A User's Manual for MNFRSIM -
The University of Minnesota's Forest
Sampling Simulator

by

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and

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Table of Contents

Introduction

Data

Computation
  1. Simple Random Sampling
  2. Systematic Sampling
  3. Stratified Random Sampling
  4. Double Sampling
  5. Two-Stage Sampling
  6. Confidence Intervals and Degrees of Freedom

Input
  1. Simulation-Input Option
  2. User Specified Sample Data Option
  3. Error Checking

Output

Literature Cited

Appendices
  1. Examples 1 and 2
  2. Examples 3 and 4
  3. Formulas
  4. Program Description and Source Listing
INTRODUCTION

Simulation has long been a useful research tool in the quantitative sciences. In the past twenty years simulation techniques have found diverse application to forestry problems. Examples include testing tolerance intervals of wood strength (Habermann and Ethington, 1975), projection of stand characteristics and evaluation of alternative management opportunities (Ek and Monserud, 1974), and testing efficiency and cost-effectiveness of various sampling designs (O'Regan and Arvanitis, 1969). Simulators also offer valuable educational opportunities where situations which could take years to encounter in actual field work can be stochastically generated in minutes on modern computers.

This paper describes a sampling simulation program (referred to hereafter as the Minnesota Forest Sampling Simulator or MNFRSIM) written for classroom use in undergraduate forest mensuration. Using repeated samples, instructors can give students "hands on" examples of the relative advantages of various designs under a large number of combinations of forest type, plot size, and sampling intensity. Asymptotic and distribution properties of various estimators can also be studied without the student being bogged down in theoretical drudgery.

Pelz (1976) describes a simulator written for similar purposes. MNFRSIM represents an effort to expand the possible combinations which can be studied, without excessively increasing user cost. Three forest arrangements (random, stratified, periodic) of 360 acres each can be sampled using four plot sizes (1/10, 1/5, 1/2, 1 acre) and five sample
designs (simple random, stratified random, systematic, two-stage, double). Two examples appear in Appendix 2. There is also an option available to analyze user inputted data. With this option one may analyze data collected using any of the five designs mentioned above. The option assumes data were collected following the usual randomization specified under the design. Two examples are given in Appendix 1.

Disclaimer. MNFRSIM has been extensively tested and examined for accuracy, and, to the best of our knowledge, is accurate. However, neither the University of Minnesota nor any of the authors claim any responsibility for any errors that do arise. Documentation of any problems or suggestions for improvements would be greatly appreciated and may be sent directly to any of the authors.
DATA

Data used to create the simulator's three forests were obtained from inventory records of red pine and aspen stands in northern and central Minnesota and upland oak stands in central Iowa. The basic unit in each forest is a tenth acre plot. Neighboring plots are systematically combined if sample units of other sizes are desired. Each unit has an associated volume and basal area measurement. Volume in cubic feet is assumed to be the variable of interest. Basal area data are utilized as auxiliary information with the double sampling design.

With the random forest, plots are randomly distributed over the 360 acres irrespective of the volume or species present. The stratified forest consists of three strata: (1) 180 acres of red pine; (2) 90 acres of aspen; (3) 90 acres of upland oak. Within each stratum available data were randomly assigned to plot locations. The periodic forest represents a situation which commonly occurs in mountainous areas. Strips of alternating high and low volume plots make up this forest. The strips are several plots wide and are in the direction in which systematic samples are drawn. Population parameters for each of the forests are given in Table 1.

Any sample design can be used in combination with any of the three forests. It should be recognized, however, that reasonable strata are only available using the stratified forest. Both the stratified and periodic forests were set up for purely illustrative purposes. We do not claim that they depict anything that would be found from actual field observation.
Table 1: Population parameters

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<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
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<th>(7)</th>
<th>(8)</th>
<th>(9)</th>
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<td>6.73</td>
<td>134</td>
<td>17.1</td>
<td>10189</td>
<td>.931</td>
<td>22.7</td>
<td>0.50</td>
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<td>0.59</td>
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<td>0.01</td>
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<td>0.97</td>
<td>0.11</td>
<td>0.57</td>
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<tr>
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<td>386</td>
<td>37.4</td>
<td>28114</td>
<td>.889</td>
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<td>-0.12</td>
<td>0.62</td>
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<td>13.9</td>
<td>14887</td>
<td>.834</td>
<td>27.2</td>
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<td>0.52</td>
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<td>0.17</td>
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<td>0.67</td>
<td>-0.28</td>
<td>0.52</td>
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<td>94.0</td>
<td>67735</td>
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<td>0.24</td>
<td>-0.35</td>
<td>-0.35</td>
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<td>35283</td>
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<td>0.56</td>
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<td>1.02</td>
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<td>497</td>
<td>43.1</td>
<td>18351</td>
<td>.951</td>
<td>19.6</td>
<td>0.45</td>
<td>0.63</td>
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<tr>
<td>Stratum I 1 acre</td>
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<td>188.9</td>
<td>126369</td>
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<td>0.09</td>
<td>0.06</td>
<td>0.17</td>
<td>0.03</td>
</tr>
<tr>
<td>Stratum II 1 acre</td>
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<td>2415</td>
<td>92.5</td>
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<td>.741</td>
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<td>Stratum III 1 acre</td>
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<td>269.2</td>
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<td>22.4</td>
<td>1.45</td>
<td>1.79</td>
<td>2.17</td>
<td>3.18</td>
</tr>
</tbody>
</table>

(1) square feet of basal area per plot  
(2) cubic foot volume per plot  
(3) basal area mean square error  
(4) volume mean square error  
(5) correlation between basal area and volume  
(6) regression coefficient of volume on basal area  
(7) skewness of basal area  
(8) skewness of volume  
(9) kurtosis of basal area (corrected)  
(10) kurtosis of volume (corrected)
COMPUTATIONS

Most of the estimators used by MNFRSIM are the standard ones associated with each particular design. A short discussion of these estimators will now be given. Peculiarities of each design as they apply to the simulator will also be pointed out. For sake of continuity, actual formulas are presented in Appendix 3. Description of the computational procedures used in the program is provided in Appendix 4. A source listing is also provided there.

Simple Random Sampling

Under this design, a random sample of size n is drawn without replacement. Equations A3.1 and A3.3 are then used to estimate mean volume per acre and the standard error of this estimate. The variance of the observations on a per acre basis, is calculated using A3.2. A slight variant of Stein's two step method (Stein, 1944) is then used (Eq A3.4) to find the required sample size to meet user specified precision and probability requirements. Additional plots are then drawn to meet this required number. The statistics are also recalculated. If several repetitions have been requested these steps are repeated. As with all designs, the user may decide whether individual results of each repetition or only a graphical summary of the results is to be outputted.

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1/ This discussion assumes the option of sampling from one of the three forests has been selected. If user specified data is to be analyzed, the same formulas apply, but the discussion of repeated samples is not relevant.
Simple random sampling can be used with any plot size-forest combination. It is often used as the standard for precision comparisons of various designs.

**Systematic Sampling**

For systematic sampling the user specifies a sampling interval \( I \) which directly determines sampling intensity (Eq A3.5). Two random integers between \([1, I]\) are then used to select a plot from the \( I \times I \) plots in the northwest corner of the forest. Every subsequent plot is then taken at the interval \( I \) in both directions. Equation A3.1 and A3.3 are again used to compute the estimate of mean volume per acre and its standard error. The variance of the observations is estimated by A3.6. This estimator has the same expectation as A3.2, but is not as adversely affected by the presence of a trend in the population (Lindgren, 1976). Required sample size is then found using A3.4. The sampling interval corresponding to this is found by inverting A3.5. Since this value must be an integer, exact requirements will seldom be met. Round-off becomes worse as plot size increases.

These steps are then repeated the desired number of times. Caution should be exercised when examining these repeated sampling results. When systematic sampling in the above manner only \( I^2 \) independent samples are available. For example when sampling fifth acre plots with \( I = 10 \) only 100 independent systematic samples exist, while over \( 10^{42} \) simple random samples are possible.
Stratified Simple Random Sampling

Stratified sampling estimates are computed on every forest as if three strata were present (Figure 1). Since this is true for only the stratified forest, comparisons with other designs should be made using the stratified forest. First, estimates of stratum means and variances

<table>
<thead>
<tr>
<th>I.</th>
<th>II.</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 acres</td>
<td>90 acres</td>
</tr>
<tr>
<td>red pine</td>
<td>aspen</td>
</tr>
<tr>
<td></td>
<td>III.</td>
</tr>
<tr>
<td></td>
<td>90 acres</td>
</tr>
<tr>
<td></td>
<td>hardwood</td>
</tr>
</tbody>
</table>

Figure 1: Configuration assumed under stratified sampling

are found using equations A3.7 and A3.8. These values are outputted only when data have been specified by the user. Estimates on a forest basis are then found by the usual weighting procedures (Eqs A3.9 and A3.10). Standard error of mean volume per acre is calculated using A3.11. Sample size required to obtain a standard error of D is then found using either A3.12 or A3.13. Additional samples are then drawn as needed and the procedure repeated as with simple random sampling.

2/ This assumes user specified data is not being analyzed.
Double Sampling

Double sampling is carried out by first randomly drawing \( m \) plots and then randomly picking a subset of \( n \) (\( n < m \)) of these (without replacement in both cases). Information on basal area is obtained on all \( m \) plots, while both basal area and volume are found for the subset of \( n \). The procedure is logically sound no matter what forest situation is present.

Three estimators are available for summarizing the results: (1) simple linear regression; (2) ratio-of-means; and (3) mean-of-ratios. The reader is referred to figures 2 through 7 and discussions by Freese (1962) and Ek (1971) to determine the appropriateness of each estimator. If simple linear regression is selected, equations A3.22 and A3.24 are used to estimate mean volume per acre and its standard error. Similarly, A3.28 and A3.31 or A3.33 and A3.35 are used if ratio-of-means or mean-of-ratios, respectively, is chosen as the estimator. The variance of the volume observations is estimated using A3.23, the equivalent of A3.2. This way the standard errors from repeated trials of different designs can be put on a common scale by comparing variances of the actual observations that were observed.

Sample sizes needed to obtain a standard error of \( D \) cubic feet per acre are found using A3.25 and A3.26.\(^3\) The additional mreq-m samples are then drawn, along with a subsample of size mreq-n from the mreq (independent of the n previously drawn). Estimators are then recalculated and the procedure repeated as before.

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\(^3\) After: Ware, K. D. 1962. Forest Inventory with Double Sampling and Aerial Photos. Forestry 543 lecture notes. Iowa State University, Ames, Iowa.
Figure 2: Scatterplots of data from the random forest - 1/10 acre (a), 1/5 acre (b) plots.
Figure 3: Scatterplots of data from the random forest - 1/2 acre (a), 1 acre (b) plots.
Figure 4: Scatterplots of data from the periodic forest - 1/10 acre (a), 1/5 acre (b) plots.
Figure 5: Scatterplots of data from the periodic forest - 1/2 acre (a), 1 acre (b) plots.
Figure 6: Scatterplots of data from the stratified forest - 1/10 acre (a), 1/5 acre (b) plots.
Figure 7: Scatterplots of data from the stratified forest - 1/2 acre (a), 1 acre (b) plots.
Two-Stage Sampling

If two-stage sampling is selected, the forest under consideration is divided into eighteen, twenty acre square blocks. These form the primary sample units. A random selection (without replacement) of m of these is then obtained. For each primary, n secondary units or sample plots are chosen (at random without replacement) for estimation of volume.

Various authors have chosen to present the estimation formulas for two-stage sampling in many different fashions. The presentation here follows Freese (op cit.). Mean volume per acre is estimated using A3.36. Standard error of this estimate is found using A3.40. In Freese's notation $S_w^2$ is a pooled estimate of variance among secondaries within primaries and $S_b^2$ is the estimate of variance between primary units on a secondary unit basis. This is not the variance of the primary means or primary totals, but rather the component of variation between primaries if one were to break up the total variation (A3.37) via analysis of variance techniques. An estimate of the variance of the volume observations is given by A3.37. This estimate is biased due to the restricted randomization implicit in the design.

Additional sampling requirements are found using A3.41 and A3.42. Requirements are then met using the primaries already sampled and any additional primaries necessary. If more primaries are needed than are available, a warning will be printed and computations continued. In this case the number of secondaries found using A3.41, will be insufficient to meet precision requirements. The same holds true if more secondaries
are needed than are available. That such problems arise is due to the inappropriateness of the cost function implicit in the derivation of A3.41 and A3.42. In the first case the design becomes a pseudo-stratified design and in the second a pseudo-cluster design.

**Confidence Intervals and Degrees of Freedom**

Confidence intervals for mean volume per acre and variance of the observations of volume per acre are found by A3.43 and A3.44, respectively. Values of the statistics used are those found by the previous equations appropriate for each design. The confidence intervals are approximate in all cases, the validity of the approximation depending on how strongly the design restricts randomization and the skewness and kurtosis present in the population (Cochran, 1977).

Approximate degrees of freedom associated with variance estimates in each design are given in Table A3.1. These are very crude approximations in all cases but simple random sampling.
INPUT

Discussion of data inputting will be separated for the two ways the program can be used, sampling simulation or for calculation of user specified sampling data.

Simulation Input Option

There are two types of data inputs with this option. Program requested inputs are taken care of internally by the control programs such as sampling forest data. User inputs are all free formatted. All numbers requested are in integer form except plot size and sampling costs which can be real numbers. When a choice is to be made by the user concerning one of many options, reference numbers appear next to the choices. The user then inputs one of these integers.

User Specified Sample Data Option

Inputting procedures for this option are more complex because sample observations are now entered by the user and must conform to the requirements of the various sampling designs.

Data can be entered either into a local file or be typed in over the terminal. The following discussion applies to both procedures equally. It is important, however, to point out that data files should be local and accessible by MNFRSIM (see illustrative examples in Appendix 1).

The question for amount of data refers to the number of sampling observations (sample units such as plots) that were collected. It must be
entered as an integer. In the following step, these sample data must be supplied.

Single random and systematic sampling are the easiest to input. Just enter the data - no specific organization is necessary.

Stratified and two-stage sampling require organization of data. For stratified sampling, data should be inputted by stratum, while in two-stage sampling, data should be organized and inputted by primaries.

Double sampling requires more attention. The small sample (plots on which two variables were measured) should be entered first. The independent (e.g. basal area) and dependent (e.g. volume) variables for a plot are entered one after the other with one or more pairs of such numbers per line as desired. These pairs of simultaneous observations should be followed by the remaining observations on the independent variable.

The amount of data asked for in some cases must be an integer. The data following, however, can be entered as integers or real numbers. They can be entered one per line or as many as desired per line as long as several records per line are separated by a comma or one or more blank spaces. The last record on a line should not have a trailing comma. The examples shown in Appendices 1 and 2 should be studied carefully before attempting to run the program.

Error Checking

All inputs are subject to error processing to determine their validity. It would be redundant to detail the limits of the inputs since the program
will demand the correct numbers. Only a few rules of thumb will be presented. First, negative numbers are not considered valid inputs. Second, if a real number is typed in where an integer is called for, the system itself, rather than MNFRSIM, will issue an error message. Third, if an integer is typed in where a real number is called for, the system will convert the integer into a real number. All other erroneous inputs will be handled by MNFRSIM with an informative message printed and the allowance made for correction of the input.
OUTPUTS

Output of all results calculated by the program are completely controlled by the user. Options include (1) a list of summary information on each sample drawn including mean, variance, and standard error, confidence intervals for the mean and variance, and sample size(s). If a given sample was not sufficient to reach the specified precision level, additional samples will be drawn and information will be outputted from the newly calculated sample size sufficient to meet precision requirements; (2) histograms of means, variances, ranges\(^1\), and standard errors; the second histogram in each case contains observations for the enlarged samples that were calculated necessary to meet precision requirements. Any one of these outputs can be suppressed by the user.

Graphs and summary statistics together with the true population parameters (Table 1) provide the information to properly interpret simulation results. Since sample by sample listing requires a considerable amount of printing time, it is suggested that most users will wish to suppress the printing of intermediate statistics.\(^2\)

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\(^1\) For simple random sampling only.

\(^2\) If this option is selected a pause in the outputting will occur while the simulation is being carried out.
LITERATURE CITED


Appendix 1

This appendix contains two examples using user specified data. The first comes from Freese (op. cit.) pages 21-26. Cordwood volume was measured on twenty-five quarter-acre plots selected by simple random sampling. The population was a 250 acre plantation. Ninety-five percent confidence intervals were also formed. Precision requirements for sample size determination were a confidence interval half-width of three (3) cords at the ninety-nine (99) percent level.\(^1\)

The second example comes from Freese (op. cit.) pages 28-31.\(^2\) In this case the design was stratified random sampling. Before accessing MNFRSIM the data was stored on file FRESE.\(^3\) Once the program is accessed questions are answered just as in the simple random sampling example. Note that in this case (as with all designs other than simple random sampling and systematic sampling) precision requirements are specified using desired standard error of the mean (on a per acre basis). Costs are on a per plot basis.

\(^1\) Sample size results are inconsistent since two different methods were used.

\(^2\) Freese does not consider desired sample size for this example.

\(^3\) Any valid system filename is acceptable.
YOU HAVE ENTERED THE MINNESOTA FOREST SAMPLING SIMULATOR
FOR USER INFORMATION, SEE:
A USERS MANUAL TO THE MINNESOTA FOREST SAMPLING SIMULATOR

DATA INPUT SOURCE:
1. SAMPLE DATA DRAWN FROM A FOREST ON FILE
2. USER SPECIFIED

THIS PROGRAM WILL COMPUTE THE STATISTICS FOR THE DATA YOU INPUT.
HOW WILL YOU INPUT THE DATA?
1. FROM THE TERMINAL
2. FROM A FILE

TYPE OF CALCULATIONS:
1. SIMPLE RANDOM
2. REGRESSION / DOUBLE
3. MEAN - OF - RATIOS / DOUBLE
4. RATIO - OF - MEANS / DOUBLE
5. STRATIFIED
6. TWO - STAGE
7. SYSTEMATIC

NUMBER OF STRATA
3

PLOT SIZE
1.0

PRECISION LEVEL: REQUIRED SAMPLE SIZE
75

PROBABILITY LEVEL: CONFIDENCE INTERVALS
95

SAMPLE SIZE FOR STRATUM NUMBER 1
10
TOTAL POSSIBLE SAMPLE SIZE FOR THE STRATUM M1
320

SAMPLE SIZE FOR STRATUM NUMBER 2
10
TOTAL POSSIBLE SAMPLE SIZE FOR THE STRATUM M2
140

SAMPLE SIZE FOR STRATUM NUMBER 3
10
TOTAL POSSIBLE SAMPLE SIZE FOR THE STRATUM M3
340
YOU HAVE ENTERED THE MINNESOTA FOREST SAMPLING SIMULATOR
FOR USER INFORMATION, SEE:
A USERS MANUAL TO THE MINNESOTA FOREST SAMPLING SIMULATOR

DATA INPUT SOURCE:
1. SAMPLE DATA DRAWN FROM A FOREST ON FILE
2. USER SPECIFIED

THIS PROGRAM WILL COMPUTE THE STATISTICS FOR THE DATA YOU INPUT.
HOW WILL YOU INPUT THE DATA?
1. FROM THE TERMINAL
2. FROM A FILE

TYPE OF CALCULATIONS:
1. SIMPLE RAMOQK
2. REGRESSION / DOUBLE
3. MEAN - OF - RATIOS / DOUBLE
4. RATIO - OF - MEANS / DOUBLE
5. STRATIFIED
6. TWO - STAGE
7. SYSTEMATIC

PLOT SIZE
.25

TOTAL POSSIBLE SAMPLE SIZE (N)
1000

PRECISION LEVEL: REQUIRED SAMPLE SIZE
3

PROBABILITY LEVEL: REQUIRED SAMPLE SIZE
99

PROBABILITY LEVEL: CONFIDENCE INTERVALS
95

NUMBER OF PLOTS
7

INPUT THE DATA
7 8 2 6 7 1 0 8 6 7 3 7 9 1 1 8 4 7 7 8 7 7 5 8 8 7

* MEAN / PLOT = 7.00
MEAN / ACRE = 28.00
VARIANCE / ACRE = 61.33
STANDARD ERROR / ACRE = 1.55

CONFIDENCE INTERVALS
MEAN / ACRE VARIANCE / ACRE
24.81 31.19 37.30 118.74

THE REQUIRED SAMPLE SIZE = 52
TYPE OF ALLOCATION:
1. OPTIMAL
2. PROPORTIONAL

COST OF SAMPLING FROM STRATUM NUMBER 1
5
COST OF SAMPLING FROM STRATUM NUMBER 2
10
COST OF SAMPLING FROM STRATUM NUMBER 3
7.5

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<tr>
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<tr>
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<table>
<thead>
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<table>
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<td>VARIANCE / ACRE = 12204.44</td>
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<th>ALL STRATA COMBINED</th>
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<tr>
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<tr>
<td>VARIANCE / ACRE = 3978.63</td>
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<thead>
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PRECISION LEVEL ALREADY ACHIEVED. NO PLOTS NEED BE DRAWN.
Appendix 2

This appendix contains examples using simulator generated data. The first uses twenty-five one-fifth acre plots and simple random sampling. The second uses double sampling and the mean-of-ratios estimator. Both use data from the random forest and are repeated 200 times. Interesting differences are obviously present. A portion of the intermediate output from the simple random sampling example is also included.

Below are listed a portion of some of the larger simulation runs carried out by the authors. The results from these simulations is currently being used for classroom discussion.

<table>
<thead>
<tr>
<th>Forest</th>
<th>Design</th>
<th>Plot Size</th>
<th>Number Repetitions</th>
<th>Number Plots or Samples</th>
<th>Specified(^1)</th>
<th>Simulator Cost</th>
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<tr>
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<td>50</td>
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</tbody>
</table>

\(^1\) For systematic and random sampling precision is confidence interval half-width/probability level - for all others precision is desired standard error.
YOU HAVE ENTERED THE MINNESOTA FOREST SAMPLING SIMULATOR
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DATA INPUT SOURCE:
1. SAMPLE DATA DRAWN FROM A FOREST ON FILE
2. USER SPECIFIED

FOREST TYPE:
1. RANDOM DISTRIBUTION
2. SYSTEMATIC DISTRIBUTION
3. STRATIFIED DISTRIBUTION

PLOT SIZE (IN ACRES): 0.1, 0.2, 0.5, 1.0

SAMPLING DESIGN:
1. SIMPLE RANDOM
2. DOUBLE
3. STRATIFIED
4. TWO-STAGE
5. SYSTEMATIC

TYPE OF OUTPUT:
1. PRINT OUT STATISTICS
2. SUPPRESS PRINTING OF STATISTICS

SAMPLE SIZE (NUMBER OF PLOTS)

NUMBER OF REPETITIONS

PRECISION LEVEL: REQUIRED SAMPLE SIZE

PROBABILITY LEVEL: REQUIRED SAMPLE SIZE

PROBABILITY LEVEL: CONFIDENCE INTERVALS

SIMPLE RANDOM SAMPLING
PLOTS PER SAMPLE = 25
NUMBER OF SAMPLES = 200

FOREST TYPE IS RANDOM

PRECISION LEVEL IS 150 CUBIC FEET PER ACRE AT 80 PERCENT

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<th>S.E.</th>
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PERCENT CONFIDENCE INTERVALS CONTAINING TRUE POPULATION VALUES

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WOULD YOU LIKE THE GRAPH OF THE MEANS? (1 = YES, 2 = NO)

FREQUENCY DISTRIBUTION OF THE MEANS

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<td>55</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>65</td>
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</table>

THERE WERE 1 OBSERVATIONS TOO LARGE
AND 0 OBSERVATIONS TOO SMALL TO FIT ON THE GRAPH

THE SCALE OF THE GRAPH IS

| MEAN OF MEANS = 1323.73 |
| VARIANCE OF MEANS = 21041.66 |
FREQUENCY DISTRIBUTION OF THE MEANS

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 961- |-***          |-***          |-***          |1011-*          |-*          |-*          |1061-*****          |-*****          |-*****          |1111-************          |-************          |-************          |1161-***************          |-***************          |-***************          |1211-********************          |-********************          |-********************          |1261-********************************************************|-********************************************************          |-********************************************************          |1311-********************************************************|-********************************************************          |-********************************************************          |1361-********************************************************|-********************************************************          |-********************************************************          |1411-********************************************************          |-********************************************************          |-********************************************************          |1461-********************************************************          |-********************************************************          |-********************************************************          |1511-************          |-************          |-************          |1561-*          |-*          |-*          |1611-*          |-*          |-*          |1661-          |-          |1711-          |          |          |          |          |          |          |          |

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

5 10 15 20 25 30 35 40 45 50 55 60 65

THERE WERE 0 OBSERVATIONS TOO LARGE
AND 0 OBSERVATIONS TOO SMALL TO FIT ON THE GRAPH

THE SCALE OF THE GRAPH IS X 1
MEAN OF MEANS = 1315.77
VARIANCE OF MEANS = 14207.14
WOULD YOU LIKE THE GRAPH OF THE VARIANCES  (1 = YES, 2 = NO)  

FREQUENCY DISTRIBUTION OF THE VARIANCES

8820-**  
-**  
-***  
-***  
15620-***  
-***  
-***  
22420-**************************  
-**************************  
-**************************  
-**************************  
29220-**************************  
-**************************  
-**************************  
36020-**************************  
-**************************  
-**************************  
42820-**************************  
-**************************  
-**************************  
I 49620-**************************  
N 56420-**************************  
E 63220-**************************  
R 70020-********  
V 76820-*****  
A 83620-***  
L 90420-  
T 97220-  

THERE WERE 1 OBSERVATIONS TOO LARGE  
AND 0 OBSERVATIONS TOO SMALL TO FIT ON THE GRAPH

THE SCALE OF THE GRAPH IS □ 10  
MEAN OF VARIANCES = 474204.70  
VARIANCE OF VARIANCES = 3044164521.03
FREQUENCY DISTRIBUTION OF THE VARIANCES

8820-**
-**

15620-***
-***

22420-***************************
-***************************

29220-***************************
-***************************

36020-***************************
-***************************

42820-***************************
-***************************

49620-***************************

56420-***************************

63220-********
-********

70020-**
-**

76820-**
-**

83620-
-#

90420-
-#

97220-
-

*****-
-

*****-
-

----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
5 10 15 20 25 30 35 40 45 50 55 60 65

THERE WERE 0 OBSERVATIONS TOO LARGE
AND 0 OBSERVATIONS TOO SMALL TO FIT ON THE GRAPH

THE SCALE OF THE GRAPH IS \times 10

MEAN OF VARIANCES = 450160.05
VARIANCE OF VARIANCES = 19165399002.62
Would you like the graph of the std. err. (1 = yes, 2 = no)

Would you like the graph of the range (1 = yes, 2 = no)

Would you like the graph of the number req (1 = yes, 2 = no)

Frequency distribution of the number req

0-********************************************************************************
1-******************************************************************************
2-******************************************************************************
3-******************************************************************************
4-******************************************************************************
5-******************************************************************************
6-******************************************************************************
7-******************************************************************************
8-******************************************************************************
9-******************************************************************************
10-*****************************************************************************
11-*****************************************************************************
12-*****************************************************************************
13-*****************************************************************************
14-*****************************************************************************
15-*****************************************************************************
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53-*****************************************************************************
54-*****************************************************************************
55-*****************************************************************************
56-*****************************************************************************
57-*****************************************************************************
58-*****************************************************************************
59-*****************************************************************************
60-*****************************************************************************
61-*****************************************************************************
62-*****************************************************************************
63-*****************************************************************************
64-*****************************************************************************
65-*****************************************************************************

There were 4 observations too large
And 0 observations too small to fit on the graph

The scale of the graph is X

Mean of number req = 12.25
Variance of number req = 146.04
YOU HAVE ENTERED THE MINNESOTA FOREST SAMPLING SIMULATOR FOR USER INFORMATION, SEE:
A USERS MANUAL TO THE MINNESOTA FOREST SAMPLING SIMULATOR

DATA INPUT SOURCE:
1. SAMPLE DATA DRAWN FROM A FOREST ON FILE
2. USER SPECIFIED

? 1

FOREST TYPE:
1. RANDOM DISTRIBUTION
2. SYSTEMATIC DISTRIBUTION
3. STRATIFIED DISTRIBUTION

? 1

PLOT SIZE (IN ACRES): 0.1, 0.2, 0.5, 1.0

? 2

SAMPLING DESIGN:
1. SIMPLE RANDOM
2. DOUBLE
3. STRATIFIED
4. TWO - STAGE
5. SYSTEMATIC

? 2

TYPE OF OUTPUT:
1. PRINT OUT STATISTICS
2. SUPPRESS PRINTING OF STATISTICS

? 2

SAMPLE SIZE (NUMBER OF PLOTS)

? 34

NUMBER OF SECONDARIES

? 17

NUMBER OF REPETITIONS

? 200

PRECISION LEVEL: REQUIRED SAMPLE SIZE

? 75

PROBABILITY LEVEL: CONFIDENCE INTERVALS

? 95

METHOD OF CALCULATIONS:
1. REGRESSION
2. RATIO - OF - MEANS
3. MEAN - OF - RATIOS

? 3

DOUBLE SAMPLING MEAN OF RATIOS

FOREST TYPE IS RANDOM PLOT SIZE = .2 ACRE NUMBER OF SAMPLES = 200
LARGE SAMPLE SIZE = 34 SMALL SAMPLE SIZE = 17
PRECISION LEVEL IS 75 CUBIC FEET PER ACRE

PERCENT CONFIDENCE INTERVALS CONTAINING TRUE POPULATION VALUES

<table>
<thead>
<tr>
<th></th>
<th>MEAN</th>
<th>VARIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>USER SPECIFIED SAMPLE</td>
<td>95.00</td>
<td>92.00</td>
</tr>
<tr>
<td>REQUIRED SAMPLE SIZE</td>
<td>91.00</td>
<td>91.50</td>
</tr>
</tbody>
</table>

WOUDL YOU LIKE THE GRAPH OF THE MEANS (1 = YES, 2 = NO)

? 1
FREQUENCY DISTRIBUTION OF THE MEANS

1010-###
  ###
  ###
1040-####
  ####
  ****
1086-#######
  #######
  ########
1124-~~~~~~~~~~
  ~~~~~~~~~~~~~
  ~~~~~~~~~~~~
1162-~~~~~~~~~~
  ~~~~~~~~~~~~~
  ~~~~~~~~~~~~
1200-~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
1238-~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
1276-~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
1314-~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
1352-~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
  ~~~~~~~~~~~~~~~~~
1390-~~~~~~~~~~
  ~~~~~~~~~~~~
  ~~~~~~~~~~~~
1428-~~~~~~~~~~
  ~~~~~~~~~~~~
  ~~~~~~~~~~~~
1466-~~~~~~~~~~
  ~~~~~~~~~~~~
  ~~~~~~~~~~~~
1504-~~~~~~~~~~
  ~~~~~~~~~~~~
  ~~~~~~~~~~~~
1542-~~
  ~~
  ~~
1580-

<table>
<thead>
<tr>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

THERE WERE 3 OBSERVATIONS TOO LARGE
AND 0 OBSERVATIONS TOO SMALL TO FIT ON THE GRAPH

THE SCALE OF THE GRAPH IS  X  1
MEAN OF MEANS = 1295.08
VARIANCE OF MEANS = 15407.11
FREQUENCY DISTRIBUTION OF THE MEANS

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1010-</td>
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<tr>
<td>1040-</td>
<td></td>
</tr>
<tr>
<td>1080-</td>
<td></td>
</tr>
<tr>
<td>1120-</td>
<td></td>
</tr>
<tr>
<td>1160-</td>
<td></td>
</tr>
<tr>
<td>1200-</td>
<td></td>
</tr>
<tr>
<td>1230-</td>
<td></td>
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<tr>
<td>1270-</td>
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</tr>
<tr>
<td>1310-</td>
<td></td>
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<td>1350-</td>
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</tr>
<tr>
<td>1390-</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>1460-</td>
<td></td>
</tr>
<tr>
<td>1500-</td>
<td></td>
</tr>
<tr>
<td>1540-</td>
<td></td>
</tr>
<tr>
<td>1580-</td>
<td></td>
</tr>
</tbody>
</table>

There were 0 observations too large and 0 observations too small to fit on the graph.

The scale of the graph is X

Mean of means = 1294.86
Variance of means = 7221.28
WILL YOU LIKE THE GRAPH OF THE VARIANCES (1 = YES, 2 = NO)

WILL YOU LIKE THE GRAPH OF THE STD. ERR. (1 = YES, 2 = NO)

WILL YOU LIKE THE GRAPH OF THE NUMBER REQ (1 = YES, 2 = NO)

FREQUENCY DISTRIBUTION OF THE NUMBER REQ

<table>
<thead>
<tr>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>***</td>
<td>****</td>
<td>****</td>
<td>****</td>
<td>****</td>
<td>****</td>
<td>****</td>
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<td>****</td>
<td>****</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
<td>45</td>
<td>50</td>
<td>55</td>
<td>60</td>
<td>65</td>
</tr>
</tbody>
</table>

There were 1 observations too large.

The scale of the graph is X

Mean of number req = 20.34

Variance of number req = 344.39
APPENDIX 3

SIMPLE RANDOM SAMPLING

\[
\bar{Y} = \frac{\sum_{i=1}^{n} Y_i}{n} \quad \left(\frac{1}{Q}\right) \quad [A3.1]
\]

\[
S_Y^2 = \frac{\sum_{i=1}^{n} Y_i^2 - \left(\frac{\sum_{i=1}^{n} Y_i}{n}\right)^2}{n-1} \quad \left(\frac{1}{Q}\right)^2 \quad [A3.2]
\]

\[
S_Y = \sqrt{\frac{S_Y^2}{n} (1 - \frac{n}{N})} \quad [A3.3]
\]

\[
n_{req} = \frac{1}{\frac{E^2}{S_Y^2} \frac{t^2}{\alpha/2} + \frac{1}{N}} \quad [A3.4]
\]

where:

- \( y_i \) = ith observation of volume per plot
- \( n \) = number of plots per sample
- \( Q \) = plot size in acres
- \( \bar{Y} \) = average volume per acre
- \( S_Y^2 \) = variance of volume per acre
- \( S_Y \) = standard error of mean volume per acre
- \( N \) = number of plots of size \( Q \) in the forest
- \( n_{req} \) = number of required plots to achieve specified precision
- \( t_{\alpha/2} \) = precision specified as Students-t (1-\( \alpha \)) percent, \( n-1 \) d.f.
- \( E \) = precision specified as cubic feet per acre
SYSTEMATIC SAMPLING

\[ n = \frac{N}{I^2} \] \hspace{1cm} [A3.5]

\[ s^2_y = \frac{n-1}{2(n-1)} \left( \sum_{i=1}^{n} (y_{i+1} - y_i)^2 \right) \frac{1}{Q} \] \hspace{1cm} [A3.6]

where:

I = sampling interval

and other variables are defined as before
STRATIFIED RANDOM SAMPLING

\[
\bar{y}_h = \frac{\sum_{j=1}^{n_h} y_{jh}}{n_h} \quad \left( \frac{1}{Q} \right)
\]

\[\text{[A3.7]}\]

\[
S^2_h = \frac{\sum_{j=1}^{n_h} y_{jh}^2 - n_h \bar{y}_h^2}{n_h - 1} \quad \left( \frac{1}{Q} \right)^2
\]

\[\text{[A3.8]}\]

\[
\bar{y} = \frac{\sum_{h=1}^{L} n_h \bar{y}_h}{N}
\]

\[\text{[A3.9]}\]

\[
S^2_Y = \frac{\sum_{h=1}^{L} N_h S^2_h}{N^2}
\]

\[\text{[A3.10]}\]

\[
S_Y = \sqrt{\frac{1}{N^2} \sum_{h=1}^{L} \left[ \frac{N_h^2 S^2_h}{n_h} \left( 1 - \frac{n_h}{N_h} \right) \right]}
\]

\[\text{[A3.11]}\]

\[
nreq_p = \frac{N \sum_{h=1}^{L} N_h S^2_h}{N^2 D^2 + \sum_{h=1}^{L} N_h S^2_h}
\]

\[
nreq_{p(h)} = \left( \frac{n_h}{N_h} \right) nreq_p
\]

\[\text{[A3.12]}\]

\[
nreq_o = \frac{\left( \sum_{h=1}^{L} N_h S_h \sqrt{c_h} \right) \sum_{h=1}^{L} N_h S_h}{N^2 D^2 + \sum_{h=1}^{L} N_h S^2_h}
\]
\[ n_{req}^o(h) = \frac{\sum_{h=1}^{L} \left( \frac{N_h S_h}{\sqrt{c_h}} \right)}{n_{req}^p} \]

where:

- \( y_{jh} \) = jth observation of volume per plot in hth stratum
- \( \bar{y}_h \) = mean volume per plot in hth stratum
- \( n_h \) = number of plots in sample from hth stratum
- \( L \) = number of strata
- \( N_h \) = number of plots of size Q in the hth stratum
- \( S_h^2 \) = variance of volume per acre in hth stratum
- \( n_{req}^p \) = total required sample size to meet specified precision under proportional allocation
- \( n_{req}^p(h) \) = number of samples allocated to hth stratum — proportional allocation
- \( n_{req}^o \) = total required sample size to meet specified precision under optimal allocation
- \( n_{req}^o(h) \) = number of samples allocated to hth stratum — optimal allocation
- \( D \) = desired precision specified as standard error of mean volume per acre
- \( c_h \) = cost of sampling a plot in the hth strata

[A3,13]
DOUBLE SAMPLING—REGRESSION

\[ \bar{X} = \frac{\sum_{i=1}^{m} X_i}{m} \]  \hspace{1cm} \text{[A3.14]} \]

\[ \bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \]  \hspace{1cm} \text{[A3.15]} \]

\[ \bar{Y}_S = \frac{\sum_{i=1}^{n} Y_i}{n} \]  \hspace{1cm} \text{[A3.16]} \]

\[ B = \frac{\sum_{i=1}^{n} x_i y_i - n \bar{X} \bar{Y}_S}{\sum_{i=1}^{n} x_i^2 - n \bar{X}^2} \]  \hspace{1cm} \text{[A3.17]} \]

\[ TSS = \sum_{i=1}^{n} y_i^2 - n \bar{Y}_S^2 \]  \hspace{1cm} \text{[A3.18]} \]

\[ REG = B^2 \left( \frac{\sum_{i=1}^{n} x_i^2}{n} - n \bar{X}^2 \right) \]  \hspace{1cm} \text{[A3.19]} \]

\[ S_{y.x}^2 = \frac{TSS - REG}{n - 2} \]  \hspace{1cm} \text{[A3.20]} \]

\[ r = \sqrt{\frac{REG}{TSS}} \]  \hspace{1cm} \text{[A3.21]} \]

\[ \bar{y} = (\bar{Y}_S + B (\bar{X} - \bar{x})) \left( \frac{1}{Q} \right) \]  \hspace{1cm} \text{[A3.22]} \]

\[ S_y^2 = \frac{\sum_{i=1}^{n} y_i^2 - n \bar{Y}_S^2}{n - 1} \left( \frac{1}{Q^2} \right) \]  \hspace{1cm} \text{[A3.23]} \]
\[
S_{Y|x} = \sqrt{\frac{S_{y|x}^2 (\frac{1}{n} + \frac{(\bar{X} - \bar{x})^2}{n \sum_{i=1}^{m} x_i^2 - n \bar{x}^2})}{\left(1 - \frac{n}{m}\right) \frac{1}{Q^2} + \frac{S_{y|x}^2}{m} (1 - \frac{m}{N})}} \quad [A3.24]
\]

\[
n_{req} = \frac{s_{y}^2 - r^2 s_{y|x}^2 \left[1 - \frac{1-r^2}{r^2}\right]}{d^2} \quad [A3.25]
\]

\[
m_{req} = \frac{r^2 s_{y}^2 \left[1 + \sqrt{\frac{1-r^2}{r^2}}\right]}{d^2} \quad [A3.26]
\]

where:

- \(x_i\) = \(i\)th observation of basal area in large sample
- \(\bar{X}\) = mean basal area per plot in large sample
- \(m\) = sample size of large sample
- \(\bar{x}\) = mean basal area per plot in subsample
- \(n\) = sample size of subsample
- \(\bar{y}_s\) = mean volume per plot in subsample
- \(x_{i}\) = \(i\)th observation of basal area in subsample
- \(y_{i}\) = \(i\)th observation of volume in subsample
- \(B\) = regression coefficient--volume on basal area
- \(S_{y|x}^2\) = variance due to the regression of volume on basal area
- \(r\) = correlation coefficient--volume on basal area
- \(n_{req}\) = number of subsample plots to achieve specified precision
- \(m_{req}\) = number of large sample plots to achieve specified precision
DOUBLE SAMPLING—RATIO-OF-MEANS

\[ R = \frac{\bar{y}_s}{\bar{x}} \]  \hspace{1cm} [A3.27]

\[ \bar{y} = R \bar{x} * \frac{1}{Q} \]  \hspace{1cm} [A3.28]

\[ S_x^2 = \frac{\sum_{i=1}^{n} x_i^2 - n \bar{x}^2}{n - 1} \left( \frac{1}{Q^2} \right) \]  \hspace{1cm} [A3.29]

\[ S_{yx} = \frac{\sum_{i=1}^{n} x_i y_i - n \bar{x} \bar{y}_s}{n - 1} \left( \frac{1}{Q^2} \right) \]  \hspace{1cm} [A3.30]

\[ S_{\bar{y}} = \sqrt{\left(1 - \frac{n}{m}\right) \left(\frac{\bar{X}}{x}\right)^2 S_Y^2 + R^2 S_x^2 - 2 R S_{yx} + \frac{S_Y^2}{m} \left(1 - \frac{m}{N}\right)} \]  \hspace{1cm} [A3.31]

where all variables are defined as before
DOUBLE SAMPLING—MEAN-OF-RATIOS

\[ R = \frac{\sum_{i=1}^{n} r_i}{n} \text{, where } r_i = \frac{y_i}{x_i} \]  

[A3.32]

\[ \bar{y} = R \bar{x} \times \frac{1}{Q} \]  

[A3.33]

\[ S_r^2 = \frac{\sum_{i=1}^{n} r_i^2 - n R^2}{n - 1} \left( \frac{1}{Q^2} \right) \]  

[A3.34]

\[ S_{\bar{y}} = \sqrt{\left(1 - \frac{n}{m}\right) \bar{x}^2 \left( \frac{S_r^2}{n} \right) + \frac{S_y^2}{m} \left( 1 - \frac{m}{N} \right)} \]  

[A3.35]

where all variables are defined as before
TWO-STAGE SAMPLING

\[ \bar{Y} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} Y_{ij}}{mn} \left( \frac{1}{Q} \right) \]  \hspace{1cm} \text{[A3.36]}

\[ S_y^2 = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} Y_{ij}^2 - \left( \sum_{i=1}^{m} \sum_{j=1}^{n} Y_{ij} \right)^2}{nm - 1} \left( \frac{1}{Q^2} \right) \]  \hspace{1cm} \text{[A3.37]}

\[ S_b^2 = \frac{\sum_{i=1}^{m} \left( \sum_{j=1}^{n} Y_{ij} \right)^2 - \left( \sum_{i=1}^{m} \sum_{j=1}^{n} Y_{ij} \right)^2}{mn} \left( \frac{1}{Q^2} \right) \]  \hspace{1cm} \text{[A3.38]}

\[ S_w^2 = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} Y_{ij}^2 - \sum_{i=1}^{m} \left( \sum_{j=1}^{n} Y_{ij} \right)^2}{m(n-1)} \left( \frac{1}{Q^2} \right) \]  \hspace{1cm} \text{[A3.39]}

\[ S_y = \sqrt{\frac{1}{nm} \left[ S_b^2 \left( 1 - \frac{m}{n} \right) + \frac{m S_w^2}{M} \left( 1 - \frac{n}{N} \right) \right]} \]  \hspace{1cm} \text{[A3.40]}

\[ n_{req} = \frac{S_w^2}{\sqrt{(S_b^2 - S_w^2)/n}} C_p C_s \]  \hspace{1cm} \text{[A3.41]}

\[ m_{req} = \frac{\left( (S_b^2 - S_w^2)/n \right) + \frac{S_w^2}{n_{req}}}{D^2 + \frac{1}{M} \left( (S_b^2 - S_w^2)/n \right) + \frac{S_w^2}{N}} \]  \hspace{1cm} \text{[A3.42]}
Where:

\( Y_{ij} \) = jth observation of volume in ith primary

\( m \) = number of primaries sampled

\( n \) = number of secondaries sampled per primary

\( S_b^2 \) = between primary variance

\( S_w^2 \) = within primary variance

\( M \) = total number of primaries in the forest (18 for simulated forests)

\( N \) = total number of secondaries per primary

\( n_{req} \) = number of secondaries sampled per primary to achieve desired precision

\( m_{req} \) = number of primaries sampled to achieve desired precision

\( C_P \) = cost of establishing a primary

\( C_s \) = cost of sampling a secondary
\[
\bar{Y} - (t_{\alpha/2, \text{d.f.}}) \frac{S_Y}{\sqrt{n}} < \bar{Y} < \bar{Y} + (t_{\alpha/2, \text{d.f.}}) \frac{S_Y}{\sqrt{n}} \quad \text{[A3.43]}
\]

where: \( t_{\alpha/2, \text{d.f.}} \) = Students - t, \( 1-\alpha/2 \) percentile, d.f. degrees of freedom

\( \bar{Y} \) = true population volume per acre

\[
\frac{(\text{d.f.}) S_Y^2}{\chi^2_{(1-\alpha/2), \text{d.f.}}} < \frac{\sigma^2}{2} < \frac{(\text{d.f.}) S_Y^2}{\chi^\alpha_{2, \text{d.f.}}} \quad \text{[A3.44]}
\]

where:

\( \text{d.f.} = \chi^2 \) degrees of freedom

\( \chi^2_{a,b} \) = chi-square, a percentile, b degrees of freedom

\( \sigma^2 \) = true population variance of volume per acre

Table A3.1: Degrees of freedom

<table>
<thead>
<tr>
<th>Simple Random Sampling</th>
<th>( n - 1 )</th>
<th>( n - 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic Sampling</td>
<td>( n - 1 )</td>
<td>( n - 1 )</td>
</tr>
<tr>
<td>Stratified Random Sampling</td>
<td>( n - L )</td>
<td>( n - L )</td>
</tr>
<tr>
<td>Double Sampling</td>
<td>( n - 2 )</td>
<td>( n - 1 )</td>
</tr>
<tr>
<td>Two-Stage Sampling</td>
<td>( m(n - 1) )</td>
<td>( mn - 1 )</td>
</tr>
</tbody>
</table>
APPENDIX 4

PROGRAM DESCRIPTION

General

MNFRSIM was written to conform to FORTRAN IV compiler standards. To facilitate interactive use, the program was segmented using overlay techniques. Use of the package on systems other than the Control Data Cyber 7400 may require adjustments of these overlay procedures. Replacement of the random number generator and the two distribution percentile generators (Students-t and chi-square distributions) should be the only other program modifications required to execute the package on other systems.

MNFRSIM is the direct access file which contains the compiled binary code in absolute overlay form. The program consists of one main overlay, eight primary overlays, and nineteen secondary overlays. Discussion of overlays and their functions would distract from the main purpose of this paper. Suffice it to say that the main overlay always resides in memory; it calls the primary overlays when needed, which in turn call secondary overlays. For a more detailed explanation the reader is directed to the CDC FORTRAN IV User's Manual\(^1\) or the MNF (Minnesota FORTRAN) User's Manual.\(^2\)


The following paragraphs will describe the actual programs, subroutines, and functions which make up MNFSIM. Since many of the programs and subprograms are similar, they have been classified into categories with a description of each category and a listing of the members.

Control Programs

Control programs contain the main algorithms for the simulator. These programs essentially call other control programs or other working subroutines. Control programs determine what subprograms are called and the order in which they are called. The following are control programs:

MITC, RAN, RANZ, DBL, STR, STRZ, ST6, ST62, SAM, SAM2, SET, CALC, and GRAPH.

Statistical Computation Subroutines

These subroutines calculate the statistics for the sample designs. The basic algorithm is similar for all of these. The formulas used are described in detail in an earlier section of this paper. The subroutines which fall into this category are:

Simple Random - RANCAL, RAN3
Regression/Double - REGRES, REGRES2
Ratio-of-Means/Double - RATIO, RATIO2
Mean-of-Ratios/Double - MEAN, MEAN2
Stratified - STCAL, STRAT3
Two Stage - STC2CAL, STAGE3
Systematic - SYSCAL, SAM3
Sampling Subroutines

These subroutines draw the samples from the user selected forest according to a specified design. The basic algorithm used was presented by Bebbington.\(^3\) This algorithm is more efficient than conventional algorithms for sampling from a file without replacement. Most of the routines are slight modifications of the algorithm. The sampling subroutines are:

- Simple Random - SAMPLE1
- Double - SAMPLE 2
- Stratified - SAMPLE 4
- Two Stage - SAMPLE 3
- Systematic - SAMPLE 5

Required Sample Size Functions

All of these functions are logical functions. If more plots need to be drawn to achieve the desired precision level, a value of true is returned along with the required sample size. If the precision level is already achieved, a value of false is returned. The formulas used were discussed in detail earlier in this paper. The functions are:

- Simple Random - SRSSS
- Double - DBLSS
- Stratified - LSTRAT
- Two Stage - TWOSTG
- Systematic - SYSSS

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Required Input Programs

These programs print out descriptions of user specified inputs to run MNFRSIM. All inputs are checked to insure that they conform to the specifications of MNFRSIM. The programs that comprise this category are:

RAN1, DB1, STR1, STG1, SAM1.

Other Functions, Subroutines and Programs

**Error** - This subroutine will print out an error message and then return control back to the calling routine to allow for a corrected input.

**CONF1 (CI)** - This subroutine calculates the confidence intervals for the mean and variance. It also outputs these statistics.

**CHISQ** - This computes chi-square percentile for both tails. It uses IMEL subroutine MDCHI.

**RAND** - Subroutine RAND returns a random value in the range [0,1]. The CDC random number generator RANF is used. This function allows for easy substitution of another random number generator. The parameter--RANDOM--is the dummy parameter which can be used if necessary.

**ICHR** - This function changes a number into its display code representation.

**CREAT** - This program reads in the desired forest population.

**REVAL** - This program restructuring the forest into the requested plot size.

**DRAW** - Subroutine DRAW produces all graphical output.

**INFREQ** - This subroutine scales the graphs and determines the frequencies of the classes.

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