moose expected would require 62 min to search at a base rate of 4.5 min/$mi^2$. Practice is required to gauge the flight pattern to complete the survey in the prescribed time. Both pilots and observers should practice prior to surveys.

**Figure 10.** Shrub-dominated alpine habitat in interior Alaska.

**3.6.3.2 Flight pattern**

The major determinant of search pattern in the SU is topography. Minor variation in search intensity is achieved by altering the distance between flight lines and varying the number of circles made off flight lines.

*Flat Land.*—Parallel transects are flown at 0.25-mi intervals to achieve approximately 4.5 min/mi$^2$ of search effort when few moose are present. Fly at 60 to 70 mph and 200 to 300 ft above ground. Height should be greatest when flying over tall timber. Fly transects on a compass heading parallel to the short axis of the SU. This allows better orientation and minimizes missing or duplicating areas. Estimate the number of transects to be flown by multiplying SU length in miles by 4. Make sure no fewer than this number are flown (Fig. 15, SU1). While the plane turns into another transect, mark the approximate location of the transect on the map. This helps assess transect intervals. Mark the location of moose groups on the map if time permits. Fly one or more

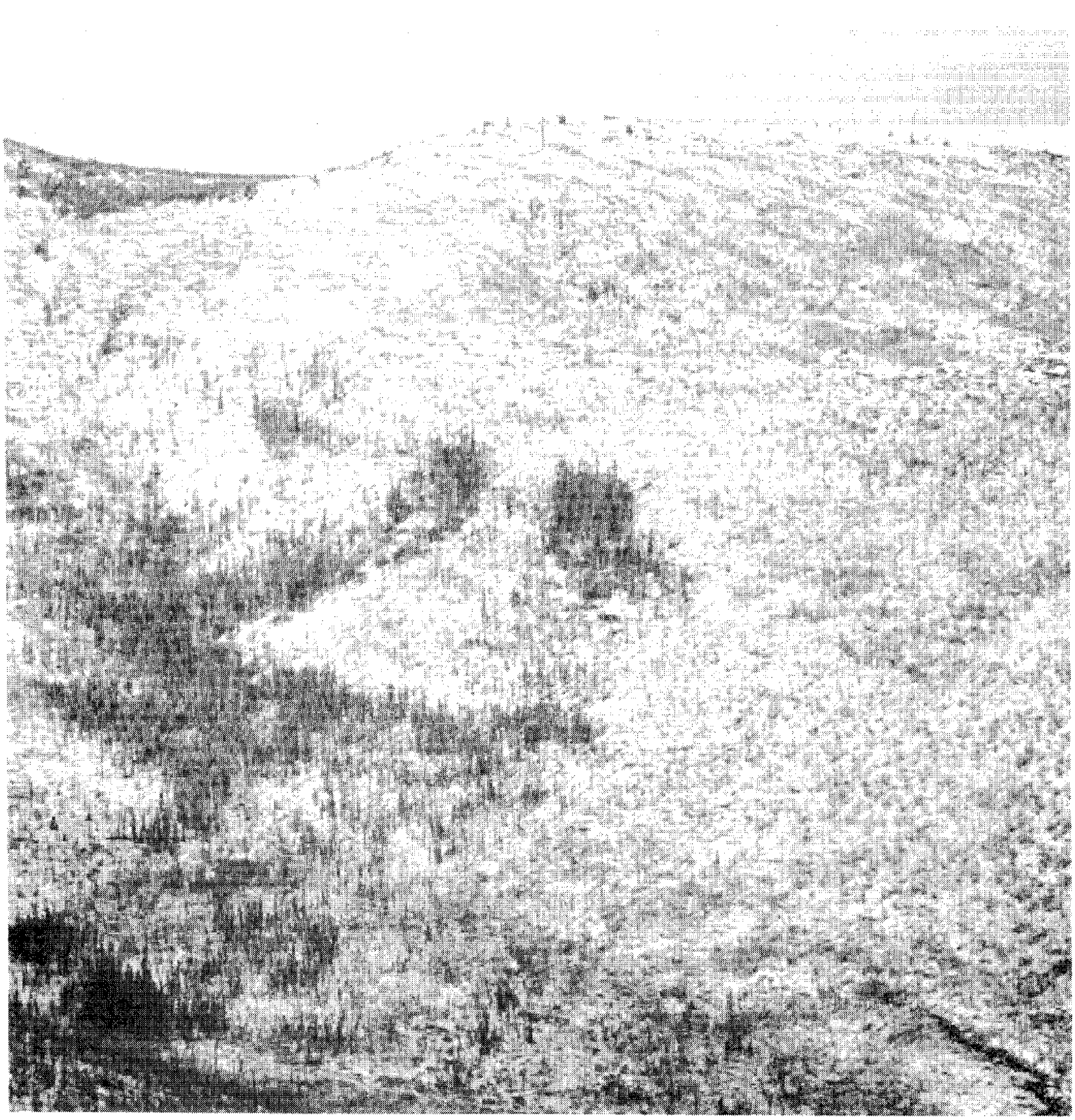

**Figure 11.** Shrub-dominated burn in interior Alaska.

circles around each group of moose or single moose to look for more moose and to classify moose by sex and age.

*Hills And Mountains.*—The flight path, flown at 60 to 75 mph, generally follows topographic features and consists of contour routes, circles, and flights along ridges and creeks. The interval between flight lines is less than or equal to 0.25 mi. Circles are very effective at heads of valleys and over ends of ridges (Fig. 15, SU2). Concentrate search effort from one side of the plane; generally the down slope side of the plane is preferred because it provides a more vertical view of trees and the best view of heads of valleys during turns. Occasionally, however, viewing the upslope side will be more effective, e.g. very steep slopes and the ends of gently rounded ridges. The height above ground varies because you are viewing slopes. Fly circles over *all* groups of moose or single moose.

The pilot's main responsibilities are to fly the appropriate search pattern and to keep the plane oriented with respect to

**Figure 12.** Shrub-dominated forest in interior Alaska.

SU boundaries. Pilots must have a map showing SU boundaries. Expect pilots to also look for moose when they can. Most survey pilots spot many moose.

### 3.6.3.3 Timing of sample unit searches

Generally, begin searching SUs the day after they are stratified. If you are confident few SU boundaries will be altered during stratification, SU searches and stratification can begin on the same day—but in different portions of the survey area. Keep planes well separated to avoid midair collisions! If SUs are searched before stratification, the stratification crew must not be told the results until the SU is stratified. When the stratification crew changes boundaries of a SU that was previously surveyed, those survey data should be discarded and the new SU of the same number should be surveyed. This is the price paid for surveying before stratification.

**Figure 13.** Deciduous tree-dominated forest in interior Alaska.

### 3.6.4 Late Winter Survey Methods (Jan-Apr)

Because moose move to areas with taller and denser forest canopies and occur in smaller groups during late winter compared to early winter, moose become more difficult to see during late winter (Fig. 10) (Lynch 1975, Novak 1981). This poses a serious problem because making an unbiased and precise estimate of sightability becomes increasingly difficult as sightability declines. Greater variation in sightability among habitat types affects bias and precision of the estimated SCF (sightability correction factor). The problem is not easily overcome, but increasing search effort and using smaller SUs can help.

The degree of change in sightability will depend on the types of habitat available to moose. The simplest case is in areas having little or no coniferous forest, e.g., the extreme northern and northwestern coast of Alaska, and northern Canada. High sightability can be obtained with little or no increase in search effort; therefore, use procedures de-

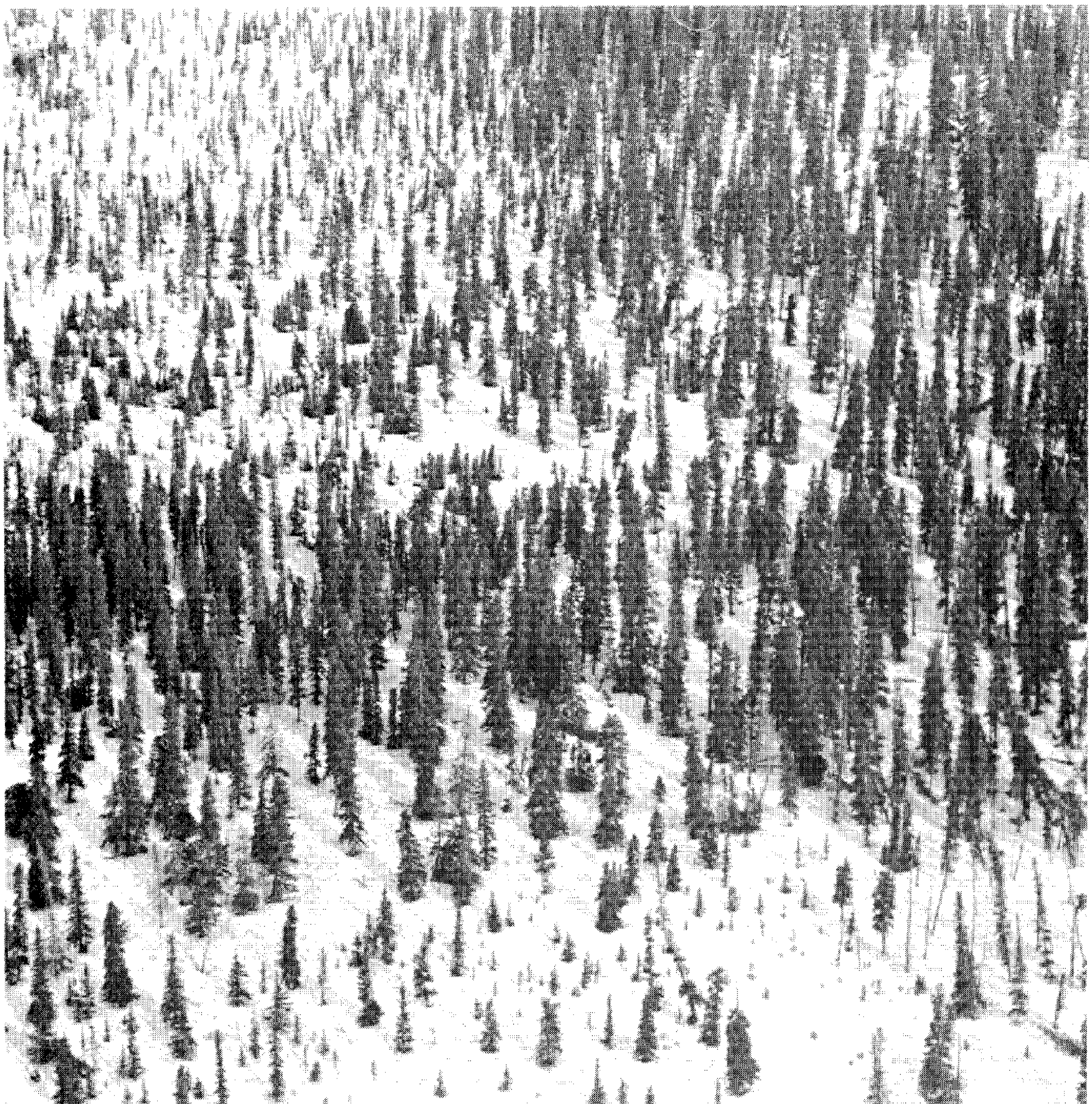

**Figure 14.** Spruce-dominated forest in interior Alaska.

scribed for early winter surveys (Section 3.6.5).

Areas with coniferous forest are more difficult to survey. The ability to precisely estimate sightability with minimum bias deteriorates rapidly as the coniferous canopy increases in height and density. The result is an underestimate of moose abundance, a widening CI, and a CI that has a lower than specified probability of containing the actual number of moose because the CI is centered on a biased estimate. Estimates made with these conditions will not be as useful as ones obtained when sightability is high. However, moose occur in expansive coniferous forests in portions of North America, and one must either work with this constraint or make no population estimates. So we offer a few brief suggestions on late winter surveys in areas containing coniferous forest. The approach varies with the openness of the coniferous canopy; we assume a late winter use of the coniferous forest by moose.

*Closed Canopy.*—Estimating numbers of moose in areas

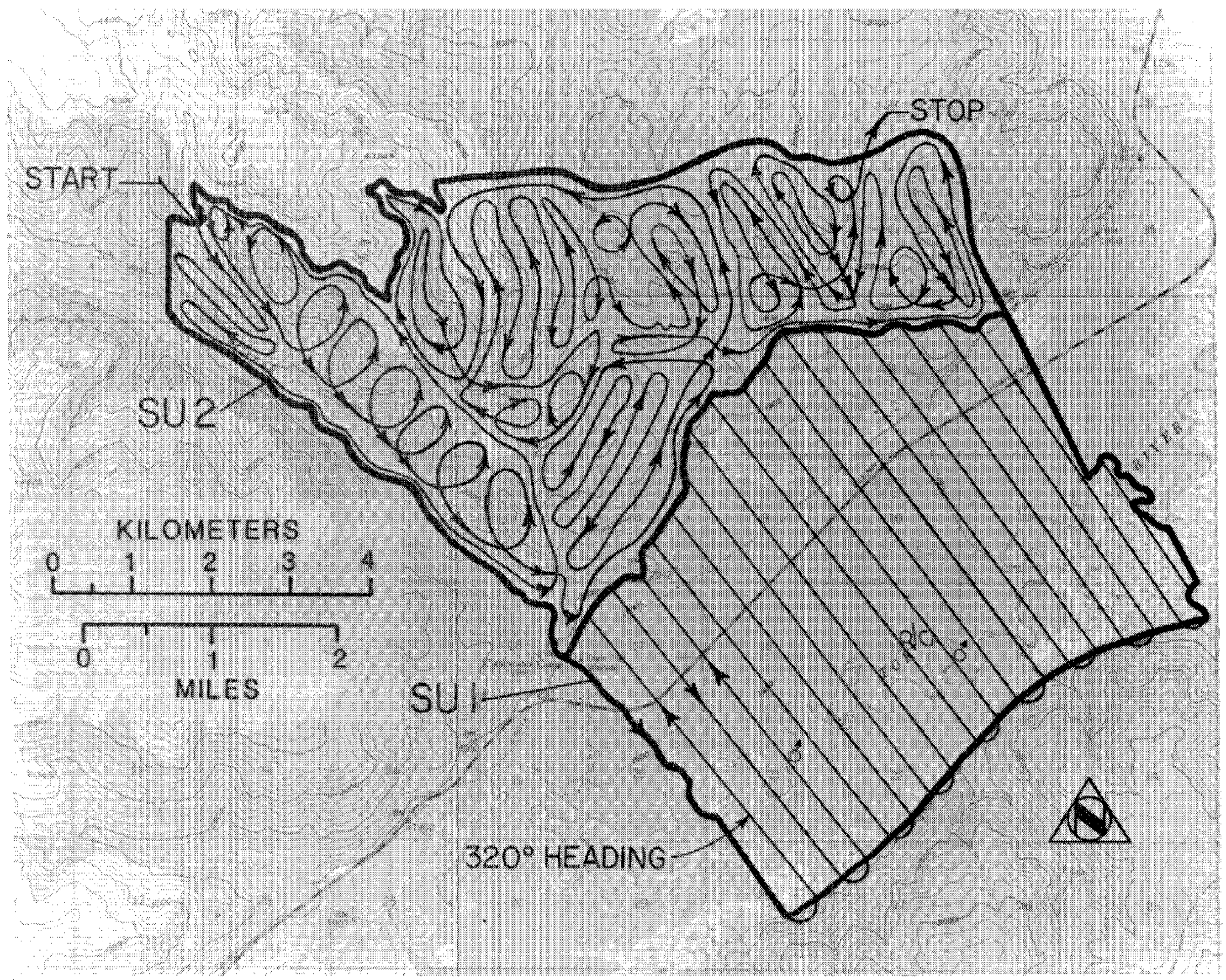


**Figure 15.** Example of flight path while searching sample units (SUs) in flat land, hills, and mountains. The flight path in the flats is a set of transects spaced 0.25 mi apart. The flight path in the hills and mountains generally follows contours and includes circles along ridges and creeks.

dominated by closed canopy coniferous forest is futile. Sightability of moose is simply too low.

*Semi-Open Canopy.*—This type of vegetation (Fig. 16) will require a high search intensity (probably greater than or equal to 30 min/mi$^2$) and small SUs of 1 to 3 mi$^2$. Unfortunately, an unbiased and precise estimate of sightability probably cannot be achieved through intensive searches. A correction factor for missed moose must be developed independent of the survey method by using radio-collared moose. This is expensive, site-specific information.

*Open Canopy.*—This is the only coniferous canopy type in which we are optimistic about obtaining late winter population estimates (Fig. 12-14). This canopy is similar to the type in which we conducted our experimental sightability studies. SUs of 8 to 12 mi$^2$ and a search intensity of at least 6 to 8 min/mi$^2$ on the initial search are recommended. An observed SCF (Section 3.6.5.1) can be estimated from a more intensive search immediately following the standard search (Section 3.6.5.2). However, an unbiased overall SCF cannot be estimated by this 2-stage search method because a large percentage of the moose are not observed during the more intensive search. Therefore, the population estimator will underestimate abundance unless an additional correction factor can be independently estimated using radio-collared moose.

If late winter population estimates in areas with coniferous forest are generally low because of the inability to estimate an appropriate SCF, can these low estimates at least provide an accurate population trend? Probably not, and the answer becomes more emphatically *no* as sightability deteriorates. The two principal reasons are that large unknown biases cannot be held constant among years and precision of the estimated SCF will be poor; therefore, the population estimate will have a large variance. In general, precision

**Figure 16.** Semi-open coniferous canopies, like this example, require a high search intensity to see a high percentage of moose present.

declines as sightability declines. Trends can only be determined from precise estimates corrected for sightability or from precise estimates where sightability error is held constant; during late winter or where moose extensively use coniferous forest, neither condition can be accomplished well.

### 3.6.5 Estimating Sightability of Moose

#### 3.6.5.1 Defining and applying sightability estimates

Sightability is defined as the percentage of moose seen in the area searched (Caughley 1974), and a SCF must be estimated to produce an estimate of population size with minimum sightability bias. The estimator of population size is the following:

$$\text{no. of moose} = \text{no. moose estimated from standard search} \times \text{SCF.}$$

The SCF is the product of an observed SCF ($SCF_0$) and a correction factor constant ($SCF_c$) for moose missed while estimating $SCF_0$. $SCF_c$ is a constant value for a set of conditions (e.g., location, habitat, season), and its value is derived experimentally using radio-collared moose.

For an early winter survey where sightability is high, the $SCF_0$ is estimated by surveying moose in a 2-$mi^2$ portion of a SU during the standard search (4 to 6 min/$mi^2$) and immediately resurveying the 2 $mi^2$ with an intensive search of 12 min/$mi^2$. The $SCF_0$ is calculated as follows:

$$SCF_0 = \frac{\text{no. moose seen during intensive search}}{\text{no. moose seen during standard search}} + \begin{array}{l}\text{correction}\\ \text{for small-}\\ \text{sample bias.}\end{array}$$

Detailed formulae for calculating $SCF_0$ and $V(SCF_0)$ are in Section 3.6.5.3.

We used radio-collared moose to estimate the bias associated with the $SCF_0$, i.e., $SCF_c$. Our experiments showed that during early winter in interior Alaska, 98% of the moose were seen with intensive searches averaging 12 min/$mi^2$. Therefore, $SCF_c = 100 \div 98 = 1.02$, and the $SCF = SCF_0 \times SCF_c = SCF_0 \times 1.02$. Using the same survey conditions but in late winter, sightability of radio-collared moose dropped to 89% producing a $SCF_c = 100 \div 89 = 1.13$. These are site-specific $SCF_c$s.

Estimating a SCF for late winter or anytime the forest canopy is dense and tall is difficult because many moose may be missed during intensive searches. Depending on the canopy cover, the standard search intensity in late winter may have to equal or exceed that of an early winter intensive search. Several options exist for estimating the SCF in late winter. First, as in early winter, estimate a $SCF_0$ during the survey and use an existing estimate for $SCF_c$ if survey conditions are similar to those where the $SCF_c$ was estimated. Second, estimate a $SCF_0$ using a very high search effort for the intensive search (e.g., 30 min/$mi^2$) and assume that $SCF = SCF_0$. In this case, no estimate of $SCF_c$ exists for the high intensity search. Third, search effort of the standard search equals that of an intensive search; therefore, the $SCF = SCF_c$. If habitat and snow conditions were similar to those used to estimate a $SCF_c$, then use a previously estimated $SCF_c$. In most cases, however, you will not have an appropriate $SCF_c$; therefore, either assume it equals 1.0, which is clearly an underestimate, or guess based on experience in other areas. Neither option is appealing.

Regardless of how sightability is estimated, when the number of moose seen on an intensive survey is not close to 100%, SCFs are subject to large and unmeasurable errors. Size of the errors directly affects moose population estimates.

#### 3.6.5.2 Survey procedures for estimating sightability in early winter

The $SCF_0$ is calculated from moose seen in 2 $mi^2$ plots in high and medium strata, assuming the average density observed in each stratum is greater than or equal to 1.0 moose/$mi^2$. No plots are searched in the low stratum because few moose are present, and it is unlikely a moose will occur in a plot. Nothing can be learned about sightability if no moose are present. Our experience shows it is not economically feasible to estimate sightability where density is less than 1.0 moose/$mi^2$ nor is it feasible to estimate a SCF for each stratum or for each pilot/observer team. Therefore, a single $SCF_0$ is estimated and applied to the pooled survey data.

Begin the population estimation survey by flying an intensive search plot in every surveyed medium- and high-density SU. You may be able to reduce this rate later in the survey, but it is generally necessary to fly intensive searches in 50 to 100% of the surveyed medium- and high-density SUs to achieve a precise population estimate. The number of intensive survey plots is determined by the optimal allocation procedure (Section 3.10.3) and is directly related to the $SCF_0$ and variance of $SCF_0$. Intensive searches are initially flown in every medium- and high-density SUs surveyed because (1) they allow you to assess sightability early in the survey, and (2) the optimal allocation procedures (Section 3.10.3) may require intensive searches in each medium- and high-density SU.

To select the portion of the SU to search intensively:

1. Divide each medium- and high-density SU into roughly four quarters on the topographic map and randomly select one quarter from each SU.
2. Draw a plot of approximately 2 $mi^2$ within the selected quarter. Plot boundaries should be terrain features identifiable on the map (Fig. 17). The search time required is approximately 0.5 hours.
3. If intensive search plots are flown in less than 100% of medium- and high-density SUs, randomly select those SUs that will receive plots.

Identify exact plot boundaries from the air immediately before beginning the standard search of the SU if plot boundaries are difficult to identify. Moose observed during the standard search must be mapped accurately with reference to the plot boundaries. If possible, survey the SU so that the 2-$mi^2$ sightability plot is flown near the end of the standard search. Immediately upon completion of the stand-

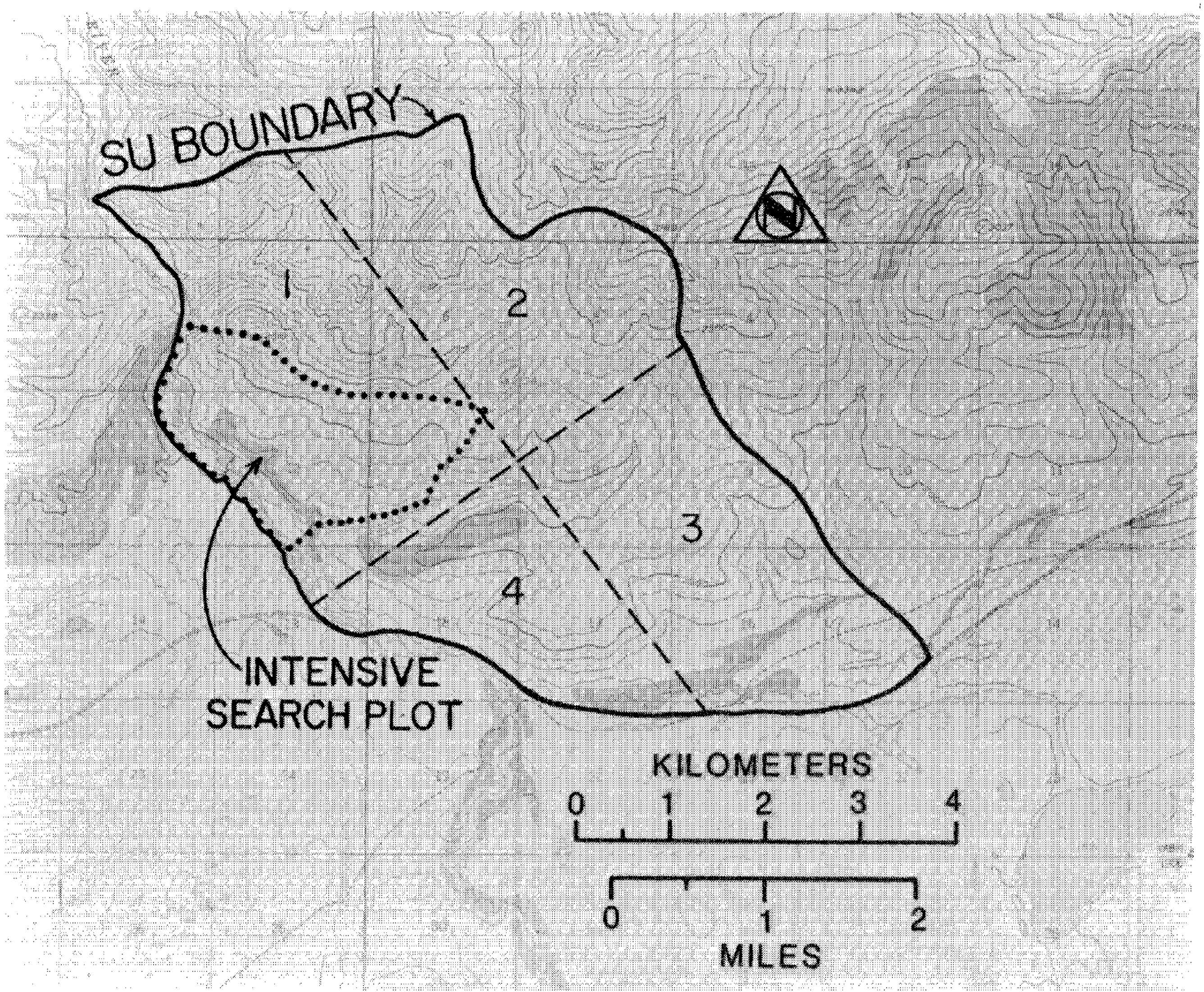


**Figure 17.** Example of a sample unit (SU) divided into 4 quarters for the purpose of randomly selecting the quarter that will contain the 2-$mi^2$ intensive search plot. Quarter number 1 was selected, and the plot was drawn as shown.

ard search of the SU, intensively search the plot a minimum of 12 min/$mi^2$ and record the number of moose seen in the plot during the intensive search. This procedure reduces the time between the two searches and the time moose have to redistribute themselves. Occasionally, identifiable groups of moose will move into or out of the plot between the two searches. If moose move into the plot, do not record them during the intensive search. If moose move out of the plot and are seen during the intensive search, record them on both searches. If moose move out of the plot and are not seen on the intensive search (but the exit was confirmed by tracks in snow), delete the observation from the standard search for sightability calculations. Moose not observed during intensive searches are compensated for by the $SCF_c$.

Do not search the plot with different effort during the standard search than is normally used for standard searches. To help ensure standard search intensity, do not inform the pilot that a plot will be resurveyed until it is time for the high-intensity search. However, the observer must know the boundaries of the plot during the standard search so that moose can accurately be mapped and tallied. The observer must also guard against changing the effectiveness of his search in the sightability plot during the standard survey.

Search intensities of greater than or equal to 12 min/$mi^2$ use a different flight pattern than those described in Section 3.6.3 for low-intensity searches.

*Flat Land.*—A series of slightly overlapping circles or ovals are flown (Fig. 18) at 200 to 300 feet above the ground and at 60 to 70 mph. The radii of circles are 0.1 to 0.3 mi, and the radii should decrease as canopy height and density increase. Observations are made from the low wing side of the plane.

*Hills and Mountains.*—Fly close contours and make frequent circles over the heads of canyons and over the ends of

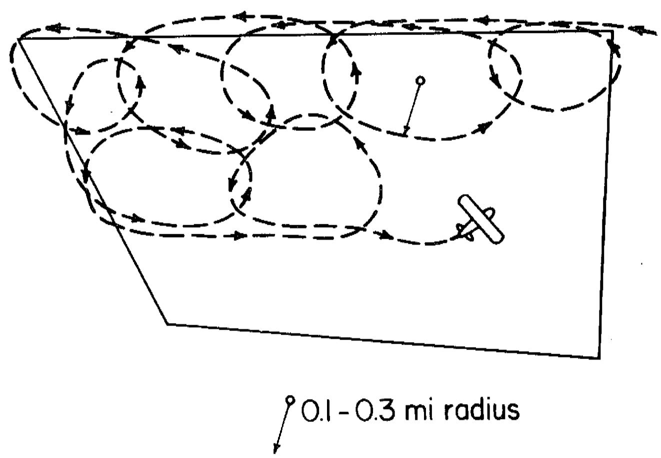


**Figure 18.** Flight pattern used over flat terrain during intensive searches of 2-mi² sightability plots.

ridges at 60 to 75 mph. This search pattern is similar to that used for the standard search of SUs (Fig. 15, SU2) except contours are closer and circling is more frequent. Height above the ground is variable because you are looking at slopes.

The $SCF_o$ should be calculated daily, and we recommend maintaining a mean value of less than or equal to 1.15. If $SCF_o$ is greater than 1.15, increase the standard search effort in future SUs. If standard search effort needs to be increased, the decision to do so should be made as early in the survey as possible. Changes in standard search effort will increase the variance of the total population estimate, so it is necessary to find and maintain an acceptable level of effort as early as possible.

$SCF_o$s as low as 1.03 have been achieved in shrub-dominated survey areas in Alaska, but the expense required to produce a low $SCF_o$ in areas dominated by coniferous forest is prohibitive.

### 3.6.5.3 Estimating the observed sightability correction factor and its sampling variance

The following symbols will be used for the calculation of $SCF_o$ and $V(SCF_o)$:

- $n_o$ = the number of 2-mi² plots surveyed with an intensive search
- $u_k$ = the number of moose seen during the intensive search in the *kth* sightability plot; $k=1 \ldots n_o$
- $v_k$ = the number of moose seen during the standard search in the *kth* sightability plot; $k=1 \ldots n_o$.

Calculate the $SCF_o$ as follows:

$$SCF_o = \frac{\text{no. moose seen during intensive search}}{\text{no. moose seen during standard search}} + \begin{array}{c}\text{correction}\\ \text{for small-}\\ \text{sample bias}\end{array}$$

or

$$SCF_o = \frac{\sum_k u_k}{\sum_k v_k} + \frac{n_o s_{uv}^2}{(\sum_k v_k)^2} - \frac{n_o(\sum_k u_k)s_v^2}{(\sum_k v_k)^3}$$

where

$$s_{uv}^2 = \frac{\sum_k u_k v_k}{n_o - 1} - \frac{\sum_k u_k(\sum_k v_k)}{n_o(n_o - 1)}$$

and

$$s_v^2 = \frac{\sum_k v_k^2}{n_o - 1} - \frac{(\sum_k v_k)^2}{n_o(n_o - 1)}$$

The sampling variance of $SCF_o$ is

$$V(SCF_o) = \frac{n_o}{(\sum_k v_k)^2}(s_{qs}^2)$$

where

$$s_{qs}^2 = \frac{\sum_k u_k^2 - 2(SCF_o)\sum_k u_k v_k + SCF_o^2 \cdot \sum_k v_k^2}{n_o - 1}$$

The formula for estimating the sightability correction factor is a ratio formula with a correction for small-sample bias. We use the bias correction because we found that the empirical distributions used in our simulations for sightability caused the standard ratio formula to yield estimates with a substantial small-sample bias. The correction for small-sample bias is based on Cochran's (1977) discussion of bias in ratio estimators. Our simulation studies indicated that, in addition to reducing bias, the corrected formula consistently yields an estimator with a smaller sampling variance than the standard formula. For small sample sizes (less than or equal to 5) the reduction in variance may be greater than 40%, whereas with large sample sizes, the variance reduction is negligible.

### 3.6.5.4 Example: calculating the observed sightability correction factor and its sampling variance

The HP 97 calculator has been programmed to calculate $SCF_o$ and $V(SCF_o)$ as part of the program designed to calculate the population estimate (Section 3.9).

Table 6. Sightability data for 10 sample units in the fictitious Square Mountain survey area.

| | Number moose seen in 2-mi$^2$ sightability plot | | | | | | | | | | Total moose seen during search |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Standard search effort ($v_k$) | 0 | 3 | 14 | 5 | 0 | 1 | 2 | 7 | 8 | 6 | 46 |
| Intensive search effort ($u_k$) | 0 | 3 | 15 | 6 | 1 | 1 | 2 | 7 | 8 | 7 | 50 |

The following example is a step-by-step guide for the hand calculation of $SCF_o$ and $V(SCF_o)$. The function of this example and others in the manual is to demonstrate to the reader how to correctly use the formulae. Other data can then be substituted for the example data with the assurance that calculations are correct. Assume that the data used in the calculations were collected during intensive searches of plots in 10 SUs during the Square Mountain survey (Table 6). When performing these calculations, it is important to use the number of decimal places indicated in this example to reduce problems with rounding error. Refer to Section 3.6.5.3 for formulae while working through calculations in this section.

$SCF_o$.—First solve for $s^2_{uv}$ and $s^2_v$.

$$s^2_{uv} = \frac{409}{10-1} - \frac{50 \times 46}{10(10-1)}$$

$$= 19.888888.$$

$$s^2_v = \frac{384}{10-1} - \frac{(46)^2}{10(10-1)}$$

$$= \frac{384}{9} - \frac{2116}{90}$$

$$= 19.155556.$$

Use the values of $s^2_{uv}$ and $s^2_v$ to solve for $SCF_o$.

$$SCF_o = \frac{50 \text{ moose}}{46 \text{ moose}} + \frac{10 \times 19.888888}{46^2} - \frac{10 \times 50 \times 19.155556}{46^3}$$

$$= 1.086957 + 0.093993 - 0.098399$$

$$= 1.082551.$$

$V(SCF_o)$.—First solve for $s^2_{qs}$.

$$s^2_{qs} = \frac{438 - 885.526718 + 450.016001}{10-1}$$

$$= 0.276587.$$

Use the value of $s^2_{qs}$ to solve for $V(SCF_o)$.

$$V(SCF_o) = \frac{10}{46^2} \times 0.276587$$

$$= 0.001307.$$

### 3.6.5.5 Estimating sightability in low-density populations

Sightability estimates, as described in Section 3.6.5.1, are not economically feasible in low-density moose populations. Put simply, one cannot afford the time or dollars to sample the very large number of plots required to precisely estimate the $SCF_o$. The probability of moose occurring in a 2-mi$^2$ plot is low, and moose must be present or sightability cannot be estimated. This is the same logic used to omit sightability plots from the low-density stratum in high-density populations.

Two options exist for estimating the $SCF_o$ for low-density populations. First, sightability estimates made in higher density populations, but under similar habitat and snow conditions, can be applied to low-density populations. However, applying a $SCF_o$ from similar, nearby areas is risky. In Alaska, early winter SCFs (i.e., $SCF_o \times SCF_c$) from four widely differing survey areas ranged from 1.05 to 1.18 when survey techniques described in this manual were used (Table 7). These data may reflect the range of potential errors. To apply SCFs from other areas, select SCFs with the most comparable survey conditions. If more than one comparable area exists, use the mean SCF or ($\overline{SCF}$), i.e., sum of SCFs ÷ no. of SCFs; the corresponding variance is approximated as

$$V(\overline{SCF}_o) = \frac{\text{mean variance of the } SCF_o\text{s}}{\text{no. of } SCF_o\text{s}}$$

Table 7. Observed sightability correction factor ($SCF_o$), sightability correction factor constant ($SCF_c$), variance [$V(SCF_o)$], and degrees of freedom of $SCF_o$ [$\nu_s$] estimated during moose surveys in Alaska. Standard search effort averaged about 4 to 5 min/mi$^2$ except where noted.

| Season and survey area | $SCF_o$ | $SCF_c$ | $V(SCF_o)$ | $\nu_s$ | Dominant habitat | Terrain |
|---|---|---|---|---|---|---|
| Early winter (Oct-Nov) | | | | | | |
| Upper Susitna | 1.027535 | 1.02 | 0.000411 | 9 | Subalpine shrub, some spruce forest | Mountains |
| Upper Nowitna | 1.069074 | 1.02 | 0.001379 | 12 | Mixed forest, shrub-dominated high ridges and a few small burns | Hills |
| Tanana Flats | 1.148780[a] | 1.02 | 0.004061 | 30 | Mixed forest interspersed with large areas of early seral shrubs | Lowland flats |
| Lower Nowitna | 1.155249 | 1.02 | 0.006667 | 11 | Mixed forest, shrubs along ponds and streams, some lowland bogs | Hills and lowland flats |
| Late winter (Feb) | | | | | | |
| Alaska Peninsula | 1.082446 | 1.02 | 0.002212 | 10 | Shrub dominated, no coniferous forest | Flats, hills, and mountains |
| Nushagak | 1.198800 | 1.13 | 0.008020 | 7 | Mixed forest with shrubs along streams and in the highlands | Flats, hills, and mountains |

[a] Standard search intensity averaged 6 min/mi$^2$.

$$= \frac{\sum_i [V(SCF_o)]_i \div n}{n}$$

$$= \frac{\bar{V}(SCF_o)}{n} \, .$$

where $n$ is the number of SCFs used to estimate the mean SCF and i = 1... $n$.

For example, assume the following two SCFs are appropriate to apply to a low-density survey area: 1.10 with variance of 0.00401 and 1.14 with variance of 0.00602. The mean values are calculated as

$$\overline{SCF} = \frac{1.10 + 1.14}{2} = 1.12$$

and

$$V(\overline{SCF}_o) = \frac{0.01003}{2} \times \frac{1}{2} = 0.00251.$$

The $\overline{SCF}$ and V($\overline{SCF}_0$) are used in the conventional manner for estimating population size and CI, respectively (see Sections 3.7.3, 3.7.4, and 3.7.5).

The second approach is to intensively search only those plots in which moose were observed during the standard search. Plots in low-density areas must be increased in size to increase the probability of plots containing moose. We recommend 4-$mi^2$ plots, i.e., double the size normally used. Using this method, time and dollars are spent intensively searching only plots where there is some known sightability information. The $SCF_0$ and V($SCF_0$) are calculated as in Section 3.6.5.3. However, these formulae are biased estimators of $SCF_0$ and V($SCF_0$), with each parameter being underestimated. Therefore, this procedure should only be used where moose densities are too low to use the unbiased method described in Section 3.6.5.1.

Our experience indicates the bias for the $SCF_0$ will be small because sightability during the standard survey is high (Table 7). Calculating biased $SCF_0$s for six surveys in Table 7 reduced the estimated mean $SCF_0$ by only 1%. However, the mean V($SCF_0$) for these six estimates declined by 27%, resulting in CIs being underestimated by an average of 15%. Because of the small bias, this method is preferred to the first option, unless you are confident that a $SCF_0$ estimated in other areas is an appropriate substitute.

### 3.6.6 Recording Survey Observations

#### 3.6.6.1 Recording data for standard searches of sample units

All data are recorded on Form 3. Routine data are recorded at the top. Only a few items require explanations.

Habitat descriptions for SUs are useful if you are interested in correlating habitat with moose density, sex and age composition, or sightability. You may have your own habitat classification system. We classify dominant habitat in the SU as one of two major types (shrub-dominated or forest-shrub mixture), each of which are further subdivided as follows:

1. Shrub-dominated habitat (equal to or greater than 80% shrub cover)
   a. Recent burn (Fig. 11)
   b. Subalpine (Fig. 12)
2. Forest-shrub habitat (less than 80% shrub cover)
   a. Shrub-dominated forest (50 to 80% shrub)(Fig. 12)
   b. Deciduous tree-dominated forest (greater than 50% forest)(Fig. 13)
   c. Spruce-dominated forest (greater than 50% forest)(Fig. 14).

Snow conditions listed on Form 3 are defined in Section 3.6.2.

Sex and age composition of moose in each group is recorded on a single line of Form 3. Three categories of bulls are identified based on antler shape and size: yearlings, medium bulls (greater than yearlings but less than 50 inches antler spread), and large bulls (equal to or greater than 50-inch antler spread). Substitute categories that may be appropriate for your studies. Cow and calf designations are self-explanatory. Groups of moose seen in the intensive search plot during the standard search must be checked off (✓) on the form during the standard search so that there is a clear record of moose seen during the standard search.

Moose behavior data can be recorded on Form 3 if desired. Activity of moose (standing or lying) can be indicated by S or L below the number of moose recorded in a sex-age category (e.g., 4/L).

Habitat use by moose is easily recorded on a check list for each group of moose (Form 3). Any habitat classification system familiar to the observer will work, so long as it is simple. We use the seven categories on Form 3: herbaceous (H), low shrub (LS) is less than 2 m tall, tall shrub (TS) is equal to or greater than 2 m tall, deciduous forest (D), sparse spruce forest (SS), spruce forest (S), and larch forest (L).

Collecting behavior and habitat data takes time that could be spent looking for moose and is of value only if there is a planned use for the data. A tape recorder could be substituted for the form, but mechanical failures can cost time and money.

#### 3.6.6.2 Recording data for intensively searched plots

Record data from intensive searches on a separate copy of Form 3. To distinguish intensive data from standard searches, check (✓) the box labeled intensive search on the form. Clearly mark moose or groups of moose not seen during standard searches with "NEW." Occasionally you may miss a moose on the intensive search that was seen on the standard search. Try to find the reason—was the moose missed or did it leave the area? Make notes if there are problems, e.g., a moose seen on the standard search walked out, or a new moose walked in between the standard and intensive search.

Keep complete records of moose seen on the standard and intensive search if the SCF is to be accurate. Check all forms for completeness while flying to the next SU.

#### 3.6.6.3 Daily summary of survey data

At the conclusion of each day of surveying, transfer SU data from Form 3 to Form 4, which was designed to summarize SU data by stratum (see Appendix 2 for blank form). Daily summaries will allow efficient daily calculation of the $SCF_0$ and population estimate.

## 3.7 CALCULATING THE POPULATION ESTIMATE AND CONFIDENCE INTERVAL

Calculation of the total population estimate involves estimating the observable moose population, correcting it for

Form 4. Daily tally of count data by stratum for moose population estimation survey.

Survey Area Fictitious Square Mountain

Game Management Unit(s) 1 Subunit(s) A

Stratum medium Stratum Area 240 $mi^2$ Total SUs In Stratum 20

| SU no. | Date searched | No. moose in SU | SU area ($mi^2$) | Search effort ($min/mi^2$) | SU density ($moose/mi^2$) | No. moose in SCF searches: Std. | No. moose in SCF searches: Int. |
|---|---|---|---|---|---|---|---|
| 38 | Nov 4 1983 | 17 | 12.0 | 5.5 | 1.4 | 2 | 2 |
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moose not seen, and calculating the precision of the total estimate. The calculations are mostly arithmetic and basic statistics and can be performed on a hand calculator. These calculations are divided below into five major steps.

### 3.7.1 Step 1.—Calculating the Observable Stratum Population Estimate and Its Sampling Variance

The observed stratum population is the number of moose that could have been seen if the entire stratum had been searched with the standard search effort (e.g., 4 to 6 min/$mi^2$ in early winter).

#### 3.7.1.1 Definition of symbols

$A_i$ = area ($mi^2$) of a particular stratum i="h", "m", "$\ell$"
$y_j$ = number of observed moose in the *jth* SU
$x_j$ = number of $mi^2$ in the *jth* SU
$\bar{x}_i$ = mean $mi^2$ of all SUs surveyed in the *ith* stratum
$n_i$ = number of SUs surveyed in the *ith* stratum
$N_i$ = total number of SUs in the *ith* stratum
$d_i$ = observable density (moose/$mi^2$) in the *ith* stratum
$\hat{T}_i$ = observable population estimate in the *ith* stratum
$V(\hat{T}_i)$ = sampling variance of observable population estimate in the *ith* stratum.

#### 3.7.1.2 Observable stratum population estimate ($\hat{T}_i$)

The observable stratum population estimate is calculated as

$$\hat{T}_i = \text{density of moose} \times \text{area of stratum}$$

or

$$\hat{T}_i = d_i A_i.$$

Moose density in a stratum (moose/$mi^2$) is calculated as

$$d_i = \frac{\text{total no. moose seen in all surveyed SUs}}{\text{total surface area of all surveyed SUs (mi}^2\text{)}}$$

or

$$d_i = \frac{\sum_j y_j}{\sum_j x_j}.$$

Area of a stratum ($A_i$) is calculated by summing the area of each SU in the stratum. The area of each SU ($x_j$) should be measured with a computer-driven digitizer or a polar compensating planimeter (purchased at graphics shops for about $200.00). A preliminary estimate of area for each SU is made from a map by counting the number of 1-$mi^2$ blocks within a SU plus the partial blocks along the SU boundaries.

#### 3.7.1.3 Sampling variance of the stratum population estimate [$V(\hat{T}_i)$]

$$V(\hat{T}_i) = A_i^2\left[\frac{1}{\bar{x}_i^2} \cdot \frac{s_{qi}^2}{n_i}\left(1 - \frac{n_i}{N_i}\right)\right].$$

To estimate $V(\hat{T}_i)$, calculate the stratum sample variance ($s_{qi}^2$) as

$$s_{qi}^2 = \frac{\sum_j y_j^2 - 2d_i \sum_j x_j y_j + d_i^2 \sum_j x_j^2}{n_i - 1}.$$

Then insert the value of $s_{qi}^2$ into the formula and compute $V(\hat{T}_i)$.

Sample variance measures the deviation in number of moose counted in a SU from the number expected based on its size. The stratum sampling variance formula also contains a finite population correction factor ($1 - n_i/N_i$), which reduces the variance of the estimate as the number of SUs surveyed increases.

### 3.7.2 Step 2.—Calculating the Observable Population Estimate and Its Sampling Variance for the Survey Area

The observable population estimate is the number of moose that could have been seen if the entire survey area had been searched with the standard search effort. It is uncorrected for sightability.

#### 3.7.2.1 Observable population estimate ($\hat{T}_o$)

$$\hat{T}_o = \Sigma \text{ observable strata population estimates}$$

or

$$\hat{T}_o = \hat{T}_h + \hat{T}_m + \hat{T}_\ell$$

where h, m, and $\ell$ indicate high-, medium-, and low-density strata, respectively.

#### 3.7.2.2 Sampling variance of observable population estimate [$V(\hat{T}_o)$]

$$V(\hat{T}_o) = \Sigma \text{ variances of observable strata population estimates}$$

or

$$V(\hat{T}_o) = V(\hat{T}_h) + V(\hat{T}_m) + V(\hat{T}_\ell)$$

where h, m, and $\ell$ indicate high-, medium-, and low-density strata, respectively.

**3.7.2.3 Degrees of freedom ($\nu_o$) for the observable population estimate**

$$\nu_o = \frac{[V(\hat{T}_o)]^2}{\frac{[V(\hat{T}_h)]^2}{n_h - 1} + \frac{[V(\hat{T}_m)]^2}{n_m - 1} + \frac{[V(\hat{T}_\ell)]^2}{n_\ell - 1}}$$

where $n_h$, $n_m$, and $n_\ell$ are the number of SUs flown in high-, medium-, and low-density strata, respectively (Satterthwaite 1946).

### 3.7.3 Step 3.—Calculating the Expanded Population Estimate and Its Sampling Variance

The observable population estimate corrected for observed sightability is referred to as the expanded population estimate. A new variance is also calculated that combines the sampling variance of the observed sightability correction factor with the sampling variance of the observable population estimate.

**3.7.3.1 Definition of symbols**

$\hat{T}_e$ = expanded population estimate for the entire survey area
$SCF_o$ = observed sightability correction factor (defined in Section 3.6.5.1)
$V(SCF_o)$ = sampling variance of the observed sightability correction factor (defined in Section 3.6.5.3)
$V(\hat{T}_e)$ = sampling variance of the expanded population estimate
$n_o$ = number of 2-mi$^2$ plots resurveyed with an intensive search for estimating $SCF_o$
$\nu_e$ = degrees of freedom for the $\hat{T}_e$
$\nu_o$ = degrees of freedom for the observable population estimate ($\hat{T}_o$) (defined in Section 3.7.2.1)
$\nu_s$ = degrees of freedom for $SCF_o$.

**3.7.3.2 Expanded population estimate ($\hat{T}_e$)**

$\hat{T}_e$ = observable population estimate × observed sightability correction factor

or

$$\hat{T}_e = \hat{T}_o \cdot SCF_o.$$

**3.7.3.3 Sampling variance of the expanded population estimate [$V(\hat{T}_e)$]**

A sampling variance approximation [$V(\hat{T}_e)$] for the expanded population estimate combines sampling variance of the observable population estimates [$V(\hat{T}_o)$] with the sampling variance of the observed sightability correction factor [$V(SCF_o)$] (Goodman 1960) as follows:

$$V(\hat{T}_e) = SCF_o^2\,[V(\hat{T}_o)] + \hat{T}_o^2\,[V(SCF_o)] - V(SCF_o)[V(\hat{T}_o)].$$

For low-density populations where $SCF_o$ cannot be estimated, substitute $\overline{SCF}$ and $V(\overline{SCF})$ for SCF and $V(SCF_o)$, respectively (see Section 3.6.5.5).

The formula for the sampling variance of the expanded population estimate is based on the theoretical assumption that observable moose and the sightability correction are estimated independently. This is clearly not the case in our sampling methodology. We tested the formula using computer simulation under two sets of conditions. For the first condition, the sightability of an individual moose was independent of moose density. For the second condition, the sightability of an individual moose was dependent upon group size in the population. Specifically, if the probability of an individual moose (group size = 1) being seen with regular search effort was $p$, we simulated the probability of a moose being missed at regular search effort for groups of size 1, 2, 3, 4... as being $(1 - p)$, $(1 - p)$, $(1 - p)^2$, $(1 - p)^3$ .... Group size distribution in sample units was based on unpublished data. We believe that the two conditions represent the opposite extremes in possible relationships between sightability and moose density. We found that the sampling variance formula provided a very good approximation of variance for our methodology under both sets of conditions, despite the lack of independence of the estimates of observable moose and sightability correction factor. While we recommend the formula for our methodology, we do not recommend the application of the formula for the product of other nonindependent estimators.

**3.7.3.4 Degrees of freedom ($\nu_e$)**

The number of degrees of freedom for our observed sightability correction factor ($SCF_o$) is

$$\nu_s = n_o - 1.$$

Then, the number of degrees of freedom for our expanded population estimate ($\hat{T}_e$) is the smaller of the two values $\nu_o$ and $\nu_s$

$$\nu_e = \text{minimum of } [\nu_o, \nu_s].$$

### 3.7.4 Step 4.—Calculating the Total Population Estimate and Its Sampling Variance

**3.7.4.1 Total population estimate ($\hat{T}$)**

$\hat{T}$ = expanded population estimate × sightability correction factor constant

or

$$\hat{T} = \hat{T}_e \cdot SCF_c.$$

#### 3.7.4.2 Sampling variance of total population estimate $[V(\hat{T})]$

$$V(\hat{T}) = V(\hat{T}_e) \cdot SCF_c^2 .$$

### 3.7.5 Step 5.—Calculating the Confidence Interval of the Total Population Estimate

#### 3.7.5.1 Definition of symbols

CI = confidence interval
$CL_u$ = upper confidence limit
$CL_\ell$ = lower confidence limit
$t$ = Student's $t$-statistic (discussed in Section 2)
$1 - \alpha$ = specified probability for the CI
$\nu_e$ = degrees of freedom (defined in Section 3.7.3.4).

#### 3.7.5.2 Confidence interval

$$\text{CI} = \text{total population estimate} \pm t_{\alpha,\nu_e} \sqrt{\begin{matrix}\text{variance of}\\ \text{total population}\\ \text{estimate}\end{matrix}}$$

or

$$\text{CI} = \hat{T} \pm t_{\alpha,\nu_e} \sqrt{V(\hat{T})}$$

The degrees of freedom ($\nu_e$) were calculated in Section 3.7.3.4. Student's $t$-values for confidence intervals of specified confidence levels ($1 - \alpha$) are found in Table 8.

The CI is commonly expressed as a percentage of the total population estimate because the percentage clearly shows the relative CI width (precision). This expression of the CI is calculated as

$$\text{CI as} \pm \% \text{ of population estimate} = \frac{\left(\begin{matrix}\text{total}\\ \text{population}\\ \text{estimate}\end{matrix} - \begin{matrix}\text{lower}\\ \text{confidence}\\ \text{limit}\end{matrix}\right) 100}{\text{total population estimate}}$$

or

$$\text{CI as} \pm \% \text{ of } \hat{T} = \frac{(\hat{T} - CL_\ell)100}{\hat{T}} .$$

The final expression is $\hat{T} \pm$ CI%, e.g., 1,000 moose ± 20%.

The formula for the confidence interval is generally reliable; however, our simulation studies demonstrated certain conditions where it can be inaccurate. This formula is sensitive to the quality of the estimate of SCF. The reason for this is that the type of data in $SCF_o$ estimates does not lend itself to the calculation of confidence intervals using Student's $t$-values, particularly with small sample sizes. This negative aspect of estimating $SCF_o$ is buffered by the way that the sampling variances of $SCF_o$ and $\hat{T}_o$ are combined to approximate the sampling variance of $\hat{T}_e$. Under most conditions, this buffering effect is adequate to ensure that the formula for confidence intervals around $\hat{T}_e$ and $\hat{T}$ are accurate.

The formula for the confidence interval around $\hat{T}$ should not be taken literally unless you have performed at least eight intensive searches ($n_o$ equal to or greater than 8) to estimate sightability. But rather than use this rule of thumb, we recommend that you apply the procedures in Section 3.10.3 which will help allocate sampling effort between standard and intensive searches. If the number of intensive searches is nearly equal to or greater than the optimal allocation, the formula of confidence intervals will be accurate. If the number of intensive searches flown is considerably

Table 8. Critical values of Student's $t$-distribution for confidence intervals (CI), and two-tailed ($\alpha$) tests.

| Degrees of freedom ($\nu$) | CI (1-$\alpha$) 80% $\alpha$ = .20 | 90% .10 | 95% .05 |
|---|---|---|---|
| 1 | 3.078[a] | 6.314 | 12.706 |
| 2 | 1.886 | 2.920 | 4.303 |
| 3 | 1.638 | 2.353 | 3.182 |
| 4 | 1.533 | 2.132 | 2.776 |
| 5 | 1.476 | 2.015 | 2.571 |
| 6 | 1.440 | 1.943 | 2.447 |
| 7 | 1.415 | 1.895 | 2.365 |
| 8 | 1.397 | 1.860 | 2.306 |
| 9 | 1.383 | 1.833 | 2.262 |
| 10 | 1.372 | 1.812 | 2.228 |
| 11 | 1.363 | 1.796 | 2.201 |
| 12 | 1.356 | 1.782 | 2.179 |
| 13 | 1.350 | 1.771 | 2.160 |
| 14 | 1.345 | 1.761 | 2.145 |
| 15 | 1.341 | 1.753 | 2.131 |
| 16 | 1.337 | 1.746 | 2.120 |
| 17 | 1.333 | 1.740 | 2.110 |
| 18 | 1.330 | 1.734 | 2.101 |
| 19 | 1.328 | 1.729 | 2.093 |
| 20 | 1.325 | 1.725 | 2.086 |
| 21 | 1.323 | 1.721 | 2.080 |
| 22 | 1.321 | 1.717 | 2.074 |
| 23 | 1.319 | 1.714 | 2.069 |
| 24 | 1.318 | 1.711 | 2.064 |
| 25 | 1.316 | 1.708 | 2.060 |
| 26 | 1.315 | 1.706 | 2.056 |
| 27 | 1.314 | 1.703 | 2.052 |
| 28 | 1.313 | 1.701 | 2.048 |
| 29 | 1.311 | 1.699 | 2.045 |
| 30 | 1.310 | 1.697 | 2.042 |
| 40 | 1.303 | 1.684 | 2.021 |
| 60 | 1.296 | 1.671 | 2.000 |
| 120 | 1.289 | 1.658 | 1.980 |
| ∞ | 1.282 | 1.645 | 1.960 |

[a] These values were extracted from Appendix Table II of Simpson et al. (1960).

Table 9. Data from a population estimation survey in the fictitious Square Mountain survey area.

| | Low stratum | | Medium stratum | | High stratum | |
|---|---|---|---|---|---|---|
| No. of SUs[a] | No. moose seen | SU area ($mi^2$) | No. moose seen | SU area ($mi^2$) | No. moose seen | SU area ($mi^2$) |
| 1 | 2 | 12 | 9 | 12 | 49 | 12 |
| 2 | 2 | 12 | 14 | 12 | 57 | 12 |
| 3 | 1 | 12 | 22 | 12 | 41 | 12 |
| 4 | 4 | 12 | 10 | 12 | 23 | 12 |
| 5 | 1 | 12 | 17 | 12 | 32 | 12 |
| 6 | | | 12 | 12 | 6 | 12 |
| 7 | | | | | 35 | 12 |
| 8 | | | | | 35 | 12 |
| 9 | | | | | 19 | 12 |
| Sample total | 10 | 60 | 84 | 72 | 297 | 108 |
| Area of *ith* stratum ($A_i$) | | 276 | | 240 | | 156 |
| Total SUs in *ith* stratum ($N_i$) | | 23 | | 20 | | 13 |

[a] SU equals sample unit.

less than the optimal allocation, your confidence intervals may not be accurate.

### 3.7.6 Summary of Calculations for the Total Population Estimate and Confidence Interval

Step 1.—Calculate observable stratum population estimates ($\hat{T}_i$) and sampling variances [$V(\hat{T}_i)$](Section 3.7.1)

Step 2.—Calculate observable population estimate ($\hat{T}_o$), sampling variance [$V(\hat{T}_o)$], and degrees of freedom ($v_o$) (Section 3.7.2)

Step 3.—Calculate expanded population estimate ($\hat{T}_e$), total sampling variance [$V(\hat{T}_e)$], and degrees of freedom ($v_e$) (Section 3.7.3)

Step 4.—Calculate total population estimate ($\hat{T}$) (Section 3.7.4)

Step 5.—Calculate confidence intervals of total population estimate (Section 3.7.5).

## 3.8 EXAMPLE: CALCULATING THE POPULATION ESTIMATE AND CONFIDENCE INTERVAL

The following example is a step-by-step procedure for calculating a population estimate and confidence interval. Data used in the example are collected from a stratified random sample of the Square Mountain survey area (Table 9). When performing these calculations, it is important to use the number of decimal places indicated in the example to reduce rounding errors. Refer to Section 3.7 for formulae while working through calculations in this section.

### 3.8.1 Step 1.—Calculating the Observable Strata Population Estimates and Their Sampling Variances

#### 3.8.1.1 Low-density stratum estimates

Density estimate:

$$d_\ell = \frac{10 \text{ moose observed in low-density SUs}}{60.0 \text{ mi}^2 \text{ surveyed in low-density stratum}}$$

$$= 0.166667 \text{ moose/mi}^2.$$

Observed stratum estimate:

$$\hat{T}_\ell = (0.166667 \text{ moose/mi}^2)(276 \text{ mi}^2 \text{ in low-density stratum})$$

$$= 46 \text{ moose}.$$

Sampling variance estimate:

First compute $s^2_{q\ell}$.

$$s^2_{q\ell} = \frac{26 - 2(0.166667)120 + 20.000160}{5 - 1} = 1.500020.$$

Use the value of $s^2_{q\ell}$ to compute $V(\hat{T}_\ell)$.

$$V(\hat{T}_\ell) = 276.0^2 \left[\frac{1}{12.00^2} \times \frac{1.500020}{5}\left(1 - \frac{5}{23}\right)\right]$$

$$= 76{,}176.00[0.0069 \times 0.300004(0.782609)]$$

$$= 123.405.$$

#### 3.8.1.2 Medium-density stratum estimates

Density estimate:

$$d_m = 1.166667 \text{ moose/mi}^2.$$

Observed population estimate:

$$\hat{T}_m = 280 \text{ moose}.$$

Sampling variance estimate:

$$s^2_{qm} = 23.600019$$

$$V(\hat{T}_m) = 1094.285.$$

#### 3.8.1.3 High-density stratum estimates

Density estimate:

$$d_h = 2.750000 \text{ moose/mi}^2.$$

Observed population estimate:

$$\hat{T}_h = 429 \text{ moose}.$$

Sampling variance estimate:

$$s^2_{qh} = 241.250000$$

$$V(\hat{T}_h) = 1384.962.$$

### 3.8.2 Step 2.—Calculating the Observable Population Estimate and Its Sampling Variance for Survey Area

Observed population estimate:

$\hat{T}_o$ = 46 in low stratum + 280 in medium stratum + 429 in high stratum

= 755 observable moose.

Sampling variance estimate:

$V(\hat{T}_o)$ = 123.405 low stratum + 1094.285 medium stratum + 1384.962 high stratum

= 2602.652.

Degrees of freedom:

$$\nu_o = \frac{(2602.652)^2}{\frac{(1384.962)^2}{9-1} + \frac{(1094.285)^2}{6-1} + \frac{(123.405)^2}{5-1}} \cong 14.$$

### 3.8.3 Step 3.—Calculating the Expanded Population Estimate and Its Sampling Variance

For this example, let us assume that 10 ($n_o$) intensive searches were flown during the Square Mountain survey and resulted in an $SCF_o = 1.08$ and $V(SCF_o) = 0.003400$.

Expanded population estimate:

$\hat{T}_e$ = 755 observable moose × 1.08 observed sightability correction factor

= 815 moose.

Variance estimate:

$$V(\hat{T}_e) = 1.08^2(2602.652) + 755^2(0.003400) - 0.003400(2602.652)$$

$$= 3035.7333 + 1938.0850 - 8.8490$$

$$= 4964.969.$$

Degrees of freedom:

First, calculate $\nu_s$ for $SCF_o$.

$$\nu_s = 10 - 1 = 9.$$

Degrees of freedom ($\nu_e$) is then used for calculating the CI which is the minimum of $\nu_o$ and $\nu_s$:

$$\nu_e = \text{minimum of } [14, 9] = 9.$$

### 3.8.4 Step 4.—Calculating the Total Population Estimate and Its Sampling Variance

Total population estimate:

$$\hat{T} = 815 \text{ moose} \times 1.02 \text{ SCF}_c = 831 \text{ moose}.$$

Sampling variance estimate:

$$V(\hat{T}) = 1.02^2 \times 4964.969 = 5165.554.$$

### 3.8.5 Step 5.—Calculating the 90% Confidence Interval for the Total Population Estimate

Confidence interval:

$$CI = 831 \pm 1.833 \sqrt{5165.554}$$

$$= 831 \pm 132 \text{ moose}.$$

Confidence limits:

$$CL_\ell = 699 \text{ moose}$$

and

$$CL_u = 963 \text{ moose}.$$

Confidence interval as a percentage of population estimate:

$$\text{CI as} \pm \% \text{ of } \hat{T} = 831 \pm \frac{(831 - 699)100}{831}$$

$$= 831 \text{ moose} \pm 15.9\%.$$

### 3.8.6 Data Summary for Population Estimation Surveys

Form 5 is used to list estimated values for strata and for the survey area (see Appendix 2 for blank form).

## 3.9 HEWLETT-PACKARD 97 PROGRAM: CALCULATING THE POPULATION ESTIMATE AND CONFIDENCE INTERVAL

### 3.9.1 Program Instructions

HP 97 program 1 in Appendix 1 estimates population size and confidence interval. Program instructions are in Table 10. The calculator display, which appears after a function key is depressed, indicates the step in the program and indicates the calculator is ready for data or an action appropriate for that step. For example, when the calculator display is "0.", you are at step 2 and need to press function key A.

### 3.9.2 Program Printout

The HP 97 printout format shown in Figure 19 uses data from the example in Section 3.8. The HP 97 prints only numbers and asterisks. Three asterisks are normally printed at the right of each number; asterisks have been omitted in this example to conserve space. Symbols were added in this example to facilitate the identification of each number.

## 3.10 OPTIMALLY ALLOCATING SAMPLING EFFORT

Optimal allocation of sampling effort is the process of distributing sampling effort to produce the most precise population estimate, i.e., how to get the most precision for your dollar. The sampling effort is distributed among strata and between standard and intensive searches. Skip this section if your budget is infinite; however, study it carefully if funds are in short supply. Cochran (1977), Stuart (1984), and Scheaffer et al. (1979) present discussions on optimally allocating effort among strata. We use their methods of allocation among strata and a heuristic extension of their methods for allocating between standard and intensive search efforts.

Optimal allocation must be considered as soon as five SUs (or some other predetermined minimum greater than 5) have been searched in each stratum. We consider five SUs to be the minimum for estimating a variance; usually more than five SUs are surveyed in each stratum. Despite the need to optimally allocate early in the survey, its discussion follows the calculation of the population estimate because strata variances are used in the allocation process.

### 3.10.1 Basis for Optimal Allocation

Conventional procedure is to allocate search effort prior to the survey and base search effort on expected sample variance among strata; i.e., the greater the expected sample variance, the greater the proportion of SUs that must be searched. Also, the size of strata influences search effort with larger strata generally requiring more search effort. The survey is concluded when these SUs are searched. In lieu of specific variance estimates, relative density estimates are commonly used along with known strata sizes to allocate effort because density and variance are generally directly related. If unexpected variances occur, the allocation is, in the end, not optimal. In fact, variances commonly behave in unexpected ways because they are dependent on how well stratification partitioned the variance among all SUs.

To overcome the inaccuracy of estimating relative variances prior to sampling, we allocate sampling effort among strata on a daily basis during the survey and base the allocation on the observed sample variance estimates of the strata. In addition, by using observed sample variances, we allocate effort between standard and intensive searches.

We will first discuss allocating effort among strata. This will provide the basis for allocating effort among strata for standard searches and between standard and intensive searches.

Form 5. Moose population estimation survey--data summary.

Survey Area Fictitious Square Mountain

Game Management Unit(s) 1 Subunit(s) A

Date of Survey Nov 1983 Survey Supervisor Jones

DATA SUMMARY FOR STRATUM

| STRATUM POPULATION ESTIMATE | Low stratum | Medium stratum | High stratum |
|---|---|---|---|
| $A_i$ = area (mi$^2$) | 276.0 | 240.0 | 156.0 |
| $N_i$ = total SUs | 23 | 20 | 13 |
| $n_i$ = no. SUs searched | 5 | 6 | 9 |
| $d_i$ = obs. density | 0.166667 | 1.166667 | 2.750000 |
| $\hat{T}_i$ = est. no. moose (uncorrected) | 46.0 | 280.0 | 429.0 |
| $V(\hat{T}_i)$ = variance of $\hat{T}_i$ | 124.200 | 1101.333 | 1393.889 |

DATA SUMMARY FOR SURVEY AREA

SURVEY AREA INFORMATION

Total area (mi$^2$) = 612.0

Total No. SUs = 56

Total No. SUs searched = 20

OBSERVED POPULATION ESTIMATE

$\hat{T}_o$ = obs. pop. est. (uncorrected) = 755.0

$V(\hat{T}_o)$ = variance obs. est. = 2619.42

$\nu_o$ = degrees of freedom = 14

$SCF_o$ = obs. sight. correction factor = 1.08

$V(SCF_o)$ = variance of $SCF_o$ = 0.003400

$n_o$ = no. SCF plots searched = 10

$\nu_s$ = degrees freedom of $SCF_o$ = 9

EXPANDED POPULATION ESTIMATE

$SCF_c$ = sight. correction constant = 1.02

$\hat{T}_e$ = expand. pop. est. ($\hat{T}_o \times SCF_c$) = 815

$V(\hat{T}_e)$ = variance of $\hat{T}_e$ = 5002

$\nu_e$ = degrees of freedom = 9

TOTAL POPULATION ESTIMATE

$\hat{T}$ = total pop. est. ($\hat{T}_e \times SCF_c$) = 832

d = density = 1.24

90% CI as % of $\hat{T}$ = 15.9

$CL_u$ = upper confidence limit = 964

$CL_\ell$ = lower confidence limit = 699

SCF = sight. correct. factor ($SCF_o \times SCF_c$) = 1.10

Table 10. Hewlett-Packard 97 program instructions for calculating a moose population estimate and confidence interval.

| Step | Display value equals | Instruction | Printout value equals |
|---|---|---|---|
| 1 | 0.00 | LOAD both sides of card 1 | |
| 2 | 0. | PRESS A | |
| 3 | −111. | Choose either:<br>(1) To enter $SCF_o$ (observed sightability correction factor) data, go to step 4; or<br>(2) To enter previously calculated $SCF_o$, $V(SCF_o)$, and $v_s$ (degrees of freedom for $SCF_o$), go to step 8 | |
| 4 | −111. | PRESS B | |
| 5 | 0 or no. data sets entered | ENTER $u_k$ (no. moose seen on intensive search)<br>PRESS R/S† | $u_k$ |
| 6 | $u_k$ | ENTER $v_k$ (no. moose seen on standard search)<br>PRESS R/S†<br>Repeat steps 5-6 until all SUs in stratum entered, then go to step 7 | $v_k$ |
| 7 | No. data sets entered | PRESS C<br>Go to Step 12 | $n_o$ (no. intensive searches)<br>$SCF_o$ (observed sightability correction factor)<br>$V(SCF_o)$ (variance)<br>$v_s$ (degrees freedom of $SCF_o$) |
| 8 | −111. | PRESS D | |
| 9 | −222. | ENTER $SCF_o$ (observed sightability correction factor)<br>PRESS R/S | $SCF_o$ |
| 10 | $SCF_o$ | ENTER $V(SCF_o)$ (variance of $SCF_o$)<br>PRESS R/S | $V(SCF_o)$ |
| 11 | $V(SCF_o)$ | ENTER $v_s$ (degrees freedom of $SCF_o$)<br>PRESS R/S | $v_s$ |
| 12 | −333. | Choose either:<br>(1) To enter density data, go to step 13; or<br>(2) To recalculate $SCF_o$ go to step 4 | |
| 13 | −333. | PRESS E | |
| 14 | −444. | ENTER $A_i$ (total area for stratum)<br>PRESS R/S†† | $A_i$ |
| 15 | $A_i$ | ENTER $N_i$ (total SUs for stratum)<br>PRESS R/S†† | $N_i$ |

Table 10. Continued.

| Step | Display value equals | Instruction | Printout value equals |
|---|---|---|---|
| 16 | 0.0 or no. data sets entered | ENTER $y_j$ (no. moose counted in $SU_j$)<br>PRESS R/S[††,†††] | $y_j$ |
| 17 | $y_i$ | ENTER $x_j$ (area of $SU_j$)<br>PRESS R/S[††,†††]<br>Repeat steps 16-17 until all SUs in stratum are entered, then go to step 18 | $x_j$ |
| 18 | No. data sets entered | PRESS f, c | $n_i$ (no. SUs surveyed in stratum)<br>$d_i$ (stratum density)<br>$\hat{T}_i$(stratum population est.)<br>$V(\hat{T}_i)$ (variance) |
| 19 | | Choose either:<br>(1) To enter more strata, go to step 14; or<br>(2) If all strata are entered, go to step 20 | |
| 20 | −444. | PRESS f, d | $\hat{T}_o$(observed population est.)<br>$V(\hat{T}_o)$ (variance)<br>$\nu_o$ (degrees freedom of $\hat{T}_o$) |
| 21 | −555. | LOAD both sides of card 2 | |
| 22 | −555. | PRESS A | $\hat{T}_e$(expanded population est.)<br>$V(\hat{T}_e)$ (variance)<br>$\nu_e$ (degrees freedom of $\hat{T}_e$) |
| 23 | −666. | ENTER $SCF_c$ (sightability correction factor constant)<br>PRESS R/S | $SCF_c$<br>$\hat{T}$ (total population est.)<br>$V(\hat{T})$ (variance) |
| 24 | −777. | Choose:<br>(1) To enter new $SCF_c$, PRESS B, and return to step 23; or<br>(2) To calculate 90% CI, PRESS D; or<br>(3) To calculate 95% CI, PRESS E | % CI selected<br>$CI_\ell$ (lower confidence limit)<br>$CI_u$ (upper confidence limit)<br>CI as ± % of $\hat{T}$<br>(i.e., $\hat{T}$ ± %) |
| END OF PROGRAM | | To rerun the program, return to step 1 and reload card 1 | |

[†] If an error is made entering $u_k$ or $v_k$, finish entering both $u_k$ and $v_k$ until positioned at step 5 again, then PRESS f, b. ENTER initial $u_k$ (whether erroneous or correct), PRESS R/S, and it will be printed. ENTER $v_k$, PRESS R/S, and it will be printed. Now you have removed the pair of values for sightability plot k that contained the error, and you are positioned again at step 5. Notice that the display value has decreased by 1 because the erroneous pair has been extracted. Proceed with step 5 and enter correct $u_k$ or $v_k$.

[††] If an error is made entering $A_i$ or $N_i$, or if the entry of $y_j$'s and $x_j$'s is in a shambles, all information for current strata can be retracted by pressing E. All previous strata (strata for which f and c were pressed in step 18) will not be affected.

[†††] If an error is made in entering $y_j$ and $x_j$, finish entering both $y_j$ and $x_j$ until positioned at step 16, then PRESS f and b. ENTER erroneous $y_j$ and $x_j$ data set, PRESS R/S, and it will be printed. You will be positioned again at step 16. Notice that the display is 1 less in value than previously. Proceed with step 16 and enter correct $y_j$ and $x_j$.

| Printout | Symbol | Printout | Symbol | Printout | Symbol |
|---|---|---|---|---|---|
| 1.08 | $SCF_o$ | 10.0 | | 9. | $n_h$ |
| 0.003400 | $V(SCF_o)$ | 12.0 | | 2.750000000 | $d_h$ |
| 9. | $\nu_s$ | 17.0 | | 429.0 | $\hat{T}_h$ |
| | | 12.0 | | 1393.889 | $V(\hat{T}_h)$ |
| | | 12.0 | | | |
| 276.0 | $A_\ell$ | 12.0 | | | |
| 23. | $N_\ell$ | | | 755.0 | $\hat{T}_o$ |
| | | 6. | $n_m$ | 2619.42 | $V(\hat{T}_o)$ |
| 2.0 | $y_j$ | 1.166666667 | $d_m$ | 14. | $\nu_o$ |
| 12.0 | $x_j$ | 280.0 | $\hat{T}_m$ | | |
| 2.0 | | 1101.333 | $V(\hat{T}_m)$ | | |
| 12.0 | | | | 815. | $\hat{T}_e$ |
| 1.0 | | | | 4984. | $V(\hat{T}_e)$ |
| 12.0 | | 156.0 | $A_h$ | 9. | $\nu_e$ |
| 4.0 | | 13. | $N_h$ | | |
| 12.0 | | | | | |
| 1.0 | | 49.0 | $y_j$ | 1.02 | $SCF_c$ |
| 12.0 | | 12.0 | $x_j$ | 832. | $\hat{T}$ |
| | | 57.0 | | 5186. | $V(\hat{T})$ |
| 5. | $n_\ell$ | 12.0 | | | |
| 0.166666667 | $d_\ell$ | 41.0 | | | |
| 46.0 | $\hat{T}_\ell$ | 12.0 | | 90. | 90% CI |
| 124.200 | $V(\hat{T}_\ell)$ | 23.0 | | 700. | $CL_\ell$ |
| | | 12.0 | | 964. | $CL_u$ |
| | | 32.0 | | 15.9 | CI as ± % $\hat{T}$ |
| 240.0 | $A_m$ | 12.0 | | | |
| 20. | $N_m$ | 6.0 | | | |
| | | 12.0 | | 95. | 95% CI |
| 9.0 | $y_j$ | 35.0 | | 669. | $CL_\ell$ |
| 12.0 | $x_j$ | 12.0 | | 995. | $CL_u$ |
| 14.0 | | 35.0 | | 19.6 | CI as ± % $\hat{T}$ |
| 12.0 | | 12.0 | | | |
| 22.0 | | 19.0 | | | |
| 12.0 | | 12.0 | | | |

**Figure 19.** Example of the Hewlett-Packard 97 printout of the program for calculating the population estimate and associated confidence interval. The tape printout has been divided into three columns; complete column 1, proceed to column 2, and finally to 3.

### 3.10.2 Optimally Allocating Among Strata

The adjustment of sampling effort among strata is accomplished by using the sample variance of each stratum ($s^2_{qi}$ calculated in Section 3.7.1.3), stratum area ($A_i$), and mean area of SUs surveyed in a stratum to date ($\bar{x}_i$) to calculate a relative variation factor ($RVF_i$) for each stratum.

$$RVF_i = \frac{A_i}{\bar{x}_i} \sqrt{s^2_{qi}}$$

Optimal allocation of search effort is achieved by solving the approximate equations

$$n^*_m \cong \frac{RVF_m}{RVF_\ell} n^*_\ell,$$

$$n^*_h \cong \frac{RVF_h}{RVF_\ell} n^*_\ell,$$

and

$$n^*_h \cong \frac{RVF_h}{RVF_m} n^*_m,$$

where $n_i^*$ is the optimal number of SUs to be searched in the *ith* stratum, i = $\ell$, m, h.

These equations are powerful tools that can be used to optimally allocate sampling effort as the survey progresses. To do this, allocate the remaining sampling effort so that the variance is minimized. When solving these equations, you must accept integer values for the $n_i^*$ that satisfy the equations as nearly as possible because you only sample whole SUs. Also, realize that there are practical bounds for $n_i^*$. That is, $n_i^*$ cannot be less than the number of SUs that have been sampled to date in the *ith* stratum, and it can be no larger than the total number of SUs in stratum i ($N_i$).

A numerical example to further explain the optimal allocation equations follows where $RVF_\ell$ = 26.73, $RVF_m$ = 79.93, and $RVF_h$ = 93.21, and you have sampled five SUs in each stratum. Compute

$$n_m^* \cong \frac{RVF_m}{RVF_\ell} n_\ell^* = \frac{79.93}{26.73} n_\ell^* = 2.99\, n_\ell^*$$

$$n_h^* \cong \frac{RVF_h}{RVF_\ell} n_\ell^* = \frac{93.21}{26.73} n_\ell^* = 3.49\, n_\ell^*$$

and

$$n_h^* \cong \frac{RVF_h}{RVF_m} n_m^* = \frac{93.21}{79.93} n_m^* = 1.17\, n_m^* .$$

The first two equations indicate that the medium- and high-density strata will require more of the remaining search effort than the low-density stratum. Because five SUs have already been flown in the low-density stratum, and it has the smallest variance as demonstrated by $RVF_\ell$, let $n_\ell^*$ = 5 to determine optimal allocation in the medium- and high-density strata.

Compute

$n_m^* \cong 2.99\, n_\ell^*$

$n_m^* \cong 2.99 \times 5$ SUs surveyed in the low-density stratum

$n_m^* = 15$,

and

$n_h^* \cong 3.49\, n_\ell^*$

$n_h^* \cong 3.49 \times 5$ SUs surveyed in the low-density stratum

$n_h^* = 17$.

Given that five SUs have been flown in the low-density stratum, the most precise population estimate will be achieved if a total of 15 and 17 SUs are flown in the medium- and high-density strata, respectively.

Notice that the allocation equation,

$$n_h^* \cong \frac{RVF_h}{RVF_m} n_m^*$$

was not used to determine optimal allocation in this example. The three equations are redundant, and it is only necessary to use the first two equations when all three strata are being sampled. If the allocation equations indicate that sampling is sufficient for one stratum, then use the one equation appropriate for the other two strata.

In our example, the medium- and high-density strata need to be sampled much more intensively than the low-density, but suppose there is not enough money to do a total of 15 and 17 SUs in the medium- and high-density strata. Then use the third allocation equation and sample proportionally 1.17 high-density SUs to one medium-density SU until you have exhausted the money.

### 3.10.3 Optimally Allocating Effort Between Standard and Intensive Searches

The proportion of SUs searched intensively affects the variability in the expanded population estimate ($\hat{T}_e$). Therefore, the allocation of effort between standard and intensive searches can be optimized in a manner similar to allocation among strata (Section 3.10.2).

It is recommended that the allocation of effort between standard and intensive searches be monitored throughout the survey, but it is not advisable to update this allocation daily as is done with allocation among strata for estimates of observable moose. When the proportion of SUs to be intensively searched is changed in the middle of a survey, assumptions may be violated concerning the random selection of units to be intensively searched. Further, the equations offered below for determining the optimal number of SUs to intensively search are subject to the same sort of variation over the course of the survey as those equations presented in Section 3.10.2.

To determine the optimal number of SUs to intensively search, first follow the procedures in Section 3.10.2 to determine $n_h^*$, $n_m^*$, and $n_\ell^*$, where these values are the actual numbers of SUs you decide to search in each stratum. In addition, retain the $RVF_i$s from Section 3.10.2. Follow procedures in Section 3.6.5.3 to obtain the $SCF_o$ and those in Section 3.7.2.1 to obtain the estimate of $\hat{T}_o$.

From these values, calculate

$$RVF_s^o = \hat{T}_o \sqrt{n_o \cdot V(SCF_o)},$$

$$\mathrm{RVF}_h^o = \mathrm{SCF}_o \cdot \mathrm{RVF}_h,$$

$$\mathrm{RVF}_m^o = \mathrm{SCF}_o \cdot \mathrm{RVF}_m,$$

and

$$\mathrm{RVF}_\ell^o = \mathrm{SCF}_o \cdot \mathrm{RVF}_\ell.$$

It is generally less expensive to fly a 2-mi$^2$ intensive search than to fly a 12-mi$^2$ standard search. Therefore, in your determination of the optimal number of SUs to intensively search, consider the relative costs of the two types of searches. Relative costs are easily expressed in units of time. Determine for your survey

$C_s$ = the number of minutes required to fly an intensive search of a 2-mi$^2$ sightability plot,

and

$C_t$ = the number of minutes required to fly a standard search of a SU.

With the cost figures, calculate

$$n_h^o \cong \frac{\mathrm{RVF}_s^o \sqrt{C_t}}{\mathrm{RVF}_h^o \sqrt{C_s}} n_h^*,$$

$$n_m^o \cong \frac{\mathrm{RVF}_s^o \sqrt{C_t}}{\mathrm{RVF}_m^o \sqrt{C_s}} n_m^*,$$

and

$$n_\ell \cong \frac{\mathrm{RVF}_s^o \sqrt{C_t}}{\mathrm{RVF}_\ell^o \sqrt{C_s}} n_\ell^*$$

The optimal number of SUs to intensively search, $n^o$, is the smaller of the three values, $n_h^o$, $n_m^o$, and $n_\ell^o$.

$$n^o = \text{minimum of } (n_h^o, n_m^o, n_\ell^o)$$

The value $n_o$ can now be used as an index to determine if the division of effort is near the optimal allocation between standard and intensive searches, by calculating

$$\%\ \text{difference} = 100 \frac{|n^o - n_o|}{n^o}$$

where $n_o$ is the number of SUs you would intensively search at the current allocation of effort. If the difference is greater than 25%, you will probably see a cost savings by reallocating effort between standard and intensive searches. If the difference is less than 25%, consideration of a change in allocation should be postponed until more information is collected. If it was advantageous to reallocate effort between standard and intensive searches, it may be necessary to recompute new values for $n_i^*$ (Section 3.10.2) and $n^o$ several times to arrive at a scheme that stays within your budget. Cheer up! This can be easily accomplished with the HP 97 program in Section 3.11. As with the allocation scheme among strata, the value of $n^o$ will vary as more data are collected but will stabilize toward the end of the survey.

### 3.10.4 Example of Optimal Allocation

An example from the Square Mountain survey area will help illustrate optimal allocation. The goal is to produce the most precise expanded population estimate possible with 30.4 hours (1,825 min) of survey time. It takes 75 min of flight time to search a SU at 6 min/mi$^2$ and 30 min to perform an intensive search on a 2-mi$^2$ area.

At the outset, you anticipate, based on previous population estimates in this area, that intensive searches will be required in about 50% of the SUs chosen from the high and medium strata.

Day 1 of the survey results in data from three high-, two medium-, and two low-density strata (Table 11). No attempt is made to allocate search effort for day 2 because at least five SUs in each stratum have not been searched. The objective of the survey crews for day 2 is to survey at least two SUs from the high stratum, three from the medium, and three from the low.

After the second day of surveying, data exist for five SUs in each stratum (Table 11). From these data, the observable number of moose ($\hat{T}_o$) was estimated to be 846. You also intensively searched five 2-mi$^2$ sightability plots ($n_o$ = 5), yielding $\mathrm{SCF}_o$ = 1.053 and $V(\mathrm{SCF}_o)$ = 0.002862. These values must be taken from the HP 97 program or hand calculations for population estimates (Section 3.6.5.3 and 3.9.2).

You used 1,275 min of the time and need to allocate the remaining 550 min. Calculate $\mathrm{RVF}_i$ for each stratum (Table 11), and the optimal allocation equations are

$$n_m^* \cong \frac{79.93}{26.73} n_\ell^* = 2.99\, n_\ell^*,$$

$$n_h^* \cong \frac{93.21}{26.73} n_\ell^* = 3.49\, n_\ell^*,$$

and

$$n_h^* \cong \frac{93.21}{79.93} n_m^* = 1.17\, n_m^*$$

The first two equations indicate that strata m and h will require more effort than stratum ℓ. Using $n_\ell^* = 5$, we get $n_m^*$ = 15, and $n_h^*$ = 17. However, because the high stratum only has 13 total SUs, $n_h^*$ can be no larger than 13. Therefore, use $n_h^*$ = 13. Because five SUs have already been sampled in each strata and only 550 min remain to allocate, you cannot

Table 11. Data needed for calculating the optimum allocation of sampling effort for a population estimation survey in the fictitious Square Mountain survey area. Data are presented for the first two days of sampling.

| | Low stratum | | | Medium stratum | | | High stratum | |
|---|---|---|---|---|---|---|---|---|
| No. moose seen | SU[a] area ($mi^2$) | Stratum value | No. moose seen | SU area ($mi^2$) | Stratum value | No. moose seen | SU area ($mi^2$) | Stratum value |
| 2 | 12.4 | | 9 | 11.5 | | 49 | 14.7 | |
| 2 | 10.9 | | 14 | 11.2 | | 57 | 15.0 | |
| 1 | 12.9 | | 22 | 14.3 | | 41 | 12.0 | |
| 4 | 13.1 | | 10 | 11.0 | | 23 | 10.7 | |
| 1 | 11.3 | | 17 | 12.0 | | 32 | 10.3 | |
| Area of *ith* stratum ($A_i$) ($mi^2$) | | 277.7 | | | 240.2 | | | 158.9 |
| Total SUs in *ith* stratum ($N_i$) | | 23 | | | 20 | | | 13 |
| Mean SU area in *ith* stratum ($\bar{x}_i$) | | 12.12 | | | 12.00 | | | 12.54 |
| *ith* stratum variance [$V(\hat{T}_i)$] | | 111.828 | | | 958.283 | | | 1069.250 |
| Sample variance in *ith* stratum ($s^2_{qi}$) | | 1.3609 | | | 15.9448 | | | 54.1066 |
| Relative variation factor [$(A_i/\bar{x}_i)\sqrt{s^2_{qi}}$] | | 26.73 | | | 79.93 | | | 93.21 |

[a] SU equals sample unit.

expect to approach satisfaction of the first two equations. This situation periodically occurs. If the remaining effort is distributed within the high and medium strata, and if you wish to continue flying intensive searches in 50% of the high and medium SUs, then the 550 min could be proportioned into six standard and three intensive searches. The six standard and three intensive searches would require 450 and 90 min, respectively.

Now you must determine the best allocation of the six remaining SUs between the high and medium strata by computing

$$n^*_h + n^*_m = 16 \text{ total SUs to be flown,}$$

or

$$1.17\, n^*_m + n^*_m \cong 16$$

where

$$n^*_h \cong 1.17\, n^*_m.$$

Two of the remaining six SUs are subjectively allocated to the medium stratum, for a total allocation of seven medium SUs. Enter seven medium SUs in the allocation equation and compute

$$1.17\,(7) + 7 \cong 16$$

$$8.19 + 7 \cong 16$$

$$15 \cong 16.$$

By surveying a total of seven SUs in the medium stratum, you have come very close to the optimal allocation, i.e., there is one additional SU which you decide to allocate to the high stratum. Eight medium SUs would mean nine highs should be sampled, which would exceed the budget of 16 total SUs in the medium and high strata. Therefore, the allocation becomes $n_\ell^* = 5$, $n_m^* = 7$, and $n_h^* = 9$. Maintaining your 50% rate of intensive searches in the high and medium stratum makes $n_o = 8$.

Now determine if the allocation of effort between standard and intensive searches is optimal. To check this allocation, calculate

$$RVF_s^o = 846\sqrt{5 \times 0.002862} = 101.2,$$

$$RVF_h^o = 1.053 \times 93.21 = 98.15,$$

$$RVF_m^o = 84.17,$$

and

$$RVF_\ell^o = 28.15.$$

The cost figures (in units of survey time) are $C_s = 30$ min for intensive searches and $C_t = 75$ min for standard searches.

Calculate

$$n_h^o \cong \frac{101.20\sqrt{75}}{98.15\sqrt{30}} \times 9 = 14.7 \cong 15,$$

$$n_m^o \cong 13.3 \cong 13,$$

and

$$n_\ell^o \cong 28.4 \cong 28.$$

Thus,

$$n^o = \text{minimum of } (15, 13, 28) = 13$$

and

$$100\frac{|n^o - n_o|}{n^o} = 100\frac{|13 - 8|}{13} = 38.5\% .$$

The high percentage difference indicates that the current allocation deviates considerably from the optimum, hence consider adjusting it. Attempt to intensively survey 2-mi$^2$ plots in nearly 100% of the subsequently searched SUs to minimize the variance of the expanded population estimate.

As you cannot afford to do intensive searches in all of the high and medium SUs to be searched, try $n_\ell^* = 5$, $n_m^* = 7$, and $n_h^* = 8$. This allocation among strata will use 375 min of the remaining air time and leave enough to perform an intensive search on all five of the remaining SUs. Recalculating $n_h^o$ will still yield $n^o = 13$. The best allocation of the remaining resources from current data is $n_\ell^* = 5$, $n_m^* = 7$, $n_h^* = 8$, and $n^o = 10$.

On the third day, you have poor weather but are able to perform a standard and intensive search on one SU in each of the high- and medium-density strata. Data for standard search effort appears in Table 12 with an estimate $\hat{T}_o = 783$. Data for intensive searches with $n_o = 7$ yield $SCF_o = 1.042$ and $V(SCF_o) = 0.002703$.

The equations for allocation among strata give $n_\ell^* = 5$, $n_m^* = 6$, and $n_h^* = 9$. So shift the remaining effort to the high-density stratum and perform both types of search on each SU surveyed.

Again, checking the allocation between standard and intensive searches;

$$RVF_s^o = 783\sqrt{7 \times 0.002703} = 107.70,$$

$$RVF_h^o = 1.042 \times 171.51 = 178.71,$$

$$RVF_m^o = 77.21,$$

$$RVF_\ell^o = 27.85,$$

and

$$n_h^o = 9,$$

$$n_m^o = 13,$$

$$n_\ell^o = 31.$$

So

$$n^o = \text{minimum of } (9, 13, 31) = 9.$$

Your planned effort of final $n^o = 10$ deviates little from $n^o = 9$. So, complete the survey on the fourth day by searching three SUs in the high stratum, with each SU getting a standard and intensive search.

This example demonstrates how the optimal allocation may vary during a survey. The equations never supply an absolute optimal allocation at any point in a survey, because the sample variance ($s_{qi}^2$) is only an estimate of the overall

Table 12. Data needed for calculating the optimum allocation of sampling effort for a population estimation survey in the fictitious Square Mountain survey area. Data are presented for the first three days of sampling.

| | Low stratum | | | Medium stratum | | | High stratum | |
|---|---|---|---|---|---|---|---|---|
| No. moose seen | SU[a] area ($mi^2$) | Stratum value | No. moose seen | SU area ($mi^2$) | Stratum value | No. moose seen | SU area ($mi^2$) | Stratum value |
| 2 | 12.4 | | 9 | 11.5 | | 49 | 14.7 | |
| 2 | 10.9 | | 14 | 11.2 | | 57 | 15.0 | |
| 1 | 12.9 | | 22 | 14.3 | | 41 | 12.0 | |
| 4 | 13.1 | | 10 | 11.0 | | 23 | 10.7 | |
| 1 | 11.3 | | 17 | 12.0 | | 32 | 10.3 | |
| | | | 12 | 11.6 | | 6 | 9.9 | |
| Area of *i*th stratum ($A_i$) ($mi^2$) | | 277.7 | | | 240.2 | | | 158.9 |
| Total SUs in *i*th stratum ($N_i$) | | 23 | | | 20 | | | 13 |
| Mean SU area in *i*th stratum ($\bar{x}_i$) | | 12.12 | | | 11.93 | | | 12.10 |
| *i*th stratum variance [$V(\hat{T}_i)$] | | 111.828 | | | 640.618 | | | 2639.885 |
| Sample variance in *i*th stratum ($s^2_{qi}$) | | 1.3609 | | | 13.5528 | | | 170.5707 |
| Relative variation factor $[(A_i/\bar{x}_i)\sqrt{s^2_{qi}}]$ | | 26.73 | | | 74.10 | | | 171.65 |

[a]SU equals sample unit.

variation in a stratum. However, the equations do provide a best estimate of optimal allocation based on accumulated survey data and improve with the inclusion of each day's data.

### 3.10.5 Optimally Allocating Search Effort in Areas of Low Moose Density

Estimating a $SCF_o$ for a low-density moose population is not feasible (Section 3.6.5.5), hence you will not be flying intensive searches. Therefore, allocating search effort between standard and intensive searches is inapplicable. Under these circumstances, simply allocate effort among strata by solving for $n_i^*$ (Section 3.10.2).

## 3.11 HEWLETT-PACKARD 97 PROGRAM: CALCULATING THE OPTIMAL ALLOCATION OF SAMPLING EFFORT

### 3.11.1 Program Instructions

HP 97 program 2 in Appendix 1 estimates the optimal sampling effort among strata and between standard and intensive searches. Program instructions are in Table 13. Using this program, either (1) base the allocation on budget and get the best allocation within budget limitations, or (2) disregard budget limitations and get the best allocation based on the variance of the population estimate. The calculator display, which appears after a function key is de-

Table 13. Hewlett-Packard 97 program instructions for calculating the optimal allocation of sampling effort.

| Step | Display value equals | Instruction | Printout value equals |
|---|---|---|---|
| 1 | 0.00 | LOAD both sides of card 1 | |
| 2 | 0. | PRESS A | |
| 3 | −211. | Choose:<br>(1) To enter low stratum data, PRESS B†; or<br>(2) To enter medium stratum data, PRESS C†; or<br>(3) To enter high stratum data, PRESS D† | |
| 4 | −222. | ENTER $V(\hat{T}_i)$ (variance of stratum population estimate)<br>PRESS R/S†† | $V(\hat{T}_i)$ |
| 5 | $V(\hat{T}_i)$ | ENTER $N_i$ (total no. of SUs in stratum)<br>PRESS R/S†† | $N_i$ |
| 6 | $N_i$ | ENTER $n_i$ (no. of SUs surveyed in stratum)<br>PRESS R/S†† | $n_i$<br>$RVF_i$ (relative variation factor) |
| 7 | −211. | Choose either:<br>(1) To enter more strata, go to step 3; or<br>(2) If all stata are entered, go to step 8. | |
| 8 | −211. | PRESS E | |
| 9 | −233. | ENTER $V(SCF_o)$ (variance of observed sightability correction factor)<br>PRESS R/S††† | $V(SCF_o)$ |
| 10 | $V(SCF_o)$ | ENTER $n_o$ (no. of intensive searches flown)<br>PRESS R/S ††† | $n_o$ |
| 11 | $n_o$ | ENTER $\hat{T}_o$(observed population est.)<br>PRESS R/S††† | $\hat{T}_o$ |
| 12 | $\hat{T}_o$ | ENTER $SCF_o$ (observed sightability correction factor)<br>PRESS R/S††† | $SCF_o$<br>$RVF_s^o$ (relative variation factor between standard and intensive searches)<br>$RVF_\ell^o$<br>$RVF_m^o$<br>$RVF_h^o$ |
| 13 | 0.0 | ENTER $C_t$ (no. of min. or dollars for standard search)<br>PRESS R/S | $C_t$ |
| 14 | $C_t$ | ENTER $C_s$ (no. of min. or dollars for intensive search)<br>PRESS R/S | $C_s$ |

Table 13. Continued.

| Step | Display value equals | Instruction | Printout value equals |
|---|---|---|---|
| 15 | −244. | LOAD both sides of card 2<br>PRESS A | |
| 16 | −255. | Choose either:<br>(1) To calculate optimum allocation based on budget, go to step 17; or<br>(2) To calculate optimum allocation by entering hypothetical $n_i$ and disregarding budget, go to step 19. | |
| 17 | −255. | PRESS E | |
| 18 | −277. | ENTER maximum budget (must be same units as $C_t$ and $C_s$)††††<br>PRESS R/S (several min. may be required for computation)<br>END PROGRAM or go to step 16 | Max. budget<br>$n_\ell^*$ (optimum no. of standard searches in low stratum)<br>$n_m^*$<br>$n_h^*$<br>$n^o$ (optimum no. of intensive searches)<br>Total cost with this allocation††††† |
| 19 | −255. | Choose:<br>(1) To use low stratum as base, PRESS B; or<br>(2) To use medium stratum as base, PRESS C; or<br>(3) To use high stratum as base, PRESS D. | |
| 20 | −266. | ENTER a hypothetical $n_i$ base (This $n_i$ may be fractional, less than the current $n_i$, or greater than $N_i$. Program will ensure that final allocation has reasonable integer values.)<br>PRESS R/S | $n_i$ base (hypothetical no. SUs to survey in stratum)<br>$n^*$ (optimum allocation in low)<br>$n_m^*$<br>$n_h^*$<br>$n^o$ (optimal no. of intensive searches)<br>Total cost |
| 21 | −255. | Choose:<br>(1) To compute an allocation with a different $n_i$ base, go to step 19; or<br>(2) To compute an allocation based on maximum budget, go to step 17; or<br>(3) END PROGRAM | |

Table 13. Continued.

† The HP 97 program must receive data for three strata in step 3. If your survey area has only one or two strata, you must enter the following data for the nonexistent stratum:

(1) For $V(\hat{T}_i)$ in step 4, ENTER 0.0001

(2) For $N_i$ in step 5, ENTER 1

(3) For $n_i$ in step 6, ENTER 1

The nonexistent stratum will be allocated one SU, and the program will also charge the cost of that SU to your maximum budget. Therefore, you can afford one more SU than indicated by the program.

†† If an error is made entering data for a particular stratum, press the corresponding function key in step 3 and reenter all data for that stratum.

††† If an error is made entering data in steps 9 to 12, return to step 2 and begin again.

†††† During the first few days of a population estimate survey, do not enter the maximum value of your budget in this step. Instead, enter the value of your anticipated expenditures for the next 2 to 3 days. Because stratum variances and allocations change as the survey progresses, entering your maximum budget early in the survey may cause you to calculate and attempt an allocation that will substantially differ from what you will calculate with more data.

††††† The program may produce an optimal allocation that does not use quite all of the available budget. You may have enough money left over to search one or two more SUs or fly an intensive search. If the total cost printed in step 20 does not use all of your budget, use the following steps to optimally allocate the remainder:

1. PRESS DSP
2. PRESS 4
3. PRESS RCL
4. PRESS 4

   The calculator will now display the noninteger value of $n_\ell^*$ in your final allocation. Write this number down.

5. Go to step 19 and PRESS B
6. Go to step 20. By increasing the size of noninteger $n_\ell^*$ in small increments (< 0.01) and substituting it for $n_i$ base in step 20, you can allocate the remainder of your budget. Continue pressing B and entering slightly larger values for $n_i$ base until total cost equals or exceeds your budget.
7. The following printout results:

   $n_i$ base (hypothetical no. SUs in stratum)
   $n_\ell^*$ (optimal allocation in low stratum)
   $n_m^*$ (optimal allocation in medium stratum)
   $n_h^*$ (optimal allocation in high stratum)
   $n^o$ (optimal no. intensive searches)

   Total cost (minutes or dollars) of this allocation

8. Choose either:

   (1) To repeat the procedure, PRESS B, C, or D; or

   (2) To continue allocation program at step 16, PRESS E

| Optimum allocation at end of day 2 | | Optimum allocation at end of day 3 | | Attempt to allocate unused portion of budget | |
|---|---|---|---|---|---|
| Printout | Symbol | Printout | Symbol | Printout | Symbol |
| 111.828 | $V(\hat{T}_\ell)$ | 111.828 | $V(\hat{T}_\ell)$ | 1.4810 | $n_i$ base |
| 23. | $N_\ell$ | 23. | $N_\ell$ | | |
| 5. | $n_\ell$ | 5. | $n_\ell$ | 5. | $n^*_\ell$ |
| 26.72932223 | $RVF_\ell$ | 26.72932223 | $RVF_\ell$ | 6. | $n^*_m$ |
| | | | | 10. | $n^*_h$ |
| 958.283 | $V(\hat{T}_m)$ | 640.618 | $V(\hat{T}_m)$ | 9. | $n^o$ |
| 20. | $N_m$ | 20. | $N_m$ | 1845. | Total Cost |
| 5. | $n_m$ | 6. | $n_m$ | | |
| 79.92842632 | $RVF_m$ | 74.10135914 | $RVF_m$ | 1.4801 | $n_i$ base |
| 1069.250 | $V(\hat{T}_h)$ | 2639.885 | $V(\hat{T}_h)$ | 5. | $n^*_\ell$ |
| 13. | $N_h$ | 13. | $N$ | 6. | $n^*_m$ |
| 5. | $n_h$ | 6. | $n_h$ | 9. | $n^*_h$ |
| 93.20759759 | $RVF_m$ | 171.5105286 | $RVF_m$ | 9. | $n^o$ |
| | | | | 1770. | Total Cost |
| 0.002862 | $V(SCF_o)$ | 0.002703 | $V(SCF_o)$ | | |
| 5. | $n_o$ | 7. | $n_o$ | 1.4805 | $n_i$ base |
| 846. | $\hat{T}_o$ | 783. | $\hat{T}_o$ | 5. | $n^*_\ell$ |
| 1.053000 | $SCF_o$ | 1.042000 | $SCF_o$ | 6. | $n^*_m$ |
| | | | | 9. | $n^*_h$ |
| 101.2022527 | $RVF^o_s$ | 107.7044891 | $RVF^o_s$ | 9. | $n^o$ |
| 28.14597631 | $RVF^o_\ell$ | 27.85195376 | $RVF^o_\ell$ | 1770. | Total Cost |
| 84.16463291 | $RVF^o_m$ | 77.21361622 | $RVF^o_m$ | | |
| 98.14760026 | $RVF^o_h$ | 178.7139708 | $RVF^o_h$ | | |
| 75.0 | $c_t$ | 75.0 | $c_t$ | | |
| 30.0 | $c_s$ | 30.0 | $c_s$ | | |
| 1825.0 | Max. Budget | 1825.0 | Max. Budget | | |
| 5. | $n^*_\ell$ | 5. | $n^*_\ell$ | | |
| 7. | $n^*_m$ | 6. | $n^*_m$ | | |
| 8. | $n^*_h$ | 9. | $n^*_h$ | | |
| 10. | $n^o$ | 9. | $n^o$ | | |
| 1800. | Total Cost | 1770. | Total Cost | | |

**Figure 20.** Example of the Hewlett-Packard 97 printout of the program for calculating the optimal allocation of sampling effort during population estimation surveys. The tape printout has been divided into three columns; complete column 1, proceed to column 2, and finally to 3.

pressed, indicates the step in the program and indicates the calculator is ready for data or an action appropriate for that step. For example, when the calculator display is "−211.", you are positioned at step 3 and need to press the function key corresponding to the stratum data being entered. The calculator printout does not list each step in the same order as the optimal allocation example in Section 3.10.4.

### 3.11.2 Program Printout

The HP 97 printout format shown in Figure 20 uses data from the example in Section 3.10.4. The HP 97 prints only numbers and asterisks. Three asterisks are normally printed at the right of each number; asterisks have been omitted in this example. Symbols were added in this example to facilitate the identification of each number.

## 3.12 SUMMING POPULATION ESTIMATES FROM ADJACENT AREAS

Two or more population estimates from adjacent areas can be summed to estimate numbers of moose in the entire area. The summed population estimate ($\hat{T}_s$) is calculated as

$$\hat{T}_s = \hat{T}_1 + \hat{T}_2 + \ldots + \hat{T}_n$$

where $\hat{T}_i$ is one of the estimates, $i = 1 \ldots n$ estimates.

The sampling variance of $\hat{T}_s$ is

$$V(\hat{T}_s) = V(\hat{T}_1) + V(\hat{T}_2) + \ldots + V(\hat{T}_n).$$

The degrees of freedom associated with the summed estimate (Satterthwaite 1946) is

$$\nu_{es} = \frac{[V(\hat{T}_1) + V(\hat{T}_2) + \ldots + V(\hat{T}_n)]^2}{\dfrac{V(\hat{T}_1)^2}{\nu_{e1}} + \dfrac{V(\hat{T}_2)^2}{\nu_{e2}} + \ldots + \dfrac{V(\hat{T}_n)^2}{\nu_{en}}}.$$

The confidence interval for the summed estimate is calculated as in Section 3.7.5.2, except $\hat{T}_s$, $V(\hat{T}_s)$, and $\nu_{es}$ are substituted for $\hat{T}$, $V(\hat{T}_e)$, and $\nu_e$.

## 3.13 SURVEY COSTS

Survey expenses can be divided into the following categories: (1) materials, (2) stratification, (3) standard SU searches, (4) intensive searches for estimating sightability, (5) ferry time, and (6) food and lodging. The following cost estimation procedures provide crude estimates, at best.

### 3.13.1 Materials

The cost of materials such as topographic maps, acetate, and other supplies is a very small proportion of the total expenses. Buy enough supplies to keep the survey progressing efficiently. The price can be high if planes are grounded because of depleted supplies.

### 3.13.2 Stratification

Stratification costs can be approximated as follows: size of survey area ($mi^2$) ÷ 150 $mi^2$ stratified per hour × hourly air charter cost. In addition, you will have to include estimated cost of ferry time (Section 3.13.5). Use Form 6 to monitor air charter expenses during a survey (see Appendix 2 for blank form).

### 3.13.3 Sample Unit Searches

Costs per SU searched include the flight time to locate the SU boundaries and flight time to survey the SU at 4 to 6 $min/mi^2$. Approximately 3 to 20 min are required to locate SU boundaries, depending on the terrain. Search time is dependent on the number of moose in the SU. Approximately 1.0 hours is required to search a SU if few groups of moose are observed, whereas 1.2 hours or more are required if 10 to 15 groups are observed.

Cost of searching SUs is estimated as follows: approximate number of SUs to be searched × 1.3 hours of air charter per SU × hourly air charter cost.

### 3.13.4 Intensive Searches of Sightability Plots

Sightability plot boundaries can generally be located in less than 5 min because you are already familiar with the entire SU. Flying the intensive search takes approximately 0.5 hours. Estimate the cost of the $SCF_o$ as follows: 0.5 hours flight time × number of intensive searches expected × hourly air charter cost.

### 3.13.5 Ferry Time

Ferry time is the time required to fly from the base of operations to the center of the survey area and return, plus the time required to fly between SUs during the day. Ferry time increases with the size of the survey area and its distance from the base. Ferry time to and from the survey area is estimated as follows: round trip flight time in hours to center of survey area × number of round trips per day per aircraft × number of aircraft used per day × hourly air charter cost × number of days required to complete the survey + a safety margin equaling the cost of one extra round trip per aircraft during the survey. Ferry time between SUs is estimated as follows: (number of SUs a plane will search per day − 1) × 0.25 hours × number of aircraft flying per day × number of days required to complete the survey × hourly air charter cost.

Ferry time between the survey area and the base may be reduced by placing fuel caches in the survey area, thus allowing aircraft to remain in the survey area all day. However, aircraft equipped with long-range fuel tanks save more time and dollars. Ferry time between SUs can be minimized by assigning a tight cluster of SUs to each aircraft.

### 3.13.6 Food and Lodging

Cost of food and lodging is quite variable. If personnel return home each day, these expenses are zero, but costs can exceed $2,000 if people are lodged in commercial facilities. Form 7 will help monitor food and lodging expenses during a survey (see Appendix 2 for a blank form).

### 3.13.7 Survey Costs in Small Areas

Surveying small areas costs proportionately more than large areas. For example, to produce population estimates of comparable precision, 20 to 25% of a large survey area may have to be sampled versus 50 to 90% of a small area (300 to 700 $mi^2$). In small areas, it may be necessary to sample most, if not all, SUs in a stratum, particularly high- and medium-density strata. We recommend survey areas smaller than 300 $mi^2$ be surveyed in their entirety, saving the expense of stratification.

Form 6. Daily aircraft charter expenses during a moose population estimation survey.

Survey Area Fictitious Square Mountain

Game Management Unit(s) 1 Subunit(s) A

| Air taxi / Hourly rate | Date | | | | | |
|---|---|---|---|---|---|---|
| | 11/4/83 | 11/5/83 | / / | / / | / / | / / |
| | No. hrs / Cost | No. hrs / Cost | No. hrs / Cost | No. hrs / Cost | No. hrs / Cost | No. hrs / Cost |
| Far North Air / C-185 @ $175/hr | 6.2 / $1085 | 6.3 / $1103 | | | | |
| Alaska Air Service / PA-18 @ $120/hr | | 3.9 / $488 | | | | |
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| | | | | | | |
| | | | | | | |
| Daily costs | $1085 | $2696 | | | | |
| Cumulative daily costs | $1085 | $3781 | | | | |

Form 7. Daily food and lodging expenses during a moose population estimation survey.

Survey Area Fictitious Square Mountain

Game Management Unit(s) 1 Subunit(s) A

| Person | Date: 11/4/83 Room / Board | 11/5/83 Room / Board | / / Room / Board | / / Room / Board | / / Room / Board | / / Room / Board | / / Room / Board | / / Room / Board | / / Room / Board | / / Room / Board |
|---|---|---|---|---|---|---|---|---|---|---|
| Gasaway | \$20 / \$25 | \$20 / \$25 | — | — | — | — | — | — | — | — |
| DuBois | \$20 / \$25 | \$20 / \$25 | — | — | — | — | — | — | — | — |
| Harbo | \$20 / \$25 | \$20 / \$25 | — | — | — | — | — | — | — | — |
| Reed | \$20 / \$25 | \$20 / \$25 | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| Daily Costs | \$180 | \$180 | | | | | | | | |
| Cumulative Daily costs | \$180 | \$360 | | | | | | | | |

## 3.14 MATERIALS LIST FOR POPULATION ESTIMATION SURVEYS

The following materials are required for population surveys. Numbers in parentheses indicate minimum quantity needed; the quantity of other items required will vary with the number of pilot-observer teams used in the survey.

- Topographic maps (7 sets of 1:63,360 scale and 4 sets of 1:250,000 scale)
- Number 2 lead pencils
- Colored pencils
- Grease pencils (3 colors, 3 each)
- Large erasers (4)
- Large scissors (3 pair)
- Large felt-tip markers (2)
- Transparent colored markers (3)
- Clear tape (8 rolls)
- Masking tape (1 roll)
- Heavy gauge acetate at least 40 in wide (enough to cover a 1:63,360 scale map of the entire survey area)
- Expandable file folders for storage of maps and data sheets (6)
- Clipboards
- Survey data sheets
- Watch
- Intercoms and headsets
- Spare batteries for intercoms
- Survival gear
- Foam pads to sit on in plane
- Air sickness pills and bags
- Sunglasses
- Yellow glasses for overcast days
- Ear plugs
- Hewlett-Packard 97 (HP 97) calculator and 2 sets of programs
- Extra batteries and paper for HP 97
- Instruction manual for HP 97
- Polar compensating planimeter (1)
- Tracing paper to be used with the planimeter
- Pad of writing paper
- Spare battery-powered calculator that can perform the required calculations in case the programmed HP 97 malfunctions
- 3-ring notebook to store all forms, calculations, and notes

# 4. DETECTING CHANGES IN POPULATION SIZE AND ESTIMATING RATES OF CHANGE

## 4.1 INTRODUCTION

Detecting changes in numbers and estimating the rates of growth or decline are vital for evaluating your management programs, formulating hunting regulations, or evaluating factors that control moose populations (Gasaway and DuBois 1987). However, population estimates are, by definition, not exact measures of population size, so we rely on statistical procedures to calculate the probability that a change occurred and the probable rate of that change. Our ability to identify a change in population size is directly related to the precision of the estimates; the greater the precision, the smaller the change that can be detected.

## 4.2 DETECTING CHANGES IN POPULATION SIZE

### 4.2.1 Detecting a Change in Population Size from Two Independent Estimates

#### 4.2.1.1 Introduction to Student's *t*-test

Student's *t*-test is used to determine the probability of two populations differing in size. Before proceeding with a statistical test, you should have in mind the three values, $\alpha$, $\beta$, and CD, which are defined as follows:

- $\alpha$—The acceptable probability of error (from a practical point of view) if you were to conclude that a change in numbers had occurred when in fact it had not changed, i.e., a Type I error.
- $\beta$—The acceptable probability of error (from a practical point of view) if you were to conclude that no change in numbers larger than CD had occurred when in fact it had changed, i.e., a Type II error.
- CD—The consequential difference of interest, i.e., the minimum change in population size that would probably cause some change in management strategy.

A change in population size smaller than CD might be statistically significant, but the knowledge that the difference is statistically significant would be of little practical value. The CD needs to be established before values for $\alpha$ and $\beta$ are considered.

Green (1979) explains $\alpha$ and $\beta$ in the following way. The test of a null hypothesis ($H_0$) results in accepting or rejecting the hypothesis, based on some estimated risk of being wrong. The probability of rejecting $H_0$ when it is true (Type I error), i.e., concluding change occurred when it did not, is usually of most concern. The largest acceptable risk of committing a Type I error is commonly set at $\alpha = 0.05$; however, the 5% level of significance is only a convention. If $H_0$ (e.g., the population size did not change) is tested at $\alpha = 0.05$, then a significant result means that, based on the evidence, there is less than a 1-in-20 chance that a significant change did not occur, and that is an acceptably low risk of being wrong. Testing at $\alpha = 0.01$ means the risk of a Type I error must be 1-in-100 or lower to be acceptable.

However, for any given sampling and statistical analysis design, lowering the Type I error level ($\alpha$) will increase the Type II error level ($\beta$), which is the probability of concluding that $H_0$ is true when in fact it is not. Here you falsely conclude that no change occurred. There is always a tradeoff; you will have to determine the consequences of making each type of error. For example, if you try to increase a moose population by decreasing the rate of harvest for 3 years, you want to be sure the strategy was effective before concluding so. Therefore, specify an $\alpha$ to guard against a Type I error. If the harvest strategy was effective, you want to have a good chance of detecting it; therefore, you must guard against making a Type II error (i.e, not detecting a change when it occurred). If a significant change is not detected, then you conclude the new harvest strategy had no effect and further reduction in harvest may be required. A Type II error results in unnecessary loss of hunting opportunity for moose hunters, whereas a Type I error maintains a harvest strategy that is not resulting in real population growth. Both errors have management implications, so consider both when testing hypotheses. The only way to reduce one error level without increasing the other is to improve the design. For example, increasing the number of samples would reduce either Type I or Type II errors or both.

Student's *t*-statistic is used to make two types of tests that detect if changes in population size are statistically significant. Use two-tailed tests when there is no preconceived idea whether the population increased or decreased. Two-tailed tests detect a change, if it occurred, in either direction. The critical values for two-tailed tests are presented in Table 8. In contrast, one-tailed tests detect change in a specific direction. For example, you may want to detect an increase in moose numbers following predator reduction. The critical values for one-tailed tests are presented in Table 14. Differences in application of one- and two-tailed tests are apparent in the statement of their associated alternative test hypothesis. Zar (1984:126) discusses using the *t*-test to test for differences in population means, which we will extend to testing for differences in population size.

When testing for differences in two population estimates, both estimates must be corrected for sightability bias to ensure differential sightability between years does not negate test results. For example, two estimates may be equal before correcting for sightability but may differ greatly after correction (Table 15). Conversely, two estimates could be different before correction but similar after correction (Table 16).

Table 14. Critical values of Student's *t*-distribution for one-tailed tests (α) and Type II error (β).

| Degrees of freedom (ν) | α and β probability .40 | .30 | .20 | .15 | .10 | .05 | .025 | .01 |
|---|---|---|---|---|---|---|---|---|
| 1 | .325[b] | .727 | 1.376 | 1.963 | 3.078 | 6.314 | 12.706 | 31.821 |
| 2 | .289 | .617 | 1.061 | 1.386 | 1.886 | 2.920 | 4.303 | 6.965 |
| 3 | .277 | .584 | .978 | 1.250 | 1.638 | 2.353 | 3.182 | 4.541 |
| 4 | .271 | .569 | .941 | 1.190 | 1.533 | 2.132 | 2.776 | 3.747 |
| 5 | .267 | .559 | .920 | 1.156 | 1.476 | 2.015 | 2.571 | 3.365 |
| 6 | .265 | .553 | .906 | 1.134 | 1.440 | 1.943 | 2.447 | 3.143 |
| 7 | .263 | .549 | .896 | 1.119 | 1.415 | 1.895 | 2.365 | 2.998 |
| 8 | .262 | .546 | .889 | 1.108 | 1.397 | 1.860 | 2.306 | 2.896 |
| 9 | .261 | .543 | .883 | 1.100 | 1.383 | 1.833 | 2.262 | 2.821 |
| 10 | .260 | .542 | .879 | 1.093 | 1.372 | 1.812 | 2.228 | 2.764 |
| 11 | .260 | .540 | .876 | 1.088 | 1.363 | 1.796 | 2.201 | 2.718 |
| 12 | .259 | .539 | .873 | 1.083 | 1.356 | 1.782 | 2.179 | 2.681 |
| 13 | .259 | .538 | .870 | 1.079 | 1.350 | 1.771 | 2.160 | 2.650 |
| 14 | .258 | .537 | .868 | 1.076 | 1.345 | 1.761 | 2.145 | 2.624 |
| 15 | .258 | .536 | .866 | 1.074 | 1.341 | 1.753 | 2.131 | 2.602 |
| 16 | .258 | .535 | .865 | 1.071 | 1.337 | 1.746 | 2.120 | 2.583 |
| 17 | .257 | .534 | .863 | 1.069 | 1.333 | 1.740 | 2.110 | 2.567 |
| 18 | .257 | .534 | .862 | 1.067 | 1.330 | 1.734 | 2.101 | 2.552 |
| 19 | .257 | .533 | .861 | 1.066 | 1.328 | 1.729 | 2.093 | 2.539 |
| 20 | .257 | .533 | .860 | 1.064 | 1.325 | 1.725 | 2.086 | 2.528 |
| 21 | .257 | .532 | .859 | 1.063 | 1.323 | 1.721 | 2.080 | 2.518 |
| 22 | .256 | .532 | .858 | 1.061 | 1.321 | 1.717 | 2.074 | 2.508 |
| 23 | .256 | .532 | .858 | 1.060 | 1.319 | 1.714 | 2.069 | 2.500 |
| 24 | .256 | .531 | .857 | 1.059 | 1.318 | 1.711 | 2.064 | 2.492 |
| 25 | .256 | .531 | .856 | 1.058 | 1.316 | 1.708 | 2.060 | 2.485 |
| 26 | .256 | .531 | .856 | 1.058 | 1.315 | 1.706 | 2.056 | 2.479 |
| 27 | .256 | .531 | .855 | 1.057 | 1.314 | 1.703 | 2.052 | 2.473 |
| 28 | .256 | .530 | .855 | 1.056 | 1.313 | 1.701 | 2.048 | 2.467 |
| 29 | .256 | .530 | .854 | 1.055 | 1.311 | 1.699 | 2.045 | 2.462 |
| 30 | .256 | .530 | .854 | 1.055 | 1.310 | 1.697 | 2.042 | 2.457 |
| 40 | .255 | .529 | .851 | 1.050 | 1.303 | 1.684 | 2.021 | 2.423 |
| 60 | .254 | .527 | .848 | 1.046 | 1.296 | 1.671 | 2.000 | 2.390 |
| 120 | .254 | .526 | .845 | 1.041 | 1.289 | 1.658 | 1.980 | 2.358 |
| ∞ | .253 | .524 | .842 | 1.036 | 1.282 | 1.645 | 1.960 | 2.326 |

[a] Discussion of Type II (β) error is found in section 4.2.1.1.

[b] These values were extracted from Appendix Table II of Simpson et al. (1960).

### 4.2.1.2 Two-tailed *t*-test

Hypotheses for a two-tailed test are

$H_o$: The population size has not changed, i.e., $T_1 = T_2$

$H_a$: The population size has increased or decreased, i.e., $T_1 \neq T_2$

where $T_1$ is the population size at time 1 and $T_2$ is the population size at time 2.

The *t*-statistic, $t'$, is the test statistic and is calculated as

$$t' = \frac{\hat{T}_2 - \hat{T}_1}{\sqrt{V(\hat{T}_1) + V(\hat{T}_2)}}$$

where $\hat{T}_1$ estimates $T_1$, $\hat{T}_2$ estimates $T_2$, and $V(\hat{T}_i)$ is the variance of the estimate $\hat{T}_i$, i = 1, 2.

An estimate of the number of degrees of freedom ($\nu_t$) associated with the test statistic, $t'$, is calculated as

$$\nu_t = \frac{[V(\hat{T}_2) + V(\hat{T}_1)]^2}{\dfrac{V(\hat{T}_2)^2}{\nu_{e2}} + \dfrac{V(\hat{T}_1)^2}{\nu_{e1}}}$$

where $\nu_{ei}$ represents the degrees of freedom of the estimate $\hat{T}_i$, i = 1, 2. The value $\nu_t$ may be rounded to the nearest integer.

To make the test, consult the table of critical *t*-values for two-tailed tests (Table 8) and find $t_{\alpha,\nu_t}$ for a two-tailed test. Reject $H_o$ in favor of $H_a$

Table 15. The effect of variable sightability on estimated total moose.

| Year | Estimated no. of observable moose | x | Sightability correction factor | = | Total population estimate |
|---|---|---|---|---|---|
| 1 | 1,000 | | 1.10 | | 1,100 |
| 2 | 1,000 | | 1.25 | | 1,250 |

$$t' \geq t_{\alpha, \nu_t}$$

or if

$$t' \leq -t_{\alpha, \nu_t}.$$

If you accept $H_a$ and conclude (with probability of error $\alpha$) that population size has changed, then compare the estimated change, $\hat{\Delta}_T = \hat{T}_2 - \hat{T}_1$, with the CD. Determine if the statistically significant $\hat{\Delta}_T$ is of practical significance and address what this means, in biological terms, for the population.

If you do not reject $H_o$, you must determine if $H_o$ can actually be accepted with a tolerable probability of error, $\beta$. The following procedure allows you to qualify a conclusion of no change in population size by establishing a confidence level associated with that conclusion. Calculate

$$t^o = \frac{CD - \sqrt{V(\hat{T}_2) + V(\hat{T}_1)} \times t_{\alpha, \nu_t}}{\sqrt{V(\hat{T}_2) + V(\hat{T}_1)}}$$

Then, go to the table of $t$-values for Type II error ($\beta$) (Table 14) and find the row of $t$-values for the proper $\nu_t$. Move across the row until $t^o$ fits between two $t$-values, or $t = t^o$ is found. Now visually interpolate to find the probability ($\beta_o$) of $t^o$, using the probability in Table 14 for $\beta_o$.

The value, $1 - \beta_o$, is the probability that a difference of size CD could have been detected, if that difference existed. This is called the power of the test. If $\beta_o$ is equal to or less than $\beta$, then accept $H_o$ with the predetermined acceptable error probability and conclude that if any change in population size occurred, it was smaller than CD and not of practical importance. If $\beta_o$ is greater than $\beta$, then you are left without a satisfactory conclusion. A precise statement of the test results would be: you were unable to detect a significant change in population size at the $\alpha$ level of error probability. The probability of detecting a change in population size of CD was $1 - \beta_o$. If you conclude that no change in size as large as CD occurred, you do so with $\beta$ probability of error.

Comment: Critical $t$-values for Type II error ($\beta$) and figuring the power of a test are always taken from Table 14, whether the test is one- or two-tailed.

Table 16. The effect of variable sightability on estimated total moose.

| Year | Estimated no. of observable moose | x | Sightability correction factor | = | Total population estimate |
|---|---|---|---|---|---|
| 1 | 909 | | 1.10 | | 1,000 |
| 2 | 800 | | 1.25 | | 1,000 |

### 4.2.1.3 Example: a two-tailed *t*-test

Moose population estimates were made during 1975 and 1980 in the Square Mountain survey area. The following data were collected:

$$\hat{T}_1 = 755 \text{ moose} \qquad \hat{T}_2 = 830 \text{ moose}$$
$$V(\hat{T}_1) = 2619 \qquad V(\hat{T}_2) = 2163$$
$$\nu_{e1} = 14 \qquad \nu_{e2} = 14.$$

You decide to use a two-tailed Student's $t$-test to determine if there has been a significant change in the size of the Square Mountain moose herd during the 5-year period. Hypotheses for the test are

$H_o$: The population size has not changed, i.e., $\hat{T}_1 = \hat{T}_2$, and

$H_a$: The population size has increased or decreased, i.e., $\hat{T}_1 \neq \hat{T}_2$.

The following criteria are established for the $t$-test:

$$CD = 30\% \text{ of } \hat{T}_1 = 227$$
$$\alpha = 0.10$$
$$\beta = 0.20$$

Student's $t$-statistic is

$$t' = \frac{830 - 755}{\sqrt{2{,}163 + 2{,}619}} = 1.085.$$

Refer to Section 4.2.1.2 for formulae corresponding to calculations in this Section. Degrees of freedom for $t'$ are

$$\nu_t = \frac{(2163 + 2619)^2}{\frac{2163^2}{14} + \frac{2619^2}{14}} = 27.7 \cong 28.$$

Now consult Table 8 and locate $t_{0.10,28}$, which equals 1.701. You find $t'$ less than $t$, i.e., 1.085 less than 1.701. Therefore, you fail to reject $H_o$: $\hat{T}_1 = \hat{T}_2$. Because $H_o$ was not rejected, it is necessary to determine if $H_o$ can be accepted with a tolerable probability of committing a Type II error ($\beta$). Calculate

$$t^o = \frac{227 - \sqrt{2163 + 2619}\,(1.701)}{\sqrt{2163 + 2619}} = 1.579.$$

Turn to Table 14 and find that for $\nu_t = 28$, $t_o$ is between 1.313 and 1.701. By visually interpolating, you estimate $\beta_o \cong 0.07$. The value of $1 - \beta_o$ or $1 - 0.07$ equals 0.93, which is the probability of detecting a difference of size CD, if it existed. This is the power of the test. Because $\beta_o$ is less than $\beta$ (i.e., $0.07 \leqslant 0.20$), you accept $H_o$ with a 0.20 probability of error and conclude that if any change occurred, it was smaller than CD (i.e., 227) and not of practical importance.

#### 4.2.1.4 One-tailed *t*-test

Hypotheses for a one-tailed test to test for an increase in population size are

$H_o$: The population size has not increased, i.e., $T_1$ equal to or greater than $T_2$, and

$H_a$: The population size has increased, i.e., $T_1$ less than $T_2$.

The test statistic is calculated as

$$t' = \frac{\hat{T}_2 - \hat{T}_1}{\sqrt{V(\hat{T}_2) + V(\hat{T}_1)}}.$$

Degrees of freedom ($\nu_t$) is calculated as in the two-tailed *t*-test (Section 4.2.1.2, also see Section 4.2.1.2 for definition of notations, e.g., $V(\hat{T}_2)$ or $\nu_t$).

To make the test, consult the *t*-table for one-tailed tests (Table 14) and find $t_{\alpha,\nu_t}$. Reject $H_o$ in favor of $H_a$ if $t'$ equal to or greater than $t_{\alpha,\nu_t}$.

If you accept $H_a$ and conclude (with probability of error $\alpha$) that a statistically significant increase in population size occurred, compare the estimated increase, $\hat{D}_T = \hat{T}_1 - \hat{T}_2$, with CD and establish whether this difference is of practical importance.

If you do not reject $H_o$, you can find the power of the test by calculating

$$t^o = \frac{CD - \sqrt{V(\hat{T}_2) + V(\hat{T}_1)} \times t_{\alpha,\nu_t}}{\sqrt{V(\hat{T}_2) + V(\hat{T}_1)}}.$$

Then, by interpolating from the table of *t*-values (Table 14), as described for the two-tailed test, find the probability ($\beta_o$) associated with $t^o$, using probabilities in Table 14 for a one-tailed test. The value $(1 - \beta_o)$ is the probability that an increase of size CD could have been detected, if an increase of this size had occurred. If $\beta_o$ is equal to or less than $\beta$, conclude (with probability of error $\beta$) that no increase as large as CD occurred. If $\beta_o$ is greater than $\beta$, then the results are inconclusive with respect to your established criteria of CD, $\alpha$, and $\beta$.

Hypotheses for a one-tailed test to test for a decrease in population size are

$H_o$: $T_1$ equal to or less than $T_2$, and

$H_a$: $T_1$ greater than $T_2$.

Procedures are the same as testing for an increase in population size if you replace $(\hat{T}_2 - \hat{T}_1)$ with $(\hat{T}_1 - \hat{T}_2)$ in the calculations of $t'$, $\hat{\Delta}_T$, and $t^o$.

#### 4.2.1.5 Combining two independent estimates from a single population

A procedure is available that allows two independent estimates from a single population to be combined to obtain a more precise overall estimate. The procedure weights each independent estimate by the inverse of the sampling variance of that estimate so that the combined estimate has the smallest variance possible of any weighted unbiased combination of the two independent estimates. The application of this method is limited by the critical assumption that the two independent estimates estimate the same population parameter. This procedure accounts only for sampling variation around the two independent estimates and does not address variation in actual population size over time. Therefore, you must be satisfied that population size did not vary when the two estimates were made. To test the validity of this assumption, decide, based on the dynamics of the study population, if variation in actual population size between estimates was negligible. If satisfied that the expected temporal variation was negligible, then test the independent estimates quantitatively by determining a CD (based on what you consider negligible), an $\alpha$, and a $\beta$. Then compute a two-tailed *t*-test (Section 4.2.1.2). If, at an acceptable level of $\beta$, there is no difference between the two estimates, combine them to form an improved estimator. The improved estimator $\hat{T}^*$ is calculated

$$\hat{T}^* = \frac{\dfrac{\hat{T}_1}{V(\hat{T}_1)} + \dfrac{\hat{T}_2}{V(\hat{T}_2)}}{\dfrac{1}{V(\hat{T}_1)} + \dfrac{1}{V(\hat{T}_2)}}$$

or

$$\hat{T}^* = \frac{\hat{T}_1 \cdot V(\hat{T}_2) + \hat{T}_2 \cdot V(\hat{T}_1)}{V(\hat{T}_1) + V(\hat{T}_2)}$$

and its variance, $V(\hat{T}^*)$, is calculated

$$V(\hat{T}^*) = \frac{V(\hat{T}_1)V(\hat{T}_2)}{V(\hat{T}_1) + V(\hat{T}_2)}$$

where $\hat{T}_i$ is one of the independent estimates, $i = 1, 2$; and $V(\hat{T}_i)$ is the variance of estimate $\hat{T}_i$.

To construct a CI around the estimator $\hat{T}^*$, estimate the degrees of freedom by

$$\nu^* = \frac{\nu_{e1}\nu_{e2}[V(\hat{T}_1) + V(\hat{T}_2)]^2}{\nu_{e2}V(\hat{T}_2)^2 + \nu_{e1}V(\hat{T}_1)^2}$$

where $\nu_{ei}$ is the number of degrees of freedom associated with the estimate $\hat{T}_i$, i = 1, 2, and select the appropriate *t*-value from Table 8.

The CI is calculated as described in Section 3.7.5.

### 4.2.2 Planning Surveys to Detect Specified Population Changes

The precision of both population estimates influences your ability to detect a given change; therefore, control over precision of estimates is necessary when attempting to detect specified changes. To determine precision needed to detect a change, first specify the CD, i.e., the minimum difference to be detected. Then decide how sure you must be that a change equal to or greater than CD occurred before you will conclude that there was a change. If one needs to be 95% sure that a change occurred, the acceptable error for this type of conclusion is 5%, giving $\alpha$ = 0.05. Next, decide how sure you need to be that any change was less than CD before you will conclude that no consequential change occurred. If you need to be 80% sure that no consequential change occurred, i.e., an 80% probability of detecting a change as large as CD, then the tolerable error for this type of conclusion is 20%, giving $\beta$ = 0.20.

Once realistic values for CD, $\alpha$, and $\beta$ are established, known and estimated values are entered into an equation and the unknown sampling variance or variances are computed. This process determines the maximum sampling variance that will allow you to detect a change in numbers with required precision. The general form of the equation that describes the relationship among $V(\hat{T}_1)$, $V(\hat{T}_2)$, CD, $\alpha$, and $\beta$ is

$$t_{\alpha,\nu} + t_{\beta,\nu} = \frac{CD}{\sqrt{V(\hat{T}_1) + V(\hat{T}_2)}} .$$

It is closely related to the *t*-test formula in Section 4.2.1.2. The changes are that CD is substituted for $\hat{T}_2 - \hat{T}_1$ and $t_{\beta,\nu}$ is added to allow you to guard against a Type II error during the planning phase of your study.

Two possible situations exist for estimating the required precision: (1) when the first survey has been completed, which fixes the precision required for the second survey, and (2) when neither survey has been completed. Each of these is discussed below. Note that within each of these situations either a one-tailed or a two-tailed test can be used, depending upon the nature of the experiment and hypotheses (see Sections 4.2.1.2 and 4.2.1.4). Select the appropriate *t*-value for the type of test (Tables 8, 14).

#### 4.2.2.1 Estimating required precision of second estimate when first survey is completed

Determine the maximum allowable sampling variance of the second population estimate, $V(\hat{T}_2)$, as follows:

$$V(\hat{T}_2) = \frac{CD^2}{(t_{\alpha,\nu} + t_{\beta,\nu})^2} - V(\hat{T}_1).$$

This is the general equation (Section 4.2.2) solved for $V(\hat{T}_2)$. For example, assume you want to detect a 40% increase in population size, based on the first estimate $\hat{T}_1$. You want to be 90% certain that you are correct if you conclude that an increase of 40% occurred ($\alpha$ = 0.1), and you would be satisfied with 80% probability of detecting an increase, if it occurred, ($\beta$ = 0.2). Data for the first estimate were $\hat{T}_1$ = 2,000, $V(\hat{T}_1)$ = 90,000, and $\nu_{e1}$ = 12. A 40% increase makes CD = 800. Because you are only interested in testing for a population increase, use a one-tailed test. The final $\nu_t$ cannot be accurately estimated at this point. The adjusted $\nu_t$ will be at least as large as $\nu_{e1}$ for the first estimate, and an error in estimating $\nu_t$ of that size will have little effect on the *t*-value or the estimated required precision. Therefore, use $\nu_{e1}$ from the first estimate, which is $\nu_{e1}$ = 12 in this example.

Solving the example problem, where $t_{\alpha,\nu}$ = 1.356 and $t_{\beta,\nu}$ = 0.873, produces

$$V(\hat{T}_2) = \frac{800^2}{(1.356 + 0.873)^2} - 90{,}000 = 38{,}813.$$

Therefore, when making the second estimate, a sampling variance equal to or less than 38,813 must be obtained if a 40% increase is to be detected with $\alpha$= 0.1 and $\beta$ = 0.2. If the population increase is larger than 40%, a significant change can be detected with a variance greater than 38,813.

Commonly, $\beta$ is not considered in statistical tests. In effect, $\beta$ becomes 0.5, at which $t_\beta$ = 0, i.e., there is a 50:50 chance of detecting a change if it occurred. Note that in the above equation $t_\alpha$ and $t_\beta$ are additive; as the probability of making a Type II error decreases the sum of the *t*-values increases. The larger the *t*-value, the greater precision required to detect a change. Increased precision translates into increased dollars. We believe the increased cost often prevents biologists from incorporating Type II error consideration in statements of required precision. Additionally, lack of appreciation for the consequences of Type II errors and the lack of understanding of interrelationships between Types I and II errors are probably major causes for neglect of $\beta$ specification.

#### 4.2.2.2 Estimating required precision before making the first of two population estimates

Because sampling variances $V(\hat{T}_1)$ and $V(\hat{T}_2)$ are additive in the formula,

$$t_{\alpha,\nu} + t_{\beta,\nu} = \frac{CD}{\sqrt{V(\hat{T}_1) + V(\hat{T}_2)}} ,$$

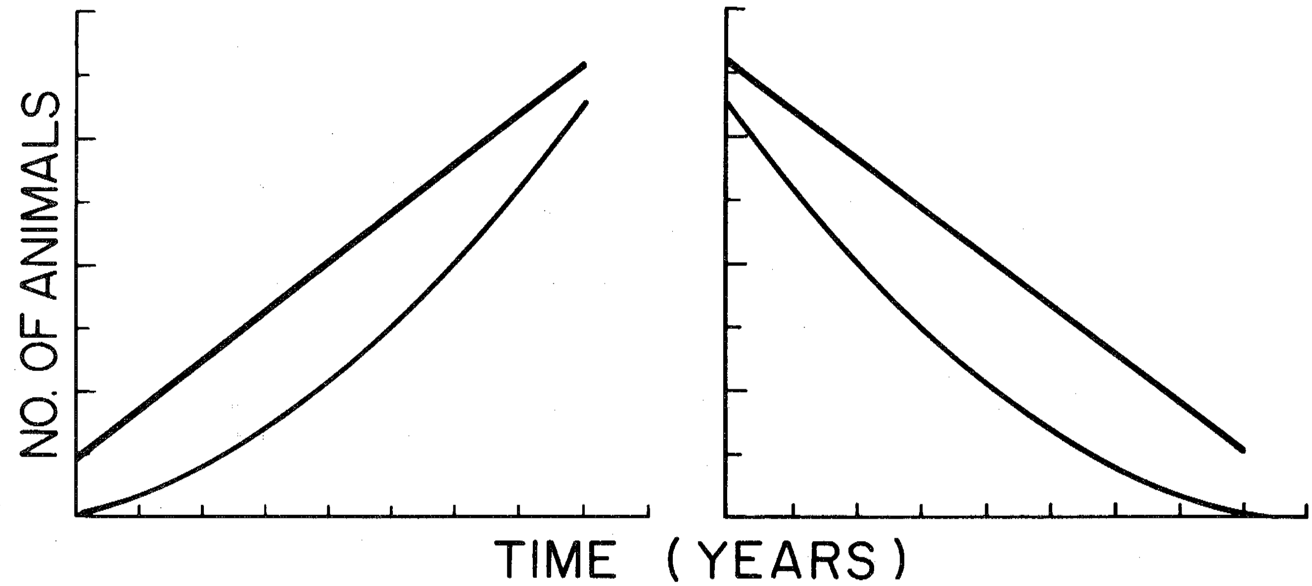


**Figure 21.** Generalized curves for population growth and decline models.

the maximum total variance is estimated when planning two surveys that will detect specified differences between population estimates. This variance is then subjectively allocated between the two estimates of $\hat{T}_1$ and $\hat{T}_2$. In theory, it should not matter whether the variance is larger or smaller for the first estimate. However, in practice, strive for about half the total variance in each estimate or slightly over half for the one you think will be higher. Avoid allowing such a large sampling variance on the first survey that an unobtainably small sampling variance is required for the second estimate.

Solve the equation for the total variance,

$$V(\hat{T}_1) + V(\hat{T}_2) = \frac{CD^2}{(t_{\alpha,\nu} + t_{\beta,\nu})^2} .$$

The $t$-values are dependent on the probability levels selected, the estimated $\nu$, and the hypothesis being tested, i.e., one-tailed or two-tailed tests.

This method of estimating precision is useful only in the planning stages. As soon as the first population survey is in progress (before completion), the required precision should be reevaluated using the tentative estimates $\hat{T}_1$ and $V(\hat{T}_1)$ (Section 4.2.2.1).

## 4.3 ESTIMATING RATE OF POPULATION CHANGE

Rate of change reflects the net increase or decrease in a population after recruitment and mortality. Rate of change is one of the more valuable figures that managers can obtain. It measures the success or failure of management actions and forecasts the short-term future of the population, assuming constancy of controlling factors. However, rate of change estimates are subject to substantial error because they are based on population estimates that contain sampling errors and sometimes bias. Assumptions also have to be made on the shape of the population growth curve between estimates.

The accuracy of the estimated rate of change depends, in part, on choosing the appropriate model. The two most common population growth and decline models are the exponential and linear (Fig. 21), of which the exponential is probably most widely used. See Caughley (1977) for a good discussion of growth rate.

Plotting a data set with three or more population estimates will assist in selecting the model most closely fitting that data set. First, plot on straight numerical scales. If data show a curve, plot on semilog paper or plot the $\log_e$ of population size against time in years (Fig. 22). The log transformation of numbers of moose (Fig. 22*c*) will straighten exponential growth or decline.

Choose the best fitting model and estimate rate of change using the appropriate estimator. If there are only two estimates of population size, choose a model based on what shape you think the curve is. Trend, recruitment, and mortality data help in making the decision.

Population estimates must be significantly different for an estimated rate of change to have meaning. See Section 4.2.1 for method of calculating the test statistic.

### 4.3.1 Exponential Model

A population exhibiting exponential change grows or declines at a constant rate, i.e., the number of animals added or lost varies among time periods, but that number, as a percentage of population size, is constant. The observed exponential rate of change is defined here as $\hat{r}$. The simplest case for calculating $\hat{r}$ is where only two population estimates exist. Here,

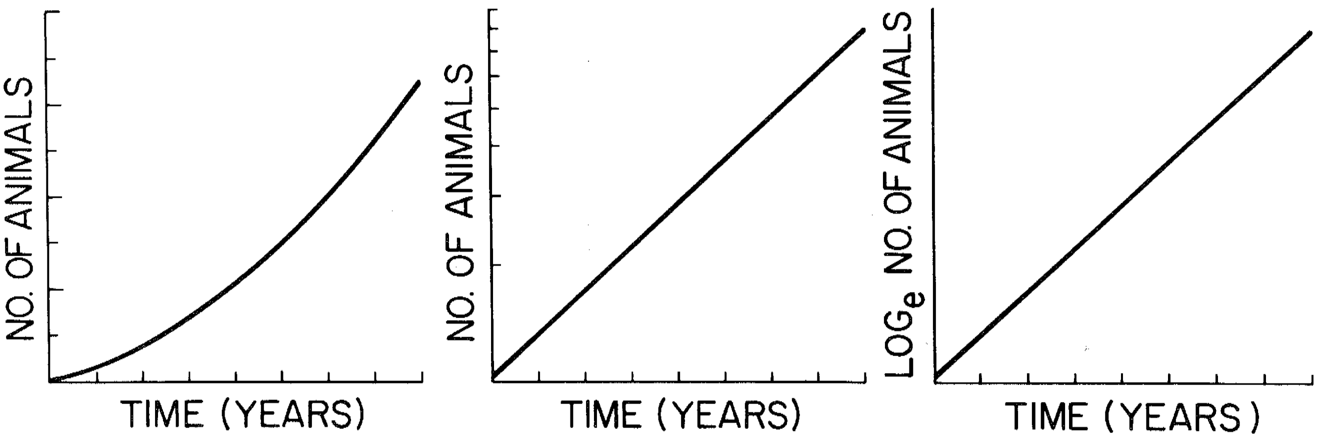


**Figure 22.** Plotting population estimates in graph (a), on a log scale (b), or as a log transformation (c) straightens exponential growth curves.

$$\hat{r} = \frac{\log_e \hat{T}_2 - \log_e \hat{T}_1}{\text{no. years between estimates}}$$

where $\hat{T}_1$ is the initial population estimate, $\hat{T}_2$ is the second population estimate, and $\log_e$ indicates taking the natural logarithm of $\hat{T}_i$, where i = 1, 2. For example, if $\hat{T}_1 = 2{,}000$, $\hat{T}_2 = 3{,}000$, and there was a 4-year interval between estimates, then

$$\hat{r} = \frac{\log_e 3{,}000 - \log_e 2{,}000}{4}$$

$$= \frac{8.006 - 7.601}{4}$$

$$= 0.101 .$$

The $\log_e$ can be easily calculated on most scientific pocket calculators. Commonly, the symbol 1n is used for $\log_e$ on these calculators. Be sure not to use common logarithms.

The precision of $\hat{r}$ can be estimated. Because $\hat{T}_1$ and $\hat{T}_2$ are estimates rather than exact counts of numbers of moose, $\hat{r}$ also has an error component.

Calculating variance and confidence intervals for $\hat{r}$ is facilitated by defining

$$L_i = \log_e \hat{T}_i$$

and approximating

$$V(L_i) = \log_e \left( \frac{V(\hat{T}_i)}{\hat{T}_i^2} + 1 \right)$$

where the variance formula is based on the variance estimate transformation for log normally distributed data (Pritsker 1974). Then

$$V(\hat{r}) = \frac{V(L_1) + V(L_2)}{\Delta_t^2}$$

where $\Delta_t$ is the number of years between estimates. To construct a confidence interval, we need to calculate the degrees of freedom for $\hat{r}$:

$$\nu_r = \frac{[V(L_1) + V(L_2)]^2}{\frac{V(L_1)^2}{\nu_{e1}} + \frac{V(L_2)^2}{\nu_{e2}}} .$$

From the example above, suppose $V(\hat{T}_1) = 96{,}000$, $V(\hat{T}_2) = 139{,}000$, $\nu_{e1} = 14$, and $\nu_{e2} = 22$. Then $L_1 = 7.601$ and $L_2 = 8.006$ with variances of

$$V(L_1) = \log_e \left( \frac{96{,}000}{2{,}000^2} + 1 \right) = 0.0237,$$

and

$$V(L_2) = \log_e \left( \frac{139{,}000}{3{,}000^2} + 1 \right) = 0.0153.$$

The variance of $\hat{r}$ is

$$V(\hat{r}) = \frac{0.0237 + 0.0153}{4^2} = \frac{0.0390}{4^2} = 0.00244 .$$

To calculate a confidence interval, degrees of freedom are needed.

$$\nu_r = \frac{(0.0390)^2}{\frac{0.0237^2}{14} + \frac{0.0153^2}{22}} \cong 30$$

From Table 8, $t_{0.10,30} = 1.697$. Therefore, a 90% CI for $\hat{r}$ is

$$\hat{r} \pm t_{\alpha,\nu_r} \sqrt{V(\hat{r})}$$

or $0.101 \pm 1.697\sqrt{0.00244}$ or $0.101 \pm 0.084$.

When more than two population estimates exist, the simplest method of estimating the exponential rates is to calculate $\hat{r}$ using only the first and last estimates. The obvious drawback is that interim estimates have no influence on the rate of change; the estimated rate depends solely on the precision of two estimates.

A method that uses all population estimates is based on weighted regression. While useful, this method assumes the aptness of an exponential model for the population being studied. If the model is appropriate, the estimate $\hat{r}$ may be interpreted in the standard manner. If the model is not appropriate over the course of the study (due perhaps to changing population dynamics) the estimate $\hat{r}$ will be a weighted average of exponential growth rates over the course of the study.

Be aware that the method we present will yield different results from a linear regression of $L_i$ on $t_i$. The variance of $\hat{r}$ ($V(\hat{r})$) that we present is based on the sampling variances of the population estimates whereas the variance of an estimate of $r$ from the linear regression is based on the deviations of observed population estimates from the fitted growth curve.

To estimate $\hat{r}$ from several population estimates ($\hat{T}_i$), a variable representing time, $t_i$, is assigned to each population estimate. Generally, $t_i$ is in terms of years, and $t_1 = 1$. For example, if $\hat{T}_1$ was made in 1976, $\hat{T}_2$ in 1980, and $\hat{T}_3$ in 1982, then the values of $t_i$ would be $t_1 = 1$, $t_2 = 5$, and $t_3 = 7$.

For each $\hat{T}_i$, values for $L_i$ and $V(L_i)$ are calculated as defined above. Then, for each population estimate, calculate

$$a_i = \frac{1}{\sqrt{V(L_i)}},$$

$$b_i = \frac{t_i}{\sqrt{V(L_i)}},$$

and

$$c_i = \frac{L_i}{\sqrt{V(L_i)}}.$$

From these values, calculate $\Sigma_i a_i^2$, $\Sigma_i b_i^2$, $\Sigma_i a_i b_i$, and then for each population estimate calculate

$$d_i = (\sum_j a_j^2)b_i - (\sum_j a_j b_j)a_i.$$

The estimate $\hat{r}$ is calculated

$$\hat{r} = \frac{\sum_i d_i c_i}{(\sum_i a_i^2)(\sum_i b_i^2) - (\sum_i a_i b_i)^2},$$

and its variance is

$$V(\hat{r}) = \frac{\sum_i d_i^2}{[(\sum_i a_i^2)(\sum_i b_i^2) - (\sum_i a_i b_i)^2]^2}.$$

The degrees of freedom for $\hat{r}$ are

$$\nu_r = \frac{(\sum_i d_i^2)^2}{\sum_i \frac{d_i^4}{\nu_{ei}}}.$$

Table 17. Example data used to calculate the exponential rate of change for a moose population.

| | Estimate | | |
|---|---|---|---|
| Parameter | 1 | 2 | 3 |
| Year | 1976 | 1980 | 1982 |
| $\hat{T}_i$ | 2,000 | 3,000 | 3,400 |
| $V(\hat{T}_i)$ | 96,000 | 139,000 | 42,000 |
| $t_i$ | 1 | 5 | 7 |
| $\nu_{ei}$ | 14 | 22 | 9 |

For example, $\hat{r}$, $V(\hat{r})$, and a 90% CI around $\hat{r}$ are calculated from the set of population estimates in Table 17. The calculations are presented with as many as 10 digits of accuracy because the final estimate is sensitive to roundoff of intermediate values. First calculate $L_i$, $V(L_i)$, $a_i$, $b_i$, and $c_i$ for each estimate (Table 18). Then calculate $d_i$ for each estimate with

$$\sum_i a_i^2 = 383.172514,$$

$$\sum_i b_i^2 = 15{,}185.6219,$$

and

$$\sum_i a_i b_i = 2{,}298.72562.$$

The estimate of $\hat{r}$ is

$$\hat{r} = \frac{(-613{,}914.946) + (-200{,}004.196) + (859{,}903.947)}{(383.172514)(15{,}185.6219) - (2{,}298.72562)^2}$$

$$= \frac{45{,}984.805}{534{,}573.44} = 0.086$$

and

$$V(\hat{r}) = \frac{(-12{,}438.51748)^2 + (-3{,}092.59834)^2 + (6{,}368.12086)^2}{(534{,}573.44)^2}$$

Table 18. Example parameter estimates used to calculate the exponential rate of change for a moose population.

| Parameter | Estimate 1 | Estimate 2 | Estimate 3 |
|---|---|---|---|
| Year | 1976 | 1980 | 1982 |
| $L_i$ | 7.60090246 | 8.00636757 | 8.13153071 |
| $V(L_i)$ | 0.02371653 | 0.01532639 | 0.00362663 |
| $a_i$ | 6.4934339 | 8.0775576 | 16.6060499 |
| $b_i$ | 6.4934339 | 40.3877880 | 116.2423493 |
| $c_i$ | 49.3559580 | 64.6718952 | 135.0326047 |
| $d_i$ | −12,438.51748 | −3,092.59834 | 6,368.12086 |

$$= \frac{204{,}833{,}844.9}{285{,}768{,}762{,}800} = 0.000717.$$

The degrees of freedom are

$$\nu_r = \frac{(204{,}833{,}844.9)^2}{\frac{(-12{,}438.51748)^4}{14} + \frac{(-3{,}092.59834)^4}{22} + \frac{(6{,}368.12086)^4}{9}}$$

$$= 22.1 \cong 22.$$

A 90% CI for $\hat{r}$ is

$$\hat{r} \pm t_{0.10,22}\sqrt{V(\hat{r})}$$

$$0.086 \pm 1.717\sqrt{0.000717}$$

$$0.086 \pm 0.046.$$

A rate of increase that is closely related to the exponential rate is the finite rate of change (λ). The estimated finite rate of change is the ratio of population size in year 1 to population size 1 year later.

$$\hat{\lambda} = \frac{\hat{T}_{i+1}}{\hat{T}_i}$$

where i is time in years. For example, in 1980 and 1981, population estimates were 2,000 and 2,500, respectively, and

$$\hat{\lambda} = \frac{2500}{2000} = 1.25.$$

When estimating λ over a time interval of 2 or more years, a constant rate of increase is assumed, as for exponential rate *r*. For example, in year 1, the population equaled $T_1$ and 3 years later the population equaled $T_4$. The growth sequence was as follows:

| Year: | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Size: | $T_1$ | $T_i\lambda$ | $T_1\lambda\lambda$ | $T_1\lambda\lambda\lambda = T_4$ |

or

$$T_1\lambda = T_2$$
$$T_2\lambda = T_3$$
$$T_3\lambda = T_4$$

where λ is simply the annual growth multiplier.

The simplest way to estimate λ when the interval between population estimates exceeds 1 year is to estimate *r* (as in this Section), and then calculate

$$\hat{\lambda} = e^{\hat{r}}$$

on a suitable pocket calculator. The constant *e* equals 2.7183. Using the example earlier in this section where $\hat{r}$ = 0.101, the finite rate of change is

$$\hat{\lambda} = e^{\hat{r}} = e^{0.101} = 1.106.$$

The population increased 1.106 times each year, equivalent to 10.6% compounded annually.

The annual percentage change is calculated as follows:

$$\%\ \text{change} = (\hat{\lambda} - 1)100.$$

For example, when a population is increasing at a finite rate = 1.106, the

$$\%\ \text{change} = (1.106 - 1)100$$
$$= 0.106 \times 100 = 10.6.$$

When the population is declining, the percentage change becomes negative. For example, when a population is declining at the same rate as the one in the above example is increasing (i.e., $\hat{r} = 0.101$), then

$$\hat{r} = -0.101$$

and

$$\hat{\lambda} = e^{\hat{r}} = 0.904.$$

The percentage change is

$$\% \text{ change} = (0.904 - 1)100$$
$$= -0.096 \times 100 = -9.6.$$

Note that with $r$, equal rates of increase and decrease are symmetrical around 0.0 and differ only by a + or − sign. In contrast, with $\lambda$, equal rates of increase and decrease are not symmetrical around 1.0 and both are positive (percentage changes calculated from $\lambda$ do have + and − signs, however). Therefore, comparison using finite rates of change can be more difficult to quickly interpret than exponential rates; however, all things considered, finite rates are generally easier for people to work with and visualize.

To calculate a confidence interval around $\hat{\lambda}$, first calculate the CI for $\hat{r}$. Let

$$\hat{r}_+ = \hat{r} + t_{\alpha,\nu}\sqrt{V(\hat{r})}$$

and

$$\hat{r}_- = \hat{r} - t_{\alpha,\nu}\sqrt{V(\hat{r})}.$$

The upper confidence limit for $\hat{\lambda}$ is

$$\hat{\lambda}_+ = e^{\hat{r}_+}$$

and the lower limit is

$$\hat{\lambda}_- = e^{\hat{r}_-}.$$

### 4.3.2 Linear Model

With linear change, a population grows or declines by a constant number of animals each year. However, the growth rate of an increasing population declines because the constant number is an ever-decreasing proportion of the increasing population. Conversely, in a declining population, the rate of decline increases each year because the constant number is an ever-increasing proportion of the declining population. You can easily demonstrate this by plotting hypothetical data sets that change annually by a constant number and calculating the percentage change for each 1 year interval.

To estimate the annual linear rate of change in population size ($\hat{g}$) between two estimates, calculate

$$\hat{g} = \frac{\hat{T}_2 - \hat{T}_1}{\Delta_t}$$

The variance of $\hat{g}$ is

$$V(\hat{g}) = \frac{V(\hat{T}_1) + V(\hat{T}_2)}{\Delta_t^2}.$$

The number of degrees of freedom is

$$\nu_g = \frac{[V(\hat{T}_1) + V(\hat{T}_2)]^2}{\frac{[V(\hat{T}_1)]^2}{\nu_1} + \frac{[V(\hat{T}_2)]^2}{\nu_2}}.$$

To estimate $g$ from more than two population estimates, assign a $t_i$ to each $\hat{T}_i$ as in Section 5.2.1. Then for each $\hat{T}_i$, calculate

$$a_i = \frac{1}{\sqrt{V(\hat{T}_i)}},$$

$$b_i = \frac{t_i}{\sqrt{V(\hat{T}_i)}},$$

and

$$c_i = \frac{\hat{T}_i}{\sqrt{V(\hat{T}_i)}}.$$

Calculate $\Sigma_i a_i^2$, $\Sigma_i b_i^2$, and $\Sigma_i a_i b_i$, and then for each $\hat{T}_i$ calculate

$$d_i = (\sum_j a_j^2)b_i - (\sum_j a_j b_j)a_i.$$

The estimate ($\hat{g}$) is then calculated

$$\hat{g} = \frac{\sum_i d_i c_i}{(\sum_i a_i^2)(\sum_i b_i^2) - (\sum_i a_i b_i)^2},$$

and its variance is

$$V(\hat{g}) = \frac{\sum_i d_i^2}{[(\sum_i a_i^2)(\sum_i b_i^2) - (\sum_i a_i b_i)^2]^2}$$

with degrees of freedom

$$\nu_g = \frac{(\sum_i d_i^2)^2}{\sum_i \frac{d_i^4}{\nu_{ei}}}.$$

### 4.3.3 Suggested Frequency of Estimating Population Size

From an economic view, successive population estimates should be separated by sufficient time to allow a detectable change to occur. The precision level of population estimates does not allow annual changes to be detected, except when there is catastrophic mortality. The minimum interval for detectable population change may be as little as 2 years or more than 5 years, depending on the dynamics of the specific population. Population estimates are expensive and their infrequent use will minimize expense and assure efficiency.

# 5. ESTIMATING SEX AND AGE COMPOSITION OF POPULATIONS

## 5.1 INTRODUCTION

Sex and age composition estimates for moose populations are confounded by moose behavior (Linkswiler 1982, Gasaway et al. 1985). Moose segregate by sex and age classes (Peek et al. 1974) and some classes are more difficult to see than others. Therefore, biases occur with subjective selection of sampled areas and not observing moose in sampled areas. Nevertheless, composition data, which had relatively constant bias, have been used to signal changes in moose population dynamics. Thus, composition estimates altered by bias may not materially affect the interpretation of some population changes. However, with representative composition data (unbiased sampling) and population estimates, numbers of calves, yearlings, adult bulls, and adult cows can be estimated. These data are valuable for estimating recruitment, setting hunting seasons for specific cohorts, and modeling population dynamics.

The following method of estimating composition has minimum bias because areas to be searched during the survey are randomly selected and the prescribed search intensity allows you to see a high percentage of moose in the SUs searched. Population composition is calculated for each stratum in the survey area, and overall composition is calculated by summing strata estimates.

Numbers of moose in particular sex-age classes and composition ratios may be estimated from survey data if moose observed during standard searches are classified into sex and age classes. Form 8 summarizes composition data from SUs (see Appendix 2 for blank form).

## 5.2 ESTIMATING NUMBER OF MOOSE IN SEX AND AGE CLASSES

### 5.2.1 Definition of Symbols

$w_j$ = number of moose in a sex-age class observed in the *jth* SU

w = as a subscript, denotes that the parameter is calculated for a specific sex-age class

$\hat{W}_i$ = stratum population estimate of moose in a sex-age class.

All other symbols are defined in Section 3.7.1.1.

### 5.2.2 Step 1.—Calculating the Observable Stratum Sex-age Class Estimate and Its Sampling Variance

Estimates of numbers of moose in sex-age classes are calculated using procedures similar to population estimates in Section 3.7.1. The observable stratum estimate of bulls, for example, is the number of bulls that could have been seen if the entire stratum had been searched with the standard search effort (e.g., 4 to 6 min/mi$^2$ in early winter). For the *ith* strata, estimate the number of observable moose in the sex-age class ($\hat{W}_i$) by calculating

$$\hat{W}_i = \text{density of sex-age class} \times \text{area of stratum}$$

or

$$\hat{W}_i = d_{iw} \cdot A_i$$

where

$$d_{iw} = \frac{\text{total number of moose in the sex-age class observed in all SUs surveyed in the } ith \text{ stratum}}{\text{total surface area of all SUs surveyed in the } ith \text{ stratum}}$$

or

$$d_{iw} = \frac{\sum_j w_j}{\sum_j x_j}.$$

The sampling variance of $\hat{W}_i$ is

$$V(\hat{W}_i) = A_i^2 \left[ \frac{1}{\bar{x}_i^2} \times \frac{s_{qiw}^2}{n_i} \left(1 - \frac{n_i}{N_i}\right) \right]$$

where

$$s_{qiw}^2 = \frac{\sum_j w_j^2 - 2d_{iw} \sum_j x_j w_j + d_{iw}^2 \sum_j x_j^2}{n_i - 1}.$$

### 5.2.3 Step 2.—Calculating the Observable Sex-age Class Estimate and Its Sampling Variance for the Survey Area

The observable sex-age class estimate for the survey area ($\hat{W}_o$) is the summation of the strata estimates, uncorrected for sightability.

$$\hat{W}_o = \hat{W}_h + \hat{W}_m + \hat{W}_\ell$$

and the sampling variance is the sum of sampling variances of observable stratum sex-age class estimates, or

$$V(\hat{W}_o) = V(\hat{W}_h) + V(\hat{W}_m) + V(\hat{W}_\ell)$$

where h, m, and ℓ are the high-, medium- and low-density strata, respectively. Degrees of freedom are calculated as

$$\nu_{ow} = \frac{[V(\hat{W}_o)]^2}{\frac{[V(\hat{W}_h)]^2}{n_h - 1} + \frac{[V(\hat{W}_m)]^2}{n_m - 1} + \frac{[V(\hat{W}_\ell)]^2}{n_\ell - 1}}.$$

Form 8. Summary information of sample unit (SU) sex and age class data.

Survey Area Fictitious Square Mountain Date ________

Game Management Unit(s) 1 Subunit(s) A

Stratum medium Stratum Area 240.0 $mi^2$ Total SUs in stratum 20

$SCF_o$ 1.08 $V(SCF_o)$ 0.003400 $\nu_s$ 9 $SCF_c$ 1.02

| SU no. | SU area ($mi^2$) | Bulls | | | No. of cows | No. of calves |
|---|---|---|---|---|---|---|
| | | No. of yearlings | No. of adults | Total no. | | |
| 38 | 12.0 | 1 | 1 | 2 | 9 | 6 |
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### 5.2.4 Step 3.—Calculating the Expanded Sex-age Class Estimate and Its Sampling Variance

The observable sex-age class estimate for the survey area is multiplied by the observed sightability correction factor (Section 3.6.5.1) to produce the expanded sex-age class estimate ($\hat{W}_e$).

$$\hat{W}_e = \hat{W}_o \cdot SCF_o$$

with a sampling variance

$$V(\hat{W}_e) = (SCF_o^2)V(\hat{W}_o) + (\hat{W}_o^2)V(SCF_o) - V(\hat{W}_o)V(SCF_o)$$

and degrees of freedom

$$\nu_{ew} = \text{minimum of } [\nu_{ow}, \nu_s],$$

Where $\nu_{ew}$ is the smaller of the two values, $\nu_{ow}$ or $\nu_s$.

### 5.2.5 Step 4.—Calculating the Total Sex-age Class Estimate and Its Variance

The expanded sex-age class estimate ($\hat{W}_e$) is multiplied by the sightability correction factor constant ($SCF_c$) to produce the total sex-age class population estimate ($\hat{W}$).

$$\hat{W} = \hat{W}_e \cdot SCF_c$$

with a sampling variance

$$V(\hat{W}) = (SCF_c)^2 V(\hat{W}_e).$$

### 5.2.6 Step 5.—Calculating the Confidence Interval of the Total Sex-age Class Estimate

The CI for $\hat{W}$ is calculated as

$$CI = \begin{matrix}\text{total sex-age}\\ \text{class estimate}\end{matrix} \pm t_{\alpha,\nu}\sqrt{\begin{matrix}\text{variance of total}\\ \text{sex-age class estimate}\end{matrix}}$$

or

$$CI = \hat{W} \pm t_{\alpha,\nu} \sqrt{V(\hat{W})}$$

where degrees of freedom $\nu = \nu_{ew}$, and Student's $t$-values are found in Table 8.

## 5.3 EXAMPLE: ESTIMATING NUMBER OF MOOSE IN A SEX-AGE CLASS

The following example is a step-by-step procedure for calculating the number of cows for the Square Mountain survey area. Data used include data in Table 19 and the following sightability data: $SCF_o = 1.08$, $V(SCF_o) = 0.003400$, $SCF_c = 1.02$, and $\nu_s = 9$. Calculations for the number of cows in the medium stratum are presented in detail. Refer to Section 5.2 for formulae while working through calculations in this section.

### 5.3.1 Step 1.—Calculating the Observed Stratum Estimate and Its Sampling Variance for Cows

#### 5.3.1.1 Low-density stratum estimates

Density estimate:

$$d_{\ell w} = 0.082508 \text{ cows/mi}^2.$$

Observed stratum estimate:

$$\hat{W}_\ell = 23 \text{ cows}.$$

Sampling variance estimate:

$$V(\hat{W}_\ell) = 76.941.$$

#### 5.3.1.2 Medium-density stratum estimates

Density estimate:

$$d_{mw} = \frac{40 \text{ cows seen in medium stratum SUs}}{71.6 \text{ mi}^2 \text{ surveyed in medium stratum}}$$

$$= 0.558659 \text{ cows/mi}^2.$$

Observed cow estimate:

$$\hat{W}_m = 0.558659 \text{ cows/mi}^2 \times 240.2 \text{ mi}^2 \text{ stratum area}$$

$$= 134 \text{ cows}.$$

Sampling variance estimate:

First solve for $s^2_{qmw}$.

$$s^2_{qmw} = \frac{324 - [2(0.558659)495.80] + [(0.558659)^2(861.74)]}{6-1}$$

$$= 7.815965.$$

Use the value of $s^2_{qmw}$ to solve for $V(\hat{W}_m)$.

$$V(\hat{W}_m) = 240.2^2 \left[\frac{1}{11.93^2} \times \frac{7.815962}{6}\left(1 - \frac{6}{20}\right)\right] = 368.528.$$

#### 5.3.1.3 High-density stratum estimates

Density estimate:

$$d_{hw} = 1.405258 \text{ cows/mi}^2.$$

Table 19. Composition data collected during a fictitious survey of the Square Mountain survey area.

| Stratum | No. of SUs[a] | Moose observed: Bulls | Cows | Calves | SU area ($mi^2$) | Total stratum area ($mi^2$) | Total SUs in stratum |
|---|---|---|---|---|---|---|---|
| Low | 1 | 0 | 2 | 0 | 12.4 | 277.7 | 23 |
| | 2 | 2 | 0 | 0 | 10.9 | | |
| | 3 | 1 | 0 | 0 | 12.9 | | |
| | 4 | 1 | 2 | 1 | 13.1 | | |
| | 5 | 0 | 1 | 0 | 11.3 | | |
| Medium | 1 | 3 | 4 | 2 | 11.5 | 240.2 | 20 |
| | 2 | 7 | 5 | 2 | 11.2 | | |
| | 3 | 7 | 12 | 3 | 14.3 | | |
| | 4 | 5 | 3 | 2 | 11.0 | | |
| | 5 | 3 | 9 | 5 | 12.0 | | |
| | 6 | 3 | 7 | 2 | 11.6 | | |
| High | 1 | 14 | 25 | 10 | 14.7 | 158.9 | 13 |
| | 2 | 9 | 33 | 15 | 15.0 | | |
| | 3 | 10 | 22 | 9 | 12.0 | | |
| | 4 | 6 | 15 | 2 | 10.7 | | |
| | 5 | 18 | 9 | 5 | 10.3 | | |
| | 6 | 2 | 4 | 0 | 11.9 | | |
| | 7 | 9 | 18 | 8 | 13.4 | | |
| | 8 | 18 | 14 | 3 | 11.4 | | |
| | 9 | 4 | 15 | 0 | 10.9 | | |

[a]SU equals sample unit.

Observed cow estimate:

$$\hat{W}_h = 223 \text{ cows.}$$

Sampling variance estimate:

$$V(\hat{W}_h) = 275.910.$$

### 5.3.2 Step 2.—Calculating the Observed Cow Estimate and Its Sampling Variance for the Survey Area

Observed cow estimate:

$$\hat{W}_o = 223 \text{ in high stratum} + 134 \text{ in medium stratum} + 23 \text{ in low stratum}$$

$$= 380 \text{ cows.}$$

Sampling variance estimate:

$$V(\hat{W}_o) = 275.910 \text{ high stratum} + 368.528 \text{ medium stratum} + 76.941 \text{ low stratum}$$

$$= 721.379.$$

Degrees of freedom:

$$\nu_{ow} = \frac{(721.379)^2}{\frac{(275.910)^2}{9-1} + \frac{(368.528)^2}{6-1} + \frac{(76.941)^2}{5-1}} \cong 14.$$

### 5.3.3 Step 3.—Calculating the Expanded Cow Estimate and Its Sampling Variance

Expanded cow estimate:

$$\hat{W}_e = 380 \text{ cows} \times SCF_o \text{ of } 1.08 = 410.$$

Sampling variance estimate:

$$\hat{W}_e = 1.08^2(721.379) + 380^2(0.003400) - 721.379(0.003400)$$

$$= 1329.924.$$

Degrees of freedom:

$$\nu_{ew} = \text{minimum of } [14, 9] = 9.$$

### 5.3.4 Step 4.—Calculating the Total Cow Estimate and Its Sampling Variance

Total cow estimate:

$$\hat{W} = 410 \text{ cows} \times SCF_c \text{ of } 1.02 = 418 \text{ cows.}$$

Sampling variance estimate:

$$V(\hat{W}) = 1.02^2(1329.924) = 1383.653.$$

### 5.3.5 Step 5.—Calculating the 90% Confidence Interval for the Total Cow Estimate

Confidence interval:

$$CI = 418 \pm 1.833 \sqrt{1383.653} = 418 \pm 68 \text{ cows}.$$

Confidence limits:

$$CL_u = 486 \text{ cows}$$

$$CL_\ell = 350 \text{ cows}.$$

## 5.4 HEWLETT-PACKARD 97 PROGRAM: ESTIMATING NUMBER OF MOOSE IN SEX AND AGE CLASSES

### 5.4.1 Program Instructions

HP 97 program 1 in Appendix 1 is used both to estimate population size (Section 3.9) and to estimate the number of moose in a sex-age class. However, instead of entering the total number of moose in a SU ($y_j$), enter the number of moose in a sex-age class in a SU ($w_j$). The total number of moose in a sex-age class is then estimated ($\hat{W}$), instead of the total population estimate ($\hat{T}$).

The HP 97 program instructions in Section 3.9 (Table 10) have been revised by substituting the appropriate statistical symbols and eliminating unnecessary portions of the program (Table 20). The calculator display, which appears after a function key is depressed, indicates the step in the program and indicates the calculator is ready for data or an action appropriate for that step. For example, when the calculator display is "– 111.", you are at step 3 and need to press function key D.

### 5.4.2 Program Printout

The HP 97 printout format shown in Figure 23 uses data from the example in Section 5.3. The HP 97 prints only numbers and asterisks. Three asterisks are normally printed at the right of each number; asterisks have been omitted in this example to conserve space. Symbols were added in this example to facilitate the identification of each number.

## 5.5 ESTIMATING SEX AND AGE RATIOS

Composition ratios are calculated using estimates of observable moose from two sex-age classes. Each ratio has a numerator sex-age class and a denominator sex-age class. In an estimate of calves/cows, "calves" is the numerator class and "cows" is the denominator class. In estimating the proportion of a population that is "cows," or "cows/total moose," "cows" is the numerator class and "total moose" is the denominator class.

Let $w_{jn}$ be the number of moose in the numerator sex-age class observed in the *jth* SU and let $w_{jd}$ be the number of moose in the denominator sex-age class observed in the *jth* SU. The estimated observable moose in the numerator and denominator classes is calculated as in the previous section (5.2).

The estimate of the composition ratio ($\hat{p}$) is

$$\hat{p} = \frac{\sum_i \hat{W}_{in}}{\sum_i \hat{W}_{id}} = \frac{\hat{W}_{on}}{\hat{W}_{od}}.$$

An approximation for the sampling variance of $\hat{p}$ requires $\hat{W}_{on}$, $\hat{W}_{od}$, $V(\hat{W}_{on})$, and $V(\hat{W}_{od})$, which can be calculated by methods previously given, plus the $Cov(\hat{W}_{in}, \hat{W}_{id})$ for each stratum. $Cov(\hat{W}_{in}, \hat{W}_{id})$ is calculated as

$$Cov(\hat{W}_{in}, \hat{W}_{id}) = A_i^2\left[\frac{1}{\bar{x}_i^2} \times \frac{s_{qind}}{n_i}\left(1 - \frac{n_i}{N_i}\right)\right]$$

where (Cochran 1977)

$$s_{qind} = \frac{\sum_j w_{jn}w_{jd} - d_{in}\sum_j x_j w_{jd} - d_{id}\sum_j x_j w_{jn} + d_{in}d_{id}\sum_j x_j^2}{n_i - 1}.$$

The sampling variance of $\hat{p}$ is calculated

$$V(\hat{p}) = \hat{p}^2\left[\frac{V(\hat{W}_{on})}{\hat{W}_{on}^2} + \frac{V(\hat{W}_{od})}{\hat{W}_{od}^2} - \frac{2\sum_i Cov(\hat{W}_{in}, \hat{W}_{id})}{\hat{W}_{on}\hat{W}_{od}}\right]$$

and the degrees of freedom are

$$\nu_p = \text{minimum } [\nu_{own}, \nu_{owd}].$$

It is sometimes preferable to present a composition ratio as numerator moose/100 denominator moose, e.g., calves/100 cows, rather than calves/cow. By calculating

$$\hat{p}_{100} = 100\hat{p}$$

and

$$V(\hat{p}_{100}) = 10{,}000V(\hat{p}),$$

the ratio can be presented as $\hat{p}_{100}$ numerator animals/100 denominator animals.

A CI for $\hat{p}_{100}$ is calculated

$$CI = \hat{p}_{100} \pm t_{\alpha,\nu}\sqrt{V(\hat{p}_{100})}$$

where degrees of freedom $\nu = \nu_p$ and Student's *t*-values are found in Table 8.

Table 20. Hewlett-Packard 97 program instructions for calculating the estimated number of moose in sex and age classes.

| Step | Display value equals | Instruction | Printout value equals |
|---|---|---|---|
| 1 | 0.00 | LOAD both sides of card 1 | |
| 2 | 0. | PRESS A | |
| 3 | −111. | PRESS D | |
| 4 | −222. | ENTER $SCF_o$ (observed sightability correction factor)<br>PRESS R/S | $SCF_o$ |
| 5 | $SCF_o$ | ENTER $V(SCF_o)$ (variance of $SCF_o$)<br>PRESS R/S | $V(SCF_o)$ |
| 6 | $V(SCF_o)$ | ENTER $\nu_s$ (degrees of freedom of $SCF_o$)<br>PRESS R/S | $\nu_s$ |
| 7 | −333. | PRESS E | |
| 8 | −444. | ENTER $A_i$ (total area for stratum)<br>PRESS R/S$^{\dagger}$ | $A_i$ |
| 9 | $A_i$ | ENTER $N_i$ (total SUs for stratum)<br>PRESS R/S$^{\dagger}$ | $N_i$ |
| 10 | 0.0 or no. of data sets entered | ENTER $w_j$ (no. moose in a sex and age class counted in $SU_j$)<br>PRESS R/S$^{\dagger,\dagger\dagger}$ | $w_j$ |
| 11 | $w_j$ or no. of data sets entered | ENTER $x_j$ (area of $SU_j$)<br>PRESS R/S$^{\dagger,\dagger\dagger}$<br>Repeat steps 10 and 11 until all SUs are entered for a stratum | $x_j$ |
| 12 | no. of data sets entered | PRESS f, c | $n_i$ (no. SUs surveyed in stratum)<br>$d_{iw}$ (stratum density)<br>$\hat{W}_i$ (stratum sex-age class population est.)<br>$V(\hat{W}_i)$ (variance) |
| 13 | −444. | Choose either:<br>(1) To enter more strata, go to step 8; or<br>(2) If all strata are entered, go to step 14 | |
| 14 | −444. | PRESS f, d | $\hat{W}_o$(observed sex-age est.)<br>$V(\hat{W}_o)$ (variance)<br>$\nu_{ow}$ (degrees freedom for $\hat{W}_o$) |

Table 20. Continued.

| Step | Display value equals | Instruction | Printout value equals |
|---|---|---|---|
| 15 | −555. | LOAD both sides of card 2 | |
| 16 | −555. | PRESS A | $\hat{W}_e$(expanded sex-age est.)<br>$V(\hat{W}_e)$ (variance)<br>$\nu_{ew}$ (degrees freedom for $\hat{W}_e$) |
| 17 | −666. | ENTER $SCF_c$ (sightability correction factor constant)<br>PRESS R/S | $SCF_c$<br>$\hat{W}$ (total sex-age est.)<br>$V(\hat{W})$ (variance) |
| 18 | −777. | Choose:<br>(1) To enter new $SCF_c$, PRESS B, and return to step 17,<br>(2) To calculate 90% CI, PRESS D; or<br>(3) To calculate 95% CI, PRESS E (i.e., $\hat{W}$ ± %) | % CI selected<br>$CI_\ell$ (lower confidence limit)<br>$CI_u$ (upper confidence limit)<br>CI as ± % of $\hat{W}$ |
| END OF PROGRAM | | To rerun the program it is necessary to return to step 1 and reload card 1 | |

† If an error is made entering $A_i$ or $N_i$, or if the entry of $y_j$s and $x_j$s is in a shambles, all information for current strata can be retracted by pressing E. All previous strata (strata for which f and c were pressed in step 18) will not be affected.

†† If an error is made in entering $w_j$ and $x_j$, finish entering both $w_j$ and $x_j$ until positioned at step 10, then PRESS f and b.
ENTER erroneous $w_j$, PRESS R/S, and it will be printed.
ENTER erroneous $x_j$, PRESS R/S, and it will be printed.

You will be positioned again at step 10. Note that the display number is 1 less than previously displayed. Proceed with step 10 and enter correct $w_j$ and $x_j$.

## 5.6 EXAMPLE: CALCULATING ESTIMATED SEX-AGE RATIOS

The following example demonstrates the procedure for calculating a bull/cow ratio from data presented in Table 19. The HP 97 program (Section 5.7) calculates ratios from uncorrected estimates ($\hat{W}_o$) of sex-age population size.

The estimated composition ratio ($\hat{p}$) is calculated using methods described in Section 5.4. The only calculations that have not been previously described are those for $V(\hat{p})$, which requires calculation of a covariance for each stratum [$Cov(W_{in}, W_{id})$]. Therefore, values for the observed stratum estimates will be listed but not calculated in this section. Calculation of covariance for the medium stratum will be demonstrated in detail. Refer to Section 5.5 for formulae while working through calculations in this section.

The values derived in these calculations will vary slightly from the HP 97 program and from your hand calculations because of rounding differences.

### 5.6.1 Low-density Stratum Estimates

$$\hat{W}_{\ell n} = 18 \text{ bulls}$$

$$V(\hat{W}_{\ell n}) = 59.705$$

$$\hat{W}_{\ell d} = 23 \text{ cows}$$

| Printout | Symbol | Printout | Symbol | Printout | Symbol |
|---|---|---|---|---|---|
| 1.08 | $SCF_o$ | 12.0 | | 13.4 | |
| 0.003400 | $V(SCF_o)$ | 14.3 | | 14.0 | |
| 9. | $\nu_s$ | 3.0 | | 11.4 | |
| | | 11.0 | | 15.0 | |
| 277.7 | $A_\ell$ | 9.0 | | 10.9 | |
| 23. | $N_\ell$ | 12.0 | | | |
| | | 7.0 | | 9. | $n_h$ |
| 2.0 | $w_j$ | 11.6 | | 1.405258386 | $d_{hw}$ |
| 12.4 | $x_j$ | | | 223.3 | $\hat{W}_h$ |
| 0.0 | | 6. | $n_m$ | 275.910 | $V(\hat{W}_h)$ |
| 10.9 | | 0.558659218 | $d_{mw}$ | | |
| 0.0 | | 134.2 | $\hat{W}_m$ | 380.4 | $\hat{W}_o$ |
| 12.9 | | 368.528 | $V(\hat{W}_m)$ | 721.38 | $V(\hat{W}_o)$ |
| 2.0 | | | | 14. | $\nu_{ow}$ |
| 13.1 | | 158.9 | $A_h$ | | |
| 1.0 | | 13. | $N_h$ | 411. | $\hat{W}_e$ |
| 11.3 | | | | 1331. | $V(\hat{W}_e)$ |
| 5. | $n_\ell$ | 25.0 | $w_j$ | 9. | $\nu_{ew}$ |
| 0.082508251 | $d_{\ell w}$ | 14.7 | $x_j$ | | |
| 22.9 | $\hat{W}_\ell$ | 33.0 | | 1.02 | $SCF_c$ |
| 76.941 | $V(\hat{W}_\ell)$ | 15.0 | | 419. | $\hat{W}$ |
| | | 22.0 | | 1385. | $V(\hat{W})$ |
| 240.2 | $A_m$ | 12.0 | | | |
| 20. | $N_m$ | 15.0 | | 90. | 90% CI |
| | | 10.7 | | 351. | $CL_\ell$ |
| 4.0 | $w_j$ | 9.0 | | 487. | $CL_u$ |
| 11.5 | $x_j$ | 10.3 | | 16.3 | CI as ±% $\hat{W}$ |
| 5.0 | | 4.0 | | | |
| 11.2 | | 11.9 | | | |
| | | 18.0 | | | |

**Figure 23.** Example of the Hewlett-Packard 97 printout of the program the estimated number of moose in sex and age classes. These data are from Table 19 and estimate the number of cow moose in the Square Mountain survey area. The tape printout has been divided into three columns; complete column 1, proceed to column 2, and finally to 3.

$$V(\hat{W}_{\ell d}) = 76.941$$

$$Cov(\hat{W}_{\ell n}, \hat{W}_{\ell d}) = -41.812.$$

### 5.6.2 Medium-Density Stratum Estimates

$$\hat{W}_{mn} = 94 \text{ bulls}$$

$$V(\hat{W}_{mn}) = 158.839$$

$$\hat{W}_{md} = 134 \text{ cows}$$

$$V(\hat{W}_{md}) = 368.528.$$

To estimate covariance $[Cov(\hat{W}_{mn}, \hat{W}_{md})]$, first solve for $s_{qmnd}$.

$$s_{qmnd} = \frac{194 - 0.391061(495.80)}{6-1} + \frac{-(0.558659)338.80}{6-1} + \frac{0.391061(0.558659)861.74}{6-1}$$

$$= -0.168301.$$

The value of $s_{qmnd}$ is used to solve for $Cov(\hat{W}_{mn}, \hat{W}_{md})$.

$$Cov(\hat{W}_{mn}, \hat{W}_{md}) = 240.2^2 \left[\frac{1}{11.93^2} \times \frac{-0.168301}{6}\left(1 - \frac{6}{20}\right)\right]$$

$$= -7.959543.$$

Table 21. Hewlett-Packard 97 program instructions for calculating estimated sex and age ratios.

| Step | Display value equals | Instruction | Printout value equals |
|---|---|---|---|
| 1 | 0.00 | LOAD both sides of card 1 | |
| 2 | 0. | PRESS A | |
| 3 | −511.<br>or<br>−533. | PRESS B | |
| 4 | 0 or<br>no. of data<br>sets entered | ENTER $w_{jn}$ (no. moose in the numerator [numer.] sex-age class counted in $SU_j$)<br>PRESS R/S† | $w_{jn}$ |
| 5 | $w_{jn}$ | ENTER $w_{jd}$ (no. moose in the demonimator [denom.] sex-age class counted in $SU_j$)<br>PRESS R/S† | $w_{jd}$ |
| 6 | $w_{jd}$ | ENTER $x_j$ (area of $SU_j$)<br>PRESS R/S†<br>Repeat steps 4-6 until all SUs in stratum are entered. | |
| 7 | No. of data<br>sets entered | PRESS C | |
| 8 | −522. | ENTER $A_i$ (total area for stratum)<br>PRESS R/S | $A_i$ |
| 9 | $A_i$ | ENTER $N_i$ (total SUs in stratum)<br>PRESS R/S | $N_i$<br>$d_{in}$ (density in numer.)<br>$\hat{W}_{in}$ (est. observable no. moose in numer.)<br>$V(\hat{W}_{in})$ (variance)<br>$d_{id}$ (density in denom.)<br>$\hat{W}_{id}$ (est. observable no. moose in denom.)<br>$V(\hat{W}_{id})$ (variance)<br>$Cov(\hat{W}_{in}, \hat{W}_{id})$ (covariance) |
| 10 | −533. | Choose either:<br>(1) To enter more strata, go to step 3; or<br>(2) If all strata are entered, go to step 11 | |
| 11 | −533. | LOAD both sides of card 2 | |

Table 21. Continued.

| Step | Display value equals | Instruction | Printout value equals |
|---|---|---|---|
| 12 | −533. | PRESS A | $\hat{W}_{on}$ (observable moose in numer.)<br>$V(\hat{W}_{on})$ (variance)<br>$\nu_{wn}$ (degrees freedom of numer.)<br>$\hat{W}_{od}$ (observable moose in denom.)<br>$V(\hat{W}_{od})$ (variance)<br>$\nu_{wd}$ (degrees freedom of denom.)<br>$\Sigma\ Cov(\hat{W}_{in}, \hat{W}_{id})$ (summation of strata covariances)<br>$\hat{p}$ (est. ratio of numer. and denom.)<br>$V(\hat{p})$ (variance)<br>$\nu_p$ (degrees freedom of $\hat{p}$) |
| 13 | −544. | Choose either:<br>(1) 90% CI of $\hat{p}$, PRESS D, or<br>(2) 95% CI of $\hat{p}$, PRESS E | % CI selected<br>$CI_\ell$ (lower confidence limit)<br>$CI_u$ (upper confidence limit)<br>CI as ± % of $\hat{p}$ (i.e., $\hat{p}$ ± %) |
| END OF PROGRAM | | To rerun the program it is necessary to return to step 1 and reload card 1. | |

† If an error is made entering $w_{jn}$, $w_{jd}$, or $x_j$, finish entering all data for $SU_j$ ($w_{jn}$, $w_{jd}$, and $x_j$) until positioned at step 4 again. Then PRESS f, b and ENTER initial $w_{jn}$ (whether erroneous or correct), PRESS R/S, and $w_{jn}$ (erroneous or correct) will be printed, ENTER initial $w_{jd}$, PRESS R/S, and $w_{jd}$ will be printed, and ENTER initial $x_j$, PRESS R/S, and $x_j$ will be printed. Now you have removed the series of values for $SU_j$ that contained the error, and you are positioned again at step 4. Notice that the display value has decreased by one because the erroneous values have been extracted. Proceed from step 4 by entering the correct series of values.

### 5.6.3 High-Density Stratum Estimates

$$\hat{W}_{hn} = 130 \text{ bulls}$$

$$V(\hat{W}_{hn}) = 198.911$$

$$\hat{W}_{hd} = 223 \text{ cows}$$

$$V(\hat{W}_{hd}) = 275.910$$

$$Cov(\hat{W}_{hn}, \hat{W}_{hd}) = 1.734.$$

### 5.6.4 Calculating the Estimated Bull/Cow Ratio

$$\hat{p} = \frac{242 \text{ bulls}}{380 \text{ cows}} = 0.636842 \text{ bulls/cow.}$$

Sampling variance estimate:

| Printout | Symbol | Printout | Symbol | Printout | Symbol |
|---|---|---|---|---|---|
| 0. | $w_{jn}$ | 3. | | 18. | |
| 2. | $w_{jd}$ | 9. | | 14. | |
| 12.4 | $x_j$ | 12.0 | | 11.4 | |
| 2. | | 3. | | 4. | |
| 0. | | 7. | | 15. | |
| 10.9 | | 11.6 | | 10.9 | |
| 1. | | 240.2 | $A_m$ | 158.9 | $A_h$ |
| 0. | | 20. | $N_m$ | 13. | $N_h$ |
| 12.9 | | 0.391061453 | $d_{mn}$ | 0.815956482 | $d_{hn}$ |
| | | 93.9 | $\hat{W}_{mn}$ | 129.7 | $\hat{W}_{hn}$ |
| 1. | | 158.839 | $V(\hat{W}_{mn})$ | 198.911 | $V(\hat{W}_{hn})$ |
| 2. | | 0.558659218 | $d_{mn}$ | 1.405258386 | $d_{hd}$ |
| 13.1 | | 134.2 | $\hat{W}_{md}$ | 223.3 | $\hat{W}_{hd}$ |
| | | 368.528 | $V(\hat{W}_{md})$ | 275.910 | $V(\hat{W}_{hd})$ |
| 0. | | -8.486 | $Cov(\hat{W}_{mn}, \hat{W}_{md})$ | 1.734 | $Cov(\hat{W}_{hn}, \hat{W}_{hd})$ |
| 1. | | | | | |
| 11.3 | | 14. | $w_{jn}$ | 242. | $\hat{W}_{on}$ |
| | | 25. | $w_{jd}$ | 417. | $V(\hat{W}_{on})$ |
| 277.7 | $A_\ell$ | 14.7 | $x_j$ | 16. | $\nu_{wn}$ |
| 23. | $N_\ell$ | | | 380. | $\hat{W}_{od}$ |
| 0.066006601 | $d_{\ell n}$ | 9. | | 721. | $V(\hat{W}_{od})$ |
| 18.3 | $\hat{W}_{\ell n}$ | 33. | | 14. | $\nu_{wd}$ |
| 59.705 | $V(\hat{W}_{\ell n})$ | 15.0 | | -49. | $\Sigma Cov(\hat{W}_{jn}, \hat{W}_{jd})$ |
| 0.082508251 | $d_{\ell d}$ | | | | |
| 22.9 | $\hat{W}_{\ell d}$ | 10. | | 0.635961418 | $\hat{p}$ |
| 76.941 | $V(\hat{W}_{\ell d})$ | 22. | | 0.005328062 | $V(\hat{p})$ |
| -41.812 | $Cov(\hat{W}_{\ell n}, \hat{W}_{\ell d})$ | 12.0 | | 14. | $\nu_p$ |
| 3. | $w_{jn}$ | 6. | | 90. | 90% CI |
| 4. | $w_{jd}$ | 15. | | 0.507384910 | $CL_\ell$ |
| 11.5 | $x_j$ | 10.7 | | 0.764537927 | $CL_u$ |
| | | | | 20.2 | CI as ± % $\hat{p}$ |
| 7. | | 18. | | | |
| 5. | | 9. | | | |
| 11.2 | | 10.3 | | | |
| 7. | | 2. | | | |
| 12. | | 4. | | | |
| 14.3 | | 11.9 | | | |
| 5. | | 9. | | | |
| 3. | | 18. | | | |
| 11.0 | | 13.4 | | | |

**Figure 24.** Example of the Hewlett-Packard 97 printout of the program for calculating estimated sex and age ratios. These data are from Table 19 and estimate the bull/cow ratio. The printout has been divided into three columns; complete column 1, proceed to column 2, and finally to 3.

$$V(\hat{p}) =$$

$$(0.636842)^2 \left[ \frac{417}{242^2} + \frac{721}{380^2} - \frac{2[(-41.812)+(-7.959)+1.734]}{242 \times 380} \right]$$

$$= 0.005124.$$

Degrees of freedom:

$$\nu_p = \text{minimum of } [16, 14] = 14.$$

### 5.6.5 Calculating the Estimated Bulls/100 Cows

$$\hat{p}_{100} = 100 \times 0.636842$$

$$= 64 \text{ bulls/100 cows.}$$

### 5.6.6 Calculating the 90% Confidence Interval for the Estimated Bulls/100 Cows

$$CI = 64 \pm 1.761 \sqrt{51.24}$$

$$= 64 \pm 13 \text{ bulls/100 cows.}$$

Confidence limits:

$$CL_u = 77 \text{ bulls/100 cows}$$

$$CL_\ell = 51 \text{ bulls/100 cows.}$$

## 5.7 HEWLETT-PACKARD 97 PROGRAM: ESTIMATING SEX AND AGE RATIOS

### 5.7.1 Program Instructions

HP 97 program 3 in Appendix 1 calculates estimates of: (1) the observable number of moose in each sex-age class, and (2) the ratio of animals between two sex-age classes. Define the desired ratio in terms of the numerator and denominator sex-age classes. For example, to calculate a bull/cow ratio, bulls are in the numerator and cows are in the denominator. Program instructions are in Table 21.

At first glance, it may appear that the HP 97 programs in Section 5.4 and this section will both calculate the number of moose in a sex-age class. This is not the case. Even though this program calculates the observed number of moose ($\hat{W}_o$) for the numerator and denominator of a ratio, it cannot be used to calculate the total moose in a sex-age class ($\hat{W}$) because it does not correct $\hat{W}_o$ by $SCF_o$ and $SCF_c$. Nor does this program calculate $V(SCF_o)$, so it will not calculate a CI for the estimates of numbers. Similarly, the sex-age class estimation program in Section 5.4 will not calculate sex-age ratios or their CIs.

The calculator display listed in Table 21, which appears after a function key is depressed, indicates the step in the program that requires data or an action. For example, when the calculator display is "− 511.", you are at step 3 and need to press function key B.

### 5.7.2 Program Printout

The HP 97 printout format shown in Figure 24 uses data from the example in Section 5.6. The HP 97 prints only numbers and asterisks. Three asterisks are normally printed at the right of each number; asterisks have been omitted in this example to conserve space. Symbols were added in this example to facilitate the identification of each number.

Table 22. Calves/100 cow moose estimated from composition surveys and population estimation surveys in the same area and at the same time. Total numbers of moose observed are in parentheses.

| Game Management Unit | Calves/100 cows | |
|---|---|---|
| | Composition survey | Population estimation survey |
| 13 | 31 (344) | 45 (459) |
| 13 | 23 (1,393) | 32 (742) |
| 12 | 20 (525) | 26 (526) |

## 5.8 BIAS IN COMPOSITION ESTIMATES

Data from population estimation surveys produce higher and more representative calf/cow ratios than Alaska Department of Fish and Game composition surveys (Table 22). We have found that the calf/cow ratio is inversely related to density within a survey area. Composition surveys focus primarily on high-density portions of the survey area, whereas population estimation surveys randomly select SUs. Therefore, composition survey methods are more biased. So far, we have not detected consistent differences in bull/cow ratios produced by the two survey techniques; however, experimental searches using radio-collared moose indicate bulls are more easily seen than cows. Therefore, if bias exists, lower intensity composition surveys will likely overestimate bulls relative to cows.

# 6. ESTIMATING RELATIVE ABUNDANCE OF MOOSE

## 6.1 INTRODUCTION

A rapid, inexpensive measure of relative abundance of moose is obtained by using only the stratification process described for estimating population size (Section 3.4). Stratification allows qualitative judgments of relative density over large areas to be systematically recorded in a form easily used by others—the end product is a moose distribution map showing relative density. This type of information is especially useful for areas where no previous survey has been conducted or where survey coverage is incomplete (e.g., much of Alaska and northern Canada).

## 6.2 SURVEY METHOD

Stratification is carried out as described for population estimation surveys (Section 3.4). The only variation in the above method is the option to use a 1:250,000 scale map, instead of a 1:63,360, assuming SU boundaries are easily found. The most useful end product is usually a 1:250,000 map delineating regions of relative density and the location and numbers of moose sighted. If 1:63,360 maps are used for stratifying, transfer data to a 1:250,000 map.

We recommend drawing SUs on stratification maps. Stratification is easiest and most accurate when SUs are classified into one of several strata rather than trying to identify actual strata boundaries, i.e., where density changes.

## 6.3 STRATIFYING AREAS ADJACENT TO SURVEY AREAS

Maximum information on relative abundance can be achieved by extending the stratification of a population estimation survey to adjacent areas following the population estimate. These areas should be stratified by the same crew that stratified the survey area, and stratification should be done immediately upon completion of the population estimate. Stratification should be based on the same moose densities used for the strata in the survey area. If habitat and snow conditions are similar in both areas, a rough estimate of moose abundance can be made by applying the respective estimated strata densities (corrected for sightability) from the surveyed area to the newly stratified area. However, the estimate in the stratified-only area has no statistical validity because it was not sampled.

Rough estimates of moose numbers during early winter can also be made from stratification flights by multiplying the number of moose seen by a range of correction factors. The mean number of moose seen during six early winter stratification flights was 37% (range 27-50%) of the estimated population (Table 23). We included the late winter Alaska Peninsula survey with those from early winter because the SCF in this shrub-dominated habitat was similar to SCF estimates during early winter surveys (Table 7). Dividing 100 by 27 and 50 produces correction factors of

Table 23. Correction factors used to calculate rough estimates of moose population size from numbers of moose seen on stratification flights.

| Period and drainage | No. seen on stratification (A) | Estimated no. (B) | Percent of estimated no. seen on stratification | Multiplier correction factor (B ÷ A) |
|---|---|---|---|---|
| Early winter (Oct-Nov) | | | | |
| Upper Nowitna | 515 | 1,883 | 27 | 3.7 |
| Upper Susitna | 581 | 2,081 | 28 | 3.6 |
| Upper Susitna | 187 | 496 | 38 | 2.7 |
| Tanana Flats | 1,252 | 3,242 | 39 | 2.6 |
| Fortymile | 257 | 630 | 41 | 2.5 |
| Late winter (Feb) | | | | |
| Nushagak[a] | 198 | 1,276 | 16 | 6.4 |
| Alaska Peninsula[b] | 566 | 1,129 | 50 | 2.0 |

[a] Late winter survey in coniferous-dominated forest area.

[b] Late winter survey in shrub-dominated area containing no coniferous trees.

3.7 and 2.0, respectively. Multiplying the number of moose seen by 2.0 and 3.7 gives an interval which may contain the estimated number of moose, if stratification is flown with conditions comparable to early winter surveys in Table 23. This relationship is not universal, and the percentage of moose seen on future stratification flights may be out of this range. As crude as these estimates may seem, they have proven valuable in areas where little was known about moose numbers. Most commonly these crude estimates have indicated that moose were more abundant than previously thought. Insufficient data exist to provide similar guidelines for late winter stratification if coniferous forest is present.

We recommend use of the stratification process in all areas where it can be applied and where quantitative information has not been collected. Using this approach, biologists can rapidly become acquainted with moose distribution and relative abundance in their areas of responsibility and gain new insights by collecting these data in a systematic manner.

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# GLOSSARY

## GREEK AND ARITHMETIC SYMBOLS

$\alpha$ — For confidence intervals: proportion of confidence intervals, from all possible samples and their estimates, that would not include the actual value ($\mu$)

For hypothesis testing: the acceptable probability of error if you were to conclude that a change in abundance had occurred when in fact it had not changed, i.e., a Type I error

$1 - \alpha$ — Specified probability for the confidence interval

$\beta$ — The acceptable probability of error if you were to conclude that no change in abundance larger than the consequential difference had occurred when in fact it had changed, i.e., a Type II error

$\beta_o$ — Probability associated with $t_o$

$\Delta_t$ — Number of years between population size estimates

$\hat{\Delta}_T$ — Change in estimated population size

$\epsilon_i$ — Random sampling error for the *ith* estimate

$\lambda$ — Finite rate of change in population size

$\mu$ — True value of parameter, e.g., number of animals or density

$\nu$ — Degrees of freedom

$\nu^*$ — Degrees of freedom for the population size estimate $\hat{T}^*$, which is based on combining two independent population estimates

$\nu_e$ — Degrees of freedom for the expanded population size estimate ($\hat{T}_e$)

$\nu_{ei}$ — Degrees of freedom for the total population size estimate ($\hat{T}_i$) in year i

$\nu_{es}$ — Degrees of freedom for the summed population size estimate ($\hat{T}_s$)

$\nu_{ew}$ — Degrees of freedom for the expanded estimate of moose in a sex-age class ($\hat{W}_e$)

$\nu_g$ — Degrees of freedom for the estimated linear rate of change in population size ($\hat{g}$)

$\nu_o$ — Degrees of freedom for the observable population size estimate ($\hat{T}_o$)

$\nu_{ow}$ — Degrees of freedom for the estimated observable number of moose in a sex-age class ($\hat{W}_o$)

$\nu_p$ — Degrees of freedom for the estimated composition ratio ($\hat{p}$)

$\nu_r$ — Degrees of freedom for the estimated exponential rate of change ($\hat{r}$)

$\nu_s$ — Degrees of freedom for the observable sightability correction factor ($SCF_o$)

$\nu_t$ — Degrees of freedom associated with the test statistic, $t'$

$\Sigma$ — Summation of the variable that follows $\Sigma$. The $\Sigma$ has a subscript that corresponds to the subscript on the variable, e.g., $\Sigma_j x_j$ is the summation of numbers of moose in the jth sample unit where j = sample units 1 through n

$\cong$ — Approximately equal to

$>$ — Greater than

$\geqslant$ — Equal to or greater than

$<$ — Less than

$\leqslant$ — Equal to or less than

$\hat{}$ — Indicates an estimate of the actual value when used as a cap above a symbol, e.g., $\hat{T}$

$|\ |$ — The absolute value, e.g., $|5| = 5, |-5| = 5$

## ROMAN SYMBOLS

$A_i$ — Area ($mi^2$) of the *ith* stratum

CD — The consequential difference of interest

CI — Confidence interval

$CL_u$ — Upper confidence limit

$CL_\ell$ — Lower confidence limit

Cov( ) — Covariance of the two variables in parentheses

$C_s$ — Number of minutes required to fly an intensive search of a 2-$mi^2$ sightability plot

$C_t$ — Number of minutes required to fly a regular search of a sample unit

d — As subscript, indicates the variable is in the denominator of a sex-age class ratio calculation, e.g., $\hat{W}_{od}$

$d_i$ — Observable density (moose/$mi^2$) in the *ith* stratum

$d_{iw}$ — Observable density of moose in a sex-age class in the *ith* stratum

$e$ — Base of the natural logarithm; a constant $\cong$ 2.71828

$g$ Annual linear rate of change in population size

$\hat{g}$ Estimated annual linear rate of change in population size

$H_a$ Alternate hypothesis

$H_o$ Null hypothesis

i Subscript denoting a specific member in a series, e.g., i commonly denotes the stratum as h (high), m (medium), or ℓ (low)

j Subscript denoting a specific sample unit in a series of sample units, j = sample units 1 through n

$L_i$ $Log_e$ of the population estimate in year i, i.e., $\log_e \hat{T}_i$

$n$ Sample size

n As subscript, indicates the variable is in the numerator of a sex-age ratio

$n_i$ Number of sample units surveyed in the *ith* stratum

$n_i^*$ Optimum number of sample units that should be searched in the *ith* stratum

$n_o$ Number of 2-$mi^2$ plots surveyed with an intensive search and used for estimating the observed sightability correction factor ($SCF_o$)

$n^o$ Optimum number of sightability plots to be intensively searched

$N_i$ Total number of sample units in the *ith* stratum

$\hat{p}$ Estimated ratio between two sex-age classes

$\hat{r}$ Observed exponential rate of population growth

$RVF_i$ Relative variation factor of the *ith* stratum's observable moose estimate used for between strata allocation of sampling effort

$RVF_i^o$ Relative variation factor of the *ith* stratum's observable moose estimate used for allocating effort between sightability estimate and stratum i's observable moose estimate

$RVF_s^o$ Relative variation factor of the observed sightability correction factor ($SCF_o$) estimate for allocation of sampling effort between sightability estimate and individual strata observable moose estimate

$s_q^2$ Sample variance for estimate of population size. Subscripts added to $s_q^2$ indicate the specific sample variance, e.g., see $s_{qi}$ below

$s_{qi}^2$ Sample variance for the estimate of population size in the *ith* stratum

$s_{qiw}^2$ Sample variance for a sex-age class in the *ith* stratum

SU Sample unit

SCF Total sightability correction factor, which is the product of $SCF_o \times SCF_c$

$\overline{SCF}$ Mean of two or more sightability correction factors

$SCF_c$ Constant sightability correction factor estimated from independent experimental work

$SCF_o$ Observed sightability correction factor estimated from a low and high intensity search of selected plots

$t$ Student's *t*-statistic

$t^o$ Calculated *t*-statistic used for evaluating the probability of making a Type II error, $\beta$

$t'$ Calculated *t*-statistic used for detecting significant differences between two population size estimates

$t_i$ A variable representing time in years that is assigned to a population size estimate that is used for calculating rate of growth

$\hat{T}$ Total population size estimate (expanded population estimate × constant sightability correction factor)

$\hat{T}_e$ Expanded population size estimate (observed population estimate × observed sightability correction factor)

$T_i$ Actual population size in the *ith* year

$\hat{T}_i$ Observable population size estimate in the *ith* stratum (all Sections except 3.12 and 4), or Estimated total population in the *ith* year (Sections 3.12 and 4)

$\hat{T}_o$ Observable population size estimate for the entire survey area

$\hat{T}_s$ The sum of two or more population size estimates from adjacent areas

$\hat{T}^*$ Population size estimated by combining two independent estimates of the same population

$u_k$ Number of moose seen during the intensive search in the *kth* plot; k = 1 through $n_o$

$v_k$ Number of moose seen during the standard search in the *kth* plot; k = 1 through $n_o$

V( ) Sampling variance of the parameter in parentheses

$w_j$ Number of moose in a sex-age class observed in the *jth* sample unit

$w_{jd}$ Number of moose in the denominator sex-age class in the *jth* sample unit

$w_{jn}$ Number of moose in the numerator sex-age class in the *jth* sample unit

$\hat{W}$ Estimated number of moose in a sex-age class, i.e., the expanded estimate corrected for the constant sightability correction factor

$\hat{W}_e$ The estimated observable number of moose expanded by the observed sightability correction factor

$\hat{W}_i$ Estimated number of observable moose in a sex-age class in the *ith* stratum

$\hat{W}_o$ Estimated number of observable moose in a sex-age class in the survey area

$\hat{W}_{od}$ Estimated observable number of moose in the sex-age class in the denominator of a composition ratio

$\hat{W}_{on}$ Estimated observable number of moose in the sex-age class in the numerator of a composition ratio

$\bar{x}$ Mean of measurements in sample units

$\bar{x}_i$ Mean area ($mi^2$) of all sample units surveyed in the *ith* stratum

$x_j$ The measurement in the j*th* sample unit (Section 2, REVIEW OF SAMPLING ERROR AND PRECISION), or
Number of $mi^2$ in the *jth* sample unit (all sections other than Section 2)

$y_j$ Number of observed moose in the *jth* sample unit

## TERMS

**Population estimate**—Estimated number of moose in a population

**Population estimation survey**—Survey to estimate numbers of moose in a population

# Appendix 1.

## Program Listings for the Hewlett-Packard 97 Calculator

# APPENDIX 1. Program Listings for the Hewlett-Packard 97 Calculator

Listings of programs used in this manual allow you to program your HP 97 calculator. To enter programs, press keys in the order indicated by the sequential steps. Once entered, store programs on magnetic cards. Refer to your HP 97 Operators Manual for details on program entry and use.

Program 1. Estimation of population size (Section 3) and numbers in sex-age classes (Section 5). The same program is used for both types of calculations. The format for the listing is the sequential step number followed by the key instruction.

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Card 1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 001 | *LBLA | 046 | RCL4 | 091 | *LBL2 | 136 | SPC | 181 | RCL9 |
| 002 | CLRG | 047 | RCL6 | 092 | RCL7 | 137 | 3 | 182 | RCLI |
| 003 | P=S | 048 | x | 093 | RCL8 | 138 | 3 | 183 | ÷ |
| 004 | CLRG | 049 | RCL9 | 094 | RCLØ | 139 | 3 | 184 | CHS |
| 005 | 1 | 050 | PRTX | 095 | x | 140 | CHS | 185 | 1 |
| 006 | 1 | 051 | ÷ | 096 | 2 | 141 | RTN | 186 | + |
| 007 | 1 | 052 | CHS | 097 | x | 142 | *LBLE | 187 | x |
| 008 | CHS | 053 | RCL8 | 098 | − | 143 | SPC | 188 | DSP3 |
| 009 | DSPØ | 054 | + | 099 | RCL5 | 144 | 4 | 189 | PRTX |
| 010 | RTN | 055 | STOA | 100 | RCLØ | 145 | 4 | 190 | ST+2 |
| 011 | *LBLB | 056 | RCL4 | 101 | $x^2$ | 146 | 4 | 191 | $x^2$ |
| 012 | Ø | 057 | $x^2$ | 102 | x | 147 | CHS | 192 | RCL9 |
| 013 | STO4 | 058 | RCL9 | 103 | + | 148 | DSPØ | 193 | 1 |
| 014 | STO5 | 059 | ÷ | 104 | RCL9 | 149 | R/S | 194 | − |
| 015 | STO6 | 060 | RCL5 | 105 | 1 | 150 | STOD | 195 | ÷ |
| 016 | STO7 | 061 | − | 106 | − | 151 | DSP1 | 196 | ST+3 |
| 017 | STO8 | 062 | RCLØ | 107 | ÷ | 152 | PRTX | 197 | SPC |
| 018 | STO9 | 063 | x | 108 | RCL9 | 153 | R/S | 198 | GTOE |
| 019 | P=S | 064 | RCLA | 109 | x | 154 | STOI | 199 | *LBLd |
| 020 | SPC | 065 | + | 110 | RCL4 | 155 | DSPØ | 200 | SPC |
| 021 | *LBL1 | 066 | RCL9 | 111 | $x^2$ | 156 | PRTX | 201 | RCL1 |
| 022 | R/S | 067 | 1 | 112 | ÷ | 157 | SPC | 202 | DSP1 |
| 023 | ENT↑ | 068 | − | 113 | STOE | 158 | DSP1 | 203 | PRTX |
| 024 | PRTX | 069 | ÷ | 114 | RTN | 159 | GTOB | 204 | STOD |
| 025 | R/S | 070 | RCL9 | 115 | *LBLD | 160 | *LBLc | 205 | RCL2 |
| 026 | PRTX | 071 | x | 116 | SPC | 161 | P=S | 206 | DSP2 |
| 027 | Σ+ | 072 | RCL4 | 117 | 2 | 162 | SPC | 207 | PRTX |
| 028 | GTO1 | 073 | $x^2$ | 118 | 2 | 163 | RCL9 | 208 | STOE |
| 029 | *LBLb | 074 | ÷ | 119 | 2 | 164 | DSPØ | 209 | $x^2$ |
| 030 | SPC | 075 | RCLØ | 120 | CHS | 165 | PRTX | 210 | RCL3 |
| 031 | R/S | 076 | + | 121 | DSPØ | 166 | RCL6 | 211 | ÷ |
| 032 | ENT↑ | 077 | STOØ | 122 | R/S | 167 | RCL4 | 212 | . |
| 033 | PRTX | 078 | STOA | 123 | DSP2 | 168 | ÷ | 213 | 5 |
| 034 | R/S | 079 | DSP6 | 124 | PRTX | 169 | STOØ | 214 | + |
| 035 | PRTX | 080 | PRTX | 125 | STOA | 170 | DSP9 | 215 | INT |
| 036 | Σ− | 081 | GSB2 | 126 | R/S | 171 | PRTX | 216 | STOI |
| 037 | SPC | 082 | STOB | 127 | DSP6 | 172 | RCLD | 217 | DSPØ |
| 038 | GTO1 | 083 | PRTX | 128 | PRTX | 173 | x | 218 | PRTX |
| 039 | *LBLC | 084 | RCL9 | 129 | STOB | 174 | DSP1 | 219 | SPC |
| 040 | P=S | 085 | 1 | 130 | R/S | 175 | PRTX | 220 | 5 |
| 041 | SPC | 086 | − | 131 | DSPØ | 176 | ST+1 | 221 | 5 |
| 042 | RCL6 | 087 | STOC | 132 | PRTX | 177 | GSB2 | 222 | 5 |
| 043 | RCL4 | 088 | DSPØ | 133 | STOC | 178 | RCLD | 223 | CHS |
| 044 | ÷ | 089 | PRTX | 134 | *LBL3 | 179 | $x^2$ | 224 | RTN |
| 045 | STOØ | 090 | GTO3 | 135 | DSPØ | 180 | x | | |

Card 2 (Program 1 continued)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 001 | *LBLA | 044 | R/S | 087 | 5 | 130 | . | 173 | RCL9 |
| 002 | DSPØ | 045 | DSP2 | 088 | 2 | 131 | 9 | 174 | ÷ |
| 003 | SPC | 046 | PRTX | 089 | 4 | 132 | 6 | 175 | RCL2 |
| 004 | RCL1 | 047 | STO6 | 090 | STO1 | 133 | STOØ | 176 | + |
| 005 | RCLA | 048 | RCL7 | 091 | 1 | 134 | 2 | 177 | RCL9 |
| 006 | x | 049 | x | 092 | . | 135 | . | 178 | ÷ |
| 007 | PRTX | 050 | DSPØ | 093 | 4 | 136 | 3 | 179 | RCL1 |
| 008 | STO7 | 051 | PRTX | 094 | 2 | 137 | 7 | 180 | + |
| 009 | RCL1 | 052 | RCL6 | 095 | 1 | 138 | 2 | 181 | RCL9 |
| 010 | $x^2$ | 053 | $x^2$ | 096 | STO2 | 139 | STO1 | 182 | ÷ |
| 011 | RCLB | 054 | RCL8 | 097 | . | 140 | 2 | 183 | RCLØ |
| 012 | x | 055 | x | 098 | 9 | 141 | . | 184 | + |
| 013 | RCLA | 056 | PRTX | 099 | 8 | 142 | 8 | 185 | *LBL9 |
| 014 | $x^2$ | 057 | SPC | 100 | 3 | 143 | 2 | 186 | RCL8 |
| 015 | RCLB | 058 | *LBL3 | 101 | STO3 | 144 | 3 | 187 | $\sqrt{x}$ |
| 016 | − | 059 | 7 | 102 | . | 145 | STO2 | 188 | x |
| 017 | RCL2 | 060 | 7 | 103 | 4 | 146 | 2 | 189 | STOØ |
| 018 | x | 061 | 7 | 104 | 3 | 147 | . | 190 | CHS |
| 019 | + | 062 | CHS | 105 | 4 | 148 | 5 | 191 | RCL7 |
| 020 | PRTX | 063 | RTN | 106 | STO4 | 149 | 5 | 192 | + |
| 021 | STO8 | 064 | *LBLD | 107 | . | 150 | 6 | 193 | RCL6 |
| 022 | Ø | 065 | 9 | 108 | 2 | 151 | STO3 | 194 | x |
| 023 | RCLC | 066 | Ø | 109 | 3 | 152 | 1 | 195 | PRTX |
| 024 | X≤Y? | 067 | PRTX | 110 | 2 | 153 | . | 196 | RCLØ |
| 025 | GTO1 | 068 | 1 | 111 | STO5 | 154 | 5 | 197 | RCL7 |
| 026 | STO9 | 069 | RCL9 | 112 | GTO8 | 155 | 9 | 198 | + |
| 027 | RCLI | 070 | X>Y? | 113 | *LBLE | 156 | STO4 | 199 | RCL6 |
| 028 | X≤Y? | 071 | GTO5 | 114 | 9 | 157 | 1 | 200 | x |
| 029 | STO9 | 072 | 6 | 115 | 5 | 158 | . | 201 | PRTX |
| 030 | GTO2 | 073 | . | 116 | PRTX | 159 | Ø | 202 | RCLØ |
| 031 | *LBL1 | 074 | 3 | 117 | 1 | 160 | 2 | 203 | RCL7 |
| 032 | RCLI | 075 | 1 | 118 | RCL9 | 161 | STO5 | 204 | ÷ |
| 033 | STO9 | 076 | 4 | 119 | X>Y? | 162 | GTO8 | 205 | 1 |
| 034 | *LBL2 | 077 | GTO9 | 120 | GTO6 | 163 | *LBL8 | 206 | Ø |
| 035 | RCL9 | 078 | *LBL5 | 121 | 1 | 164 | RCL5 | 207 | Ø |
| 036 | PRTX | 079 | 1 | 122 | 2 | 165 | RCL9 | 208 | x |
| 037 | SPC | 080 | . | 123 | . | 166 | ÷ | 209 | DSP1 |
| 038 | SPC | 081 | 6 | 124 | 7 | 167 | RCL4 | 210 | PRTX |
| 039 | *LBLB | 082 | 4 | 125 | Ø | 168 | + | 211 | SPC |
| 040 | 6 | 083 | 5 | 126 | 6 | 169 | RCL9 | 212 | DSPØ |
| 041 | 6 | 084 | STOØ | 127 | GTO9 | 170 | ÷ | 213 | GTO3 |
| 042 | 6 | 085 | 1 | 128 | *LBL6 | 171 | RCL3 | 214 | R/S |
| 043 | CHS | 086 | . | 129 | 1 | 172 | + | | |

Program 2. Optimal allocation of sampling effort (Section 3). The format for the listing is the sequential step number followed by the key instructions.

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Card 1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 001 | *LBLA | 038 | RCLC | 075 | √X | 112 | DSP9 | 149 | - |
| 002 | CLRG | 039 | STO3 | 076 | DSP9 | 113 | PRTX | 150 | + |
| 003 | P=S | 040 | P=S | 077 | PRTX | 114 | RCL1 | 151 | RCLØ |
| 004 | CLRG | 041 | GTO1 | 078 | RTN | 115 | RCLE | 152 | + |
| 005 | *LBL1 | 042 | *LBL2 | 079 | *LBLE | 116 | x | 153 | RCL8 |
| 006 | 2 | 043 | 2 | 080 | 2 | 117 | STO1 | 154 | x |
| 007 | 1 | 044 | 2 | 081 | 3 | 118 | PRTX | 155 | STO9 |
| 008 | 1 | 045 | 2 | 082 | 3 | 119 | RCL2 | 156 | RCL4 |
| 009 | CHS | 046 | CHS | 083 | CHS | 120 | RCLE | 157 | RCL5 |
| 010 | DSPØ | 047 | SPC | 084 | SPC | 121 | x | 158 | + |
| 011 | RTN | 048 | R/S | 085 | R/S | 122 | STO2 | 159 | RCL6 |
| 012 | *LBLB | 049 | STOA | 086 | STOA | 123 | PRTX | 160 | + |
| 013 | GSB2 | 050 | DSP3 | 087 | DSP6 | 124 | RCL3 | 161 | RCL7 |
| 014 | STO1 | 051 | PRTX | 088 | PRTX | 125 | RCLE | 162 | x |
| 015 | P=S | 052 | R/S | 089 | R/S | 126 | x | 163 | ST+9 |
| 016 | RCLB | 053 | GSB3 | 090 | STOB | 127 | STO3 | 164 | P=S |
| 017 | STO4 | 054 | STOB | 091 | P=S | 128 | PRTX | 165 | DSPØ |
| 018 | RCLC | 055 | DSPØ | 092 | STOØ | 129 | SPC | 166 | 2 |
| 019 | STO1 | 056 | PRTX | 093 | P=S | 130 | CLX | 167 | 4 |
| 020 | P=S | 057 | R/S | 094 | DSPØ | 131 | DSP1 | 168 | 4 |
| 021 | GTO1 | 058 | GSB3 | 095 | PRTX | 132 | P=S | 169 | CHS |
| 022 | *LBLC | 059 | STOC | 096 | SPC | 133 | R/S | 170 | R/S |
| 023 | GSB2 | 060 | PRTX | 097 | R/S | 134 | PRTX | 171 | *LBL3 |
| 024 | STO2 | 061 | CHS | 098 | STOD | 135 | STO7 | 172 | . |
| 025 | P=S | 062 | RCLB | 099 | PRTX | 136 | R/S | 173 | 5 |
| 026 | RCLB | 063 | + | 100 | R/S | 137 | PRTX | 174 | + |
| 027 | STO5 | 064 | X=Ø? | 101 | STOE | 138 | STO8 | 175 | INT |
| 028 | RCLC | 065 | GTO4 | 102 | DSP6 | 139 | P=S | 176 | RTN |
| 029 | STO2 | 066 | RCLB | 103 | PRTX | 140 | ÷ | 177 | *LBL4 |
| 030 | P=S | 067 | ÷ | 104 | SPC | 141 | √X | 178 | 1 |
| 031 | GTO1 | 068 | RCLC | 105 | RCLA | 142 | STxØ | 179 | DSP9 |
| 032 | *LBLD | 069 | ÷ | 106 | RCLB | 143 | P=S | 180 | PRTX |
| 033 | GSB2 | 070 | 1/X | 107 | x | 144 | RCL5 | 181 | RTN |
| 034 | STO3 | 071 | RCLA | 108 | √X | 145 | RCL2 | 182 | R/S |
| 035 | P=S | 072 | x | 109 | RCLD | 146 | - | | |
| 036 | RCLB | 073 | X=Ø? | 110 | x | 147 | RCL6 | | |
| 037 | STO6 | 074 | GTO4 | 111 | STOØ | 148 | RCL3 | | |

Card 2 (Program 2 continued)

```
*LBLA
2
5
5
CHS
DSPØ
R/S
*LBLB
RCL1
STOA
GTO1
*LBLC
RCL2
STOA
GTO1
*LBLD
RCL3
STOA
GTO1
*LBL1
SPC
SPC
2
6
6
CHS
R/S
DSP4
PRTX
DSPØ
RCL1
x
RCLA
÷
STO4
GSB2
GSB4
GTOA
*LBL2
P=S
RCL6
RCL3
-
RCL5
RCL2
-
+
RCLØ
+
STOB
RCL1
STOC
RCL4
STOD
P=S
RCL1
STOA
GSB3
STO7
STO6
P=S
RCL2
STOC
RCL5
STOD
P=S
RCL2
STOA
GSB3
STO8
ST+6
P=S
RCL3
STOC
RCL6
STOD
P=S
RCL3
STOA
GSB3
STO9
ST+6
RCLC
-
RCL8
P=S
RCL2
-
+
RCLØ
+
STOE
RCLB
RCLE
X≤Y?
STOB
RCLB
GSB5
STOB
RCL8
x
RCL7
P=S
RCL6
x
+
STOI
RTN
*LBL3
RCLA
RCL4
x
RCL1
÷
STOI
RCLD
X≤Y?
RTN
RCLI
RCLC
X>Y?
STOI
RCLI
RCLØ
x
RCLA
÷
STOE
RCLB
RLCE
X≤Y?
STOB
RCLI
GSB5
RTN
*LBL4
SPC
RCL7
PRTX
RCL8
PRTX
RCL9
PRTX
RCLB
PRTX
RCLI
PRTX
RTN
*LBL5
.
5
+
INT
RTN
*LBLE
SPC
SPC
2
7
7
CHS
R/S
DSP1
PRTX
STO5
DSPØ
P=S
RCL9
P=S
X≤Y?
STO5
CLX
STO4
*LBL6
1
ST+4
GSB2
RCL5
RCLI
-
X>Ø?
GTO6
X=Ø?
GTO9
1
ST-4
*LBL7
.
1
ST+4
GSB2
RCL5
RCLI
-
X>Ø?
GTO7
X=Ø?
GTO9
.
1
ST-4
*LBL8
.
Ø
1
ST+4
GSB2
RCL5
RCLI
-
X>Ø?
GTO8
X=Ø?
GTO9
.
Ø
1
ST-4
GSB2
*LBL9
GSB4
GTOA
R/S
```

Program 3. Estimation of sex-age ratios (Section 5). The format for the listing is the sequential step number followed by the key instruction.

Card 1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 001 | *LBLA | 046 | x | 091 | PRTX | 136 | RCL9 | 181 | 3 |
| 002 | CLRG | 047 | ST+8 | 092 | RCLA | 137 | RCLE | 182 | 3 |
| 003 | P=S | 048 | RCLB | 093 | x | 138 | x | 183 | CHS |
| 004 | 5 | 049 | RCLC | 094 | DSP1 | 139 | 2 | 184 | DSPØ |
| 005 | 1 | 050 | x | 095 | PRTX | 140 | x | 185 | RTN |
| 006 | 1 | 051 | ST+9 | 096 | P=S | 141 | - | 186 | *LBLb |
| 007 | CHS | 052 | GTO1 | 097 | ST+3 | 142 | RCL6 | 187 | DSP9 |
| 008 | DSPØ | 053 | *LBLC | 098 | P=S | 143 | RCLE | 188 | R/S |
| 009 | RTN | 054 | SPC | 099 | RCL2 | 144 | $x^2$ | 189 | PRTX |
| 010 | *LBLB | 055 | 5 | 100 | RCL8 | 145 | x | 190 | STOA |
| 011 | CLRG | 056 | 2 | 101 | RCLD | 146 | + | 191 | R/S |
| 012 | *LBL1 | 057 | 2 | 102 | x | 147 | RCLC | 192 | PRTX |
| 013 | RCLØ | 058 | CHS | 103 | 2 | 148 | x | 193 | STOB |
| 014 | DSPØ | 059 | DSPØ | 104 | x | 149 | DSP3 | 194 | R/S |
| 015 | SPC | 060 | R/S | 105 | - | 150 | PRTX | 195 | PRTX |
| 016 | R/S | 061 | DSP1 | 106 | RCL6 | 151 | P=S | 196 | STOC |
| 017 | PRTX | 062 | PRTX | 107 | RCLD | 152 | ST+6 | 197 | 1 |
| 018 | STOA | 063 | STOA | 108 | $x^2$ | 153 | $x^2$ | 198 | ST-Ø |
| 019 | R/S | 064 | R/S | 109 | x | 154 | RCLI | 199 | RCLA |
| 020 | PRTX | 065 | DSPØ | 110 | + | 155 | ÷ | 200 | ST-1 |
| 021 | STOB | 066 | PRTX | 111 | RCLC | 156 | ST+9 | 201 | $x^2$ |
| 022 | R/S | 067 | STOB | 112 | x | 157 | P=S | 202 | ST-2 |
| 023 | DSP1 | 068 | RCLØ | 113 | DSP3 | 158 | RCL7 | 203 | RCLB |
| 024 | PRTX | 069 | - | 114 | PRTX | 159 | RCL9 | 204 | ST-3 |
| 025 | STOC | 070 | RCLB | 115 | P=S | 160 | RCLD | 205 | $x^2$ |
| 026 | 1 | 071 | ÷ | 116 | ST+5 | 161 | x | 206 | ST-4 |
| 027 | ST+Ø | 072 | RCLA | 117 | $x^2$ | 162 | - | 207 | RCLC |
| 028 | RCLA | 073 | $x^2$ | 118 | RCLI | 163 | RCL8 | 208 | ST-5 |
| 029 | ST+1 | 074 | x | 119 | ÷ | 164 | RCLE | 209 | $x^2$ |
| 030 | $x^2$ | 075 | RCL5 | 120 | ST+8 | 165 | x | 210 | ST-6 |
| 031 | ST+2 | 076 | $x^2$ | 121 | P=S | 166 | - | 211 | RCLA |
| 032 | RCLB | 077 | ÷ | 122 | RCL3 | 167 | RCL6 | 212 | RCLB |
| 033 | ST+3 | 078 | RCLØ | 123 | RCL5 | 168 | RCLD | 213 | x |
| 034 | $x^2$ | 079 | x | 124 | ÷ | 169 | x | 214 | ST-7 |
| 035 | ST+4 | 080 | RCLØ | 125 | STOE | 170 | RCLE | 215 | RCLA |
| 036 | RCLC | 081 | 1 | 126 | DSP9 | 171 | x | 216 | RCLC |
| 037 | ST+5 | 082 | - | 127 | PRTX | 172 | + | 217 | x |
| 038 | $x^2$ | 083 | STOI | 128 | RCLA | 173 | RCLC | 218 | ST-8 |
| 039 | ST+6 | 084 | ÷ | 129 | x | 174 | x | 219 | RCLB |
| 040 | RCLA | 085 | STOC | 130 | DSP1 | 175 | PRTX | 220 | RCLC |
| 041 | RCLB | 086 | RCL1 | 131 | PRTX | 176 | P=S | 221 | x |
| 042 | x | 087 | RCL5 | 132 | P=S | 177 | ST+7 | 222 | ST-9 |
| 043 | ST+7 | 088 | ÷ | 133 | ST+4 | 178 | P=S | 223 | GTO1 |
| 044 | RCLA | 089 | STOD | 134 | P=S | 179 | SPC | 224 | R/S |
| 045 | RCLC | 090 | DSP9 | 135 | RCL4 | 180 | 5 | | |

Card 2 (Program 3 continued)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 001 | *LBLA | 046 | $x^2$ | 091 | GTO9 | 136 | 1 | 181 | ÷ |
| 002 | P=S | 047 | ÷ | 092 | *LBL5 | 137 | 2 | 182 | RCL8 |
| 003 | SPC | 048 | + | 093 | 1 | 138 | . | 183 | + |
| 004 | RCL3 | 049 | RCL7 | 094 | . | 139 | 7 | 184 | RCL2 |
| 005 | DSPØ | 050 | 2 | 095 | 6 | 140 | Ø | 185 | ÷ |
| 006 | PRTX | 051 | x | 096 | 4 | 141 | 6 | 186 | RCL7 |
| 007 | RCL5 | 052 | RCL3 | 097 | 5 | 142 | GTO9 | 187 | + |
| 008 | PRTX | 053 | ÷ | 098 | STO4 | 143 | *LBL6 | 188 | RCL2 |
| 009 | $x^2$ | 054 | RCL4 | 099 | 1 | 144 | 1 | 189 | ÷ |
| 010 | RCL8 | 055 | ÷ | 100 | . | 145 | . | 190 | RCL6 |
| 011 | ÷ | 056 | – | 101 | 5 | 146 | 9 | 191 | + |
| 012 | . | 057 | RCLØ | 102 | 2 | 147 | 6 | 192 | RCL2 |
| 013 | 5 | 058 | $x^2$ | 103 | 4 | 148 | STO4 | 193 | ÷ |
| 014 | + | 059 | x | 104 | STO5 | 149 | 2 | 194 | RCL5 |
| 015 | INT | 060 | STO1 | 105 | 1 | 150 | . | 195 | + |
| 016 | STO8 | 061 | PRTX | 106 | . | 151 | 3 | 196 | RCL2 |
| 017 | PRTX | 062 | RCL8 | 107 | 4 | 152 | 7 | 197 | ÷ |
| 018 | RCL4 | 063 | STO2 | 108 | 2 | 153 | 2 | 198 | RCL4 |
| 019 | PRTX | 064 | RCL9 | 109 | 1 | 154 | STO5 | 199 | + |
| 020 | RCL6 | 065 | X<Y? | 110 | STO6 | 155 | 2 | 200 | *LBL9 |
| 021 | PRTX | 066 | STO2 | 111 | . | 156 | . | 201 | DSP9 |
| 022 | $x^2$ | 067 | RCL2 | 112 | 9 | 157 | 8 | 202 | RCL1 |
| 023 | RCL9 | 068 | DSPØ | 113 | 8 | 158 | 2 | 203 | $\sqrt{x}$ |
| 024 | ÷ | 069 | PRTX | 114 | 3 | 159 | 3 | 204 | x |
| 025 | . | 070 | *LBL3 | 115 | STO7 | 160 | STO6 | 205 | STO3 |
| 026 | 5 | 071 | 5 | 116 | . | 161 | 2 | 206 | CHS |
| 027 | + | 072 | 4 | 117 | 4 | 162 | . | 207 | RCLØ |
| 028 | INT | 073 | 4 | 118 | 3 | 163 | 5 | 208 | + |
| 029 | STO9 | 074 | CHS | 119 | 4 | 164 | 5 | 209 | PRTX |
| 030 | PRTX | 075 | DSPØ | 120 | STO8 | 165 | 6 | 210 | RCL3 |
| 031 | RCL7 | 076 | RTN | 121 | . | 166 | STO7 | 211 | RCLØ |
| 032 | PRTX | 077 | *LBLD | 122 | 2 | 167 | 1 | 212 | + |
| 033 | SPC | 078 | SPC | 123 | 3 | 168 | . | 213 | PRTX |
| 034 | RCL3 | 079 | 9 | 124 | 2 | 169 | 5 | 214 | RCL3 |
| 035 | RCL4 | 080 | Ø | 125 | STO9 | 170 | 9 | 215 | RCLØ |
| 036 | ÷ | 081 | PRTX | 126 | GTO8 | 171 | STO8 | 216 | ÷ |
| 037 | STOØ | 082 | 1 | 127 | *LBLE | 172 | 1 | 217 | 1 |
| 038 | DSP9 | 083 | RCL2 | 128 | SPC | 173 | . | 218 | Ø |
| 039 | PRTX | 084 | X>Y? | 129 | 9 | 174 | Ø | 219 | Ø |
| 040 | RCL5 | 085 | GTO5 | 130 | 5 | 175 | 2 | 220 | x |
| 041 | RCL3 | 086 | 6 | 131 | PRTX | 176 | STO9 | 221 | DSP1 |
| 042 | $x^2$ | 087 | . | 132 | 1 | 177 | GTO8 | 222 | PRTX |
| 043 | ÷ | 088 | 3 | 133 | RCL2 | 178 | *LBL8 | 223 | GTO3 |
| 044 | RCL6 | 089 | 1 | 134 | X>Y? | 179 | RCL9 | 224 | R/S |
| 045 | RCL4 | 090 | 4 | 135 | GTO6 | 180 | RCL2 | | |

# Appendix 2.
## Data Forms

# APPENDIX 2.
## Data Forms

Photocopy and use these forms until you develop ones meeting your specific needs.

Form 1. Simple random sample of sample unit numbers drawn from a random number table. List numbers in the order of selection within columns. Place L, M, or H after each number to indicate the assigned stratum.

---

Survey Area________________________________________

Game Management Unit(s)____________________ Subunit(s)____________________

Date________________________ Range of SU Numbers____________________

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Column

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
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Form 2. Stratified random sample of sample units by stratum. Numbers are listed in order of selection within strata.

Survey Area________________________________________

Game Management Unit(s)____________________ Subunit(s)________________

Date________________________ Range of SU numbers________________

Stratum

| Low | | | Medium | | | High | | | Other | |
|---|---|---|---|---|---|---|---|---|---|---|
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Form 3. Moose survey data gathered during standard or intensive searches of sample units.

SU no.________ Date______________ Page___of___

Survey area________________________

Pilot/obs.____________________Est. area ______mi$^2$

Type of search: Standard (e.g., 4-6 min/mi$^2$) ☐
Intensive (e.g., 12 min/mi$^2$) ☐

Dominant habitat________________________

STANDARD SEARCH DATA SUMMARY

Strata H☐ , M☐ , L☐ , O☐
Total moose seen ________
Min. searched ________
Measured area (mi$^2$) ________
Search effort (min/mi$^2$) ________
Obs. density (moose/mi$^2$) ________

INTENSIVE SEARCH DATA SUMMARY

No. moose std. search ________
No. moose int. search ________
Int. search time (min) ________

WEATHER: Clouds Precipitation Temperature Wind Turbulence

LIGHT

TYPE: Bright ☐ Flat ☐

INTENSITY: High ☐ Med. ☐ Low ☐

SNOW AGE AND COVER

Fresh ☐ Moderate ☐ Old ☐

Complete ☐ Some low veg. showing ☐ Bare ground showing ☐

SEARCH TIME

Stop time ________

Start time ________

REMARKS

| In SCF plot (√) | Group no. | Bulls/Activ. Yrlg | Med | Lge | Cows and calves/Activ. ♀ | ♀/1 calf | ♀/2 calf | Lone calf | Unk. sex-age | Total moose | Habitat moose are in |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | | | | | | | | H LS TS D SS S L |
| | 2 | | | | | | | | | | H LS TS D SS S L |
| | 3 | | | | | | | | | | H LS TS D SS S L |
| | 4 | | | | | | | | | | H LS TS D SS S L |
| | 5 | | | | | | | | | | H LS TS D SS S L |
| | 6 | | | | | | | | | | H LS TS D SS S L |
| | 7 | | | | | | | | | | H LS TS D SS S L |
| | 8 | | | | | | | | | | H LS TS D SS S L |
| | 9 | | | | | | | | | | H LS TS D SS S L |
| | 10 | | | | | | | | | | H LS TS D SS S L |
| | 11 | | | | | | | | | | H LS TS D SS S L |
| | 12 | | | | | | | | | | H LS TS D SS S L |
| | 13 | | | | | | | | | | H LS TS D SS S L |
| | 14 | | | | | | | | | | H LS TS D SS S L |
| Sex-age totals | | Y= | M= | L= | ♀= | ♀= Ca= | ♀= Ca= | Ca= | U= | = Total Moose | |

Form 4. Daily tally of count data by stratum for moose population estimation survey.

Survey Area ____________________

Game Management Unit(s) ____________ Subunit(s) ____________

Stratum ________ Stratum Area ________ $mi^2$ Total SUs In Stratum ________

| SU no. | Date searched | No. moose in SU | SU area ($mi^2$) | Search effort ($min/mi^2$) | SU density ($moose/mi^2$) | No. moose in SCF searches | |
|---|---|---|---|---|---|---|---|
| | | | | | | Std. | Int. |
| | | | | | | | |
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Form 5. Moose population estimation survey--data summary.

Survey Area ______________________________

Game Management Unit(s) ______________ Subunit(s) ______________

Date of Survey ______________ Survey Supervisor ______________

DATA SUMMARY FOR STRATUM

| STRATUM POPULATION ESTIMATE | Low stratum | Medium stratum | High stratum |
|---|---|---|---|
| $A_i$ = area ($mi^2$) | ______ | ______ | ______ |
| $N_i$ = total SUs | ______ | ______ | ______ |
| $n_i$ = no. SUs searched | ______ | ______ | ______ |
| $d_i$ = obs. density | ______ | ______ | ______ |
| $\hat{T}_i$ = est. no. moose (uncorrected) | ______ | ______ | ______ |
| $V(\hat{T}_i)$ = variance of $\hat{T}_i$ | ______ | ______ | ______ |

DATA SUMMARY FOR SURVEY AREA

SURVEY AREA INFORMATION

Total area ($mi^2$) = ______

Total No. SUs = ______

Total No. SUs searched = ______

OBSERVED POPULATION ESTIMATE

$\hat{T}_o$ = obs. pop. est. (uncorrected) = ______

$V(\hat{T}_o)$ = variance obs. est. = ______

$\nu_o$ = degrees of freedom = ______

$SCF_o$ = obs. sight. correction factor = ______

$V(SCF_o)$ = variance of $SCF_o$ = ______

$n_o$ = no. SCF plots searched = ______

$\nu_s$ = degrees freedom of $SCF_o$ = ______

EXPANDED POPULATION ESTIMATE

$SCF_c$ = sight. correction constant = ______

$\hat{T}_e$ = expand. pop. est. ($\hat{T}_o \times SCF_c$) = ______

$V(\hat{T}_e)$ = variance of $\hat{T}_e$ = ______

$\nu_e$ = degrees of freedom = ______

TOTAL POPULATION ESTIMATE

$\hat{T}$ = total pop. est. ($\hat{T}_e \times SCF_c$) = ______

d = density = ______

90% CI as % of $\hat{T}$ = ______

$CL_u$ = upper confidence limit = ______

$CL_\ell$ = lower confidence limit = ______

SCF = sight. correct. factor ($SCF_o \times SCF_c$) = ______

Form 6. Daily aircraft charter expenses during a moose population estimation survey.

Survey Area ______________________________

Game Management Unit(s) ______________ Subunit(s) ______________

| | Date | | | | | |
|---|---|---|---|---|---|---|
| | / / | / / | / / | / / | / / | / / |
| Air taxi / Hourly rate | No. hrs / Cost | No. hrs / Cost | No. hrs / Cost | No. hrs / Cost | No. hrs / Cost | No. hrs / Cost |
| ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| ____ | ____ | ____ | ____ | ____ | ____ | ____ |
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| ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Daily costs | | | | | | |
| Cumulative daily costs | | | | | | |

Form 7. Daily food and lodging expenses during a moose population estimation survey.

Survey Area ______________________________

Game Management Unit(s) ______________ Subunit(s) ______________

| Person | Date | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | / / | / / | / / | / / | / / | / / | / / | / / | / / | / / |
| | Room / Board | Room / Board | Room / Board | Room / Board | Room / Board | Room / Board | Room / Board | Room / Board | Room / Board | Room / Board |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
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| | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — |
| Daily Costs | | | | | | | | | | |
| Cumulative Daily costs | | | | | | | | | | |

Form 8. Summary information of sample unit (SU) sex and age class data.

Survey Area ______________________ Date ____________

Game Management Unit(s) ______________________ Subunit(s) ____________

Stratum ____________ Stratum Area ____________ $mi^2$ Total SUs in stratum ______

$SCF_o$ ____________ $V(SCF_o)$ ____________ $\nu_s$ ____________ $SCF_c$ ____________

| SU no. | SU area ($mi^2$) | Bulls: No. of yearlings | Bulls: No. of adults | Bulls: Total no. | No. of cows | No. of calves |
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