Resource Inventory Notes

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THE EFFECT OF SAMPLE SIZE ON COEFFICIENT OF VARIATION ESTIMATION

by

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Introduction: The coefficient of variation is defined as the population standard deviation divided by its mean value, on a percentage basis.

(1) $CV = \sigma/\mu_x \cdot 100\%$

Since both the numerator and denominator are expressed in the same units of measure, one can interpret this statistic as a measure of population of variability that is independent of the scale of measure employed in the analysis of the population. As such, it provides a means of comparing the spread of populations measured in different units, or populations that cluster around different mean values.

In practice the true population mean μ_x is seldom known, and the population standard deviation, σ, is even less frequently available. Sample based estimates of these parameters must then be used to estimate CV, and it is with this form of the statistic that foresters and other workers in natural resources are most familiar.

(2) $\hat{CV} = s/\bar{x} \cdot 100\%$

Commonly, this statistic is substituted into the familiar formula (3) for simple

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random sampling prior to an inventory in order to compute the number of survey samples needed to ascertain inventory level with a specified level of precision.

$$(3)\quad n = \left[\frac{t \cdot \hat{CV}}{E}\right]^2$$

where t = Student's t value;

E = desired level of precision in percent

When more than five percent of the population is sampled, n is adjusted by

$$(4)\quad n_a = \frac{n}{1 + n/N}$$

where N = number of elements in the population. Of course, this pre-cruise estimate of survey sample size would likely be used in conjunction with knowledge of the population garnered from past inventories, ocular estimation, local conditions, and budgetary considerations to make a final determination as to sample size.

Estimates of the standard deviation and mean from many common sampling designs are unbiased regardless of sample size. However, precision in estimating these parameters increases with increasing sample size, since large samples tend to be more representative of the population than small samples. Consequently, estimates of CV also become more precise for larger samples.

Populations Examined: To study the relationship between sample size and the range of probable coefficients of variation estimates, a population of cubic foot volumes of 76 eastern white pines was studied (Husch, 1962). These volume measurements are shown plotted against corresponding dbh measurements in Figure 1. This population had the following characteristics:

$\mu_x = 25.9$

$\sigma = 22.8$

CV = 88%

A computer program was written to randomly select 25 samples of a given number of units, and to calculate the coefficient of variation in volume for each sample. Coefficients of variation were computed for 25 samples of size 8, size 10, size 12, etc. to size 24, inclusive. The results are shown graphically in Figure 2; each row of symbols represent the coefficients computed for the sample size shown along the y-axis. As expected, the range in values decreased with increasing sample size.

It should be observed that...

a) the decrease is neither steady nor continuous, but rather a general trend - a result of the chance selection of samples;

b) at each level, the CV estimates are rather symmetrically distributed around the true CV, 88%; this approximate symmetry of the distribution is apparent

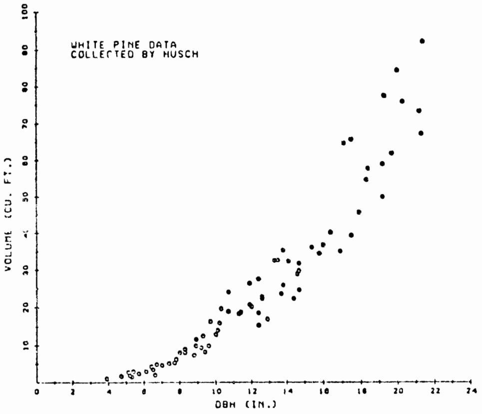

Figure 1. Population A: Cubic foot volumes plotted against the corresponding DBH values. Each circle represents one tree.

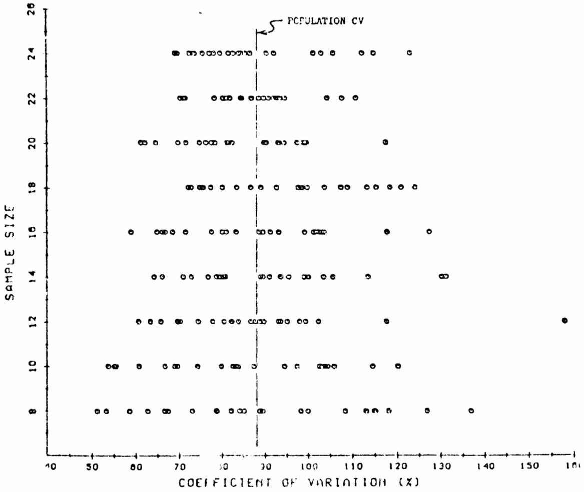

Figure 2. Range of CV estimates for various sample sizes. Each circle represents one estimate of CV. The vertical line represents actual population CV.

also in the accompanying frequency histogram (Figure 3);

c) at n = 8, the range in values is from 51% to 137%, or 86 percentage points, whereas at n = 24 the observed range is from 69% to 123% or 54 percentage points.

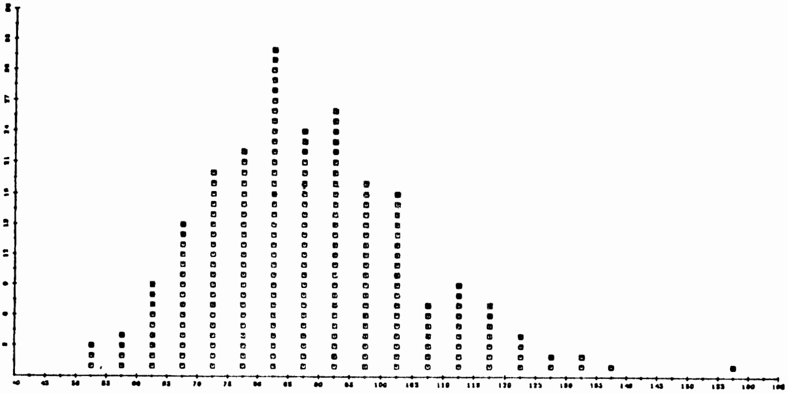

Figure 3. Frequency histogram of the 225 coefficient of variation estimates shown in Figure 2.

Three other populations were examined to determine whether the above characteristics were generally occurring.

Population B: 550 white pine board foot volumes (based on data from Treciokas, unpublished), CV = 71%.

Population C: 123 dbh measurements (Hawley, 1930, Keene plot #604), CV = 31%.

Population D: 120 counts of the number of maple tree seedlings per 30 cm strip of nursery bed (Barrett and Nutt, 1979), CV = 19%.

The $\widehat{CV}$ statistics resulting from repeated sampling from these populations are arrayed in Figure 4. From each population, 25 samples of each size (n = 8, 10, ... 24) were chosen, and the CV was computed for each sample.

For a given population the range in estimated values decreases as sample size

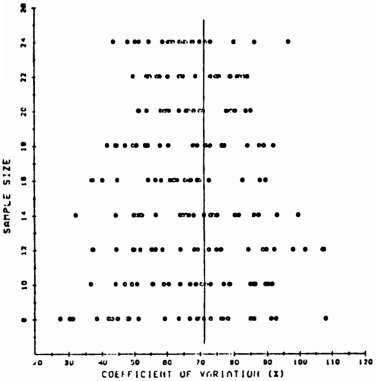

Figure 4a. Population B:
White pine board foot volumes.

N = 550

CV = 71%

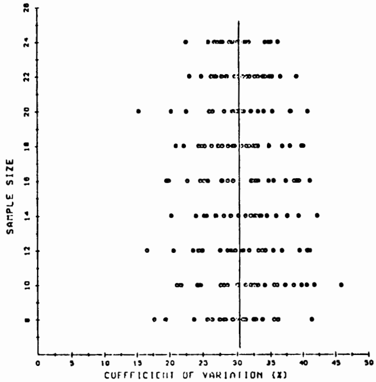

Figure 4b. Population C:
White pine diameters.

N = 123

CV = 31%

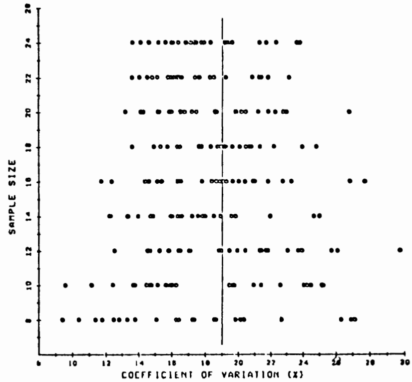

Figure 4c. Population D:
Counts of maple seedlings.

N = 120

CV = 19%

Figure 4. Estimates of CV from three other populations studied.

increases, signalling a gain in precision. As noted with Population A, this decrease is a general trend: erratic values can and do occur at any sample size.

For a given sample size, the range of probable $\widehat{CV}$ values will depend not only on the chance selection of the particular set of samples, but also on the magnitude of the actual population CV. As an example consider the range in estimates at n = 8 for Population B and Population D. The former with a CV of 71% had values ranging from 28% - 108%, whereas the latter with a CV of 19% had a range in estimated values from 8% - 28%.

		True	90% Range of $\widehat{CV}$ (%) values		
Population	Size	CV	n = 8	n = 16	n = 24
A: Pine cubic foot volume	76	88%	51 - 115	64 - 106	67 - 106
B: Pine board foot volume	550	71%	38 - 91	43 - 88	49 - 86
C: Pine DBH	123	31%	18 - 39	21 - 39	25 - 36
D: Maple seedling counts	120	19%	9 - 27	13 - 25	15 - 22

Table 1 - Range of CV estimates from 100 samples of size 8, 16, and 24 from the four populations. Range of values shown exclude the 10% most extreme values.

$CV = 88\%$	$\widehat{CV} = 115\%$	$\widehat{CV} = 51\%$
$t \cong 2$	$t \cong 2$	$t \cong 2$
$E = 20\%$	$E = 20\%$	$E = 20\%$
$n = \left[\frac{2 \cdot 88}{20}\right]^2$	$n = \left[\frac{2 \cdot 115}{20}\right]^2$	$n = \left[\frac{2 \cdot 51}{20}\right]^2$
$= 77$	$= 132$	$= 26$
$n_a = \frac{77}{1 + 77/76} = 38$	$n_a = \frac{132}{1 + 132/76} = 48$	$n_a = \frac{26}{1 + 26/76} = 19$
2a: Sample size estimate based on true CV.	2b: Sample size estimate based on $\widehat{CV}$ = 120%.	2c: Sample size estimate based on $\widehat{CV}$ = 60%.

Table 2 - Selected sample size recommendations based on CV estimates from population A.

The graphical results in Figures 2 and 4 are included in the tabulations for selected sample sizes shown in Table 1. To lessen the influences of a single set of 25 samples, three additional sets of 25 samples were drawn for each of the indicated sample sizes. Thus a pool of 100 samples in total was examined. To minimize the influences of extreme values, the range of values displayed in Table 1 exclude the most extreme 10% of the estimates.

Ramifications: Foresters concerned with volume estimation are often working with populations with very high coefficients of variation (Freese, 1962). As Figure 1 indicates, single estimates of CV could be seriously misleading. For example, an average sample size of n = 38 from Population A would be sufficient to achieve a precision level of E = 20% at the 95% confidence level, as shown in Table 2a. Had a forester been unfortunate enough to have estimated a $\widehat{CV}$ equal to 115% from a preliminary survey of 8 samples, then he would be led to believe that n = 48 samples were required to achieve this accuracy. On the other hand, had a $\widehat{CV}$ value of 51% been estimated then 19, or half the sample size necessary, would have been the survey size recommendation.

Conclusions: A survey planner is advised to interpret a CV estimate resulting from a preliminary survey guardedly. This is especially true when the magnitude of the estimated CV is large. Sometimes the size of the $\widehat{CV}$ can be reduced by an improved survey sample design such as stratification. The individual strata CV estimates will tend to be more precise, and the resulting survey size recommendation will be reduced.

An average $\widehat{CV}$ based on a large sample size or on multiple estimates would also provide a more precise estimate of the true figure. With any approach, however, the forester is limited in the time he can take in the pre-survey. After all, he could end up doing more work in the pre-survey than in the actual survey!

A forester might combine his preliminary results with general observations taken while in the field. Based on these, he could estimate the smallest and largest observations per sample unit likely to occur. Then he could make an estimate of the standard deviation by the shortened equation:

$$s = \frac{\text{(largest observation)} - \text{(smallest observation)}}{4}$$

This estimate together with $\overline{X}$ would provide a second estimate of the coefficient of variation. If one estimate differs substantially from the other than perhaps a more extensive pre-survey would be justified. The results of the second survey can be combined with those of the initial survey, thereby employing a two-step sequential approach.

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A WORLD-WIDE REVIEW OF THE PROBLEM OF NATIONAL FOREST INVENTORY SYSTEMS

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ABSTRACT

An international Symposium was held during the week of June 18-24, 1978 in Bucharest, Romania on the "National forest inventory - why is it needed and how best to conduct it." This paper is based on the author's opening address and it summarizes the main points of discussion. The national forest inventory is defined as a system which provides data on the forest resources of an entire country, current values and rates of change. The data from national inventory are used to define a national policy and express this policy as a set of national programs. The sampling designs currently applied world-wide are summarized, the basic principles to use in designing future national forest inventory systems are outlined, and several areas of research needs are identified.

INTRODUCTION

Two IUFRO (International Union of Forestry Research Organizations) Subject Groups on Forest Resource Inventory and Forest Management and Planning met together during the week of June 18-24, 1978, in Bucharest, Romania. The main purpose of the meeting was to bring together for a general discussion the biometricians in charge of forest inventory and the forest managers and planners for which the inventory data were gathered. The thought was that a joint meeting would improve the communication gap that sometimes exists between forest mensurationists and managers.

Much too often the forest inventory specialists lose sight of the basic objectives of forest inventory, the basic management needs behind these objectives and the practical uses of the data obtained; or they may be aware of these objectives, needs, or uses only in a very general and vague way. On the other hand, the forest managers may not fully realize that once their needs for forest data are determined and appropriately expressed, it is largely a matter of statistical methodology to devise a sampling method by which to obtain estimates of these data; that there are many ways to sample forests and that among the many available methods, there is generally one which seems best under the conditions of a specific inventory problem; and, finally, that the costs of taking the inventory are related to the required precision of estimates and that the required precision must be justified in terms of the actual uses of these estimates.

One of the current problems in the international forestry arena is that of the forest resource inventory on the national level. In general terms, the national forest inventory concerns itself with the periodic assessment of the forest resources of an entire country as they change over time. These assessments are the basis for the formulation of national forest policies and the translation of these policies to national legislation and programs.

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To estimate forest resources, one must use some form of sampling. From the beginning, it became apparent to professional forest statisticians that in order to be cost-efficient, the sampling techniques for national forest inventory would normally be different than the techniques currently applied in the ordinary type of operational inventory. Several countries with good statisticians in their forest organizations have developed cost-efficient sampling designs. Other countries lacking the necessary statistical expertise are presently using designs which are relatively inefficient. And finally, there are many countries that are presently in the process of establishing national forest inventory systems. Furthermore, even efficient sampling designs become inefficient with time. New statistical concepts are continuously being devised, more powerful and versatile computers are being constructed, and the new technological developments in the remote sensing area open new avenues for the methodology of assessing the national forest resources that were undreamed of until a few years ago.

For this reason the theme selected for the Bucharest meeting was "National forest inventory: Why is it needed and how best to conduct it." As the responsibility for the "why" of the inventory rests with the forest manager and the responsibility for the "how best to conduct it" rests with the biometrician, it was felt that a joint discussion on the "why" and "how" of the national forest inventory would bring forward the points of view of both, manager and biometrician, and probably would lead to a better understanding of the common problems.

The fact that the meeting was attended by over 100 foresters from some 40 countries is proof of the timely need for a meeting of this type. Almost 100 papers were presented with most of them related to the objectives and methodology of national forest inventories. There were 19 papers from Canada and the United States, 6 papers from Latin America, 14 papers from Asia and Australia, 4 papers from Africa, and 44 papers from Western and Eastern Europe. Most of these papers discussed in great detail the objectives and the sampling methodology of the national forest inventories of the various countries and arguments developed on the advantages or drawbacks of some of the basic statistical concepts used in this methodology.

In what follows we shall try to summarize some of the main points discussed in the papers. While these papers have been bound together as a set of proceedings issued and distributed at the time of the meeting by the Romanian Forest Research Institute, it will be rather difficult for the reader to obtain such a set; only a limited number was issued, and they are already out of print.

OBJECTIVES AND USES OF FOREST INVENTORIES

To better manage forest lands, one needs information about their forest resources; and most of this information is obtained through a forest inventory. Because most of the time the main marketable resource is the wood, the forest inventory may be defined as a systematic procedure for (a) collecting mensurational data on wood resources and the land on which they grow by sampling, (b) data processing and analysis, and (c) summary presentation of wood volume and area estimates by tree and forest quality classes.

It is useful to classify forest inventories in the following three general types, not necessarily mutually exclusive or exhaustive:

(1) The Operational Inventory: an intensive, in-place type of inventory primarily designed to provide estimates of the current values of forest resources. For example, the timber sales inventory, the logging inventory, etc., are such inventories.

(2) The Management Inventory: an extensive type of inventory primarily designed to insure a continuous flow of information about both, current values and rates of change of the overall resources of forest land belonging to a given ownership.

(3) The Regional or National Inventory: an extensive type of inventory which covers either entire countries or suitably defined geographical or political subdivisions of a country. Its primary objectives are to provide estimates of current values and rates of change for the overall regional or national forest land independent of the land ownership.

The data from regional or national forest inventories are used for better decision-making at the highest possible level, ordinarily federal or state governments. They are used to (a) define a national policy, (b) express this policy as a set of laws and national programs, (c) create the necessary organizational structure to carry out these programs, and (d) verify whether the consequences of these decisions are as predicted. In short, they are used to monitor and control the forest resources on the national level.

SAMPLING DESIGNS CURRENTLY USED IN NATIONAL FOREST INVENTORY SYSTEMS

The simplest way to obtain forest resource data at the national level, when operational and management inventories are available is by consolidation of the local resource data as provided by these inventories. Past experience shows that unless the country is relatively small and its forest lands are well covered by management type inventories, this procedure is seldom satisfactory; not all national lands are being covered by inventories; if covered, the objectives and measurement standards are different, the inventories are taken at various points in time, etc. This is the main procedure used in many countries, mostly those of Central and Eastern Europe.

A somewhat better procedure is to take nationwide low intensity inventories of the one-shot type, ordinarily used in operational inventories. One of the most common techniques is that of stratified sampling, where the stratification by forest types is sometimes obtained from maps, most commonly by photo-interpretation. The sample units are either plots of fixed area or variable radius plots, taken alone or in clusters, most of the time temporary, occasionally permanent. The estimates of the current values are ordinarily of acceptable precision but those of the forest growth are seldom so. Among the many countries using such designs are New Zealand, Fiji Islands, Northern Ireland, Japan, several Canadian provinces, etc.

It is extremely expensive and time consuming to stratify the forest area of an entire country by photo-interpretation and then to transfer the stratification to basic maps. Consequently, there are inventory systems that use unstratified systematic sampling designs with single or clusters of plots of the fixed area or plots of the variable radius type. Most prominent among these systems are those used in the national forest inventories of Sweden, Finland, and Austria. Coupled with special studies for estimating growth these methods yield in general sound and reliable estimates.

One way to reduce the costs of stratification and still enjoy most of the advantages of stratification is by means of double sampling designs, whereby the forest inventory is taken in two main phases. In the first phase a large number of points are randomly located on aerial photographs of the national land and by photo-interpretation classified into one of several broadly defined strata. In the second phase, a stratified subsample of these points is matched with ground plots measured for tree and stand characteristics. Finally, the data from the two phases are suitably combined to yield volume estimates. Such a sampling design is being used in the national forest inventories of France, Spain, and the United States.

Most of these sampling designs use temporary sample units and, thus, the estimation of the forest growth has poor precision. To improve the precision of the growth estimates, one must rely either on separate studies or on permanent sample plots. One method using regularly spaced permanent sample plots of fixed area is the Continuous Forest Inventory (CFI) which serves as a basic design for several national inventory systems such as that of Mexico, for example. The CFI is a statistically sound design for measuring both current values and rates of change in forest resources; but it is also a rigid and relatively expensive system.

To improve the efficiency of many of the above designs (for estimating both current values and growth) one can use the concept of Sampling with Partial Replacement (SPR). This concept requires both permanent and temporary plots and the data from all plots on all occasions are used to derive estimates at any given measurement occasion. A CFI system with SPR is being used in the State of Quebec, Canada; and a double sampling system with SPR is used in the Northeastern United States. In addition, several other countries are presently experimenting with SPR and its use will probably increase with time.

BASIC PRINCIPLES TO USE IN DESIGNING NATIONAL FOREST INVENTORY SYSTEMS

Let us now identify the main principles on which national forest inventory systems should be based if they are to be (a) statistically sound, (b) cost-efficient, and (c) sufficiently comprehensive to satisfy the ever increasing needs for forest resource data.

(1) National forest inventory should satisfy the informational needs of the modern approach to the management of the national forest resources. The type of inventory data to collect is largely conditioned by (a) the specific set of national problems a country is faced with, and (b) the management decision-making system of the given country. It is not sufficient to know what are the problems faced by the management; one must also know how these problems will be solved.

(2) The national forest inventory should be a broad, integrated, multiple-resource inventory. The major problems faced by governments are in general of wide scope that go beyond the limited scope of the forestry problems. The traditional timber resource data should be collected together with other environmental data such as, for example, data on water, air, soil, wildlife and wildlife habitat, fish and insects, grass, shrubs or needle and leaves biomass, etc. Present needs should be considered together with needs as perceived in the future. Furthermore, because the forest data will be used by the policy makers in conjunction with resource data other than forest, it may be better perhaps to think of the national forest inventory as part of a wider scope inventory of all land and water resources, including range, agricultural, or open lands. This wider scope inventory may use the same sampling design with the same sample units measured at the same time for all characteristics of interest, or may be defined as an integrated set of narrower scope inventories that may be used for specific purposes at specific times.

(3) Forest resource measurements should be made independent of the current concepts of merchantability and accessibility. For example, the basic estimates should be provided for merchantable and non-merchantable species, of total rather than merchantable volumes or biomass weights, and so on. At the same time, the inventory system should have a built-in facility to transform the field measurements taken in fixed, constant units to units that are meaningful in terms of current applications.

(4) National forest inventory systems should consist of interrelated successive inventories. The sampling design should present both a space and time dimension. That is, the design should include a basic rule stating how to select sample units at a given point in time and over a forest area, and a second basic rule stating how to select the sampling units over successive points in time. One should recognize that to estimate rates of change it is extremely advantageous to use permanent sample units.

(5) National forest inventory systems should have a built-in capability of projecting resource data to any given point in time. To do this stand projection, one would probably need to know (a) the state of the forest as measured at various discrete points in time, (b) the rates of change as measured in the past, and (c) the expected reaction of the forest to management practices.

(6) Unless strata are defined as permanent geographical units, national forest inventories should not use pre-stratification. This is because (a) it is extremely difficult to find a stratification system which is efficient for all of the main purposes of inventory, (b) stratum boundaries change with time, (c) management needs change with time, and finally (d) management may call for different systems of stratification for different needs at the same point in time. On the other hand, one could use post-stratification; several stratification systems can be used simultaneously or at different points in time and each stratification may serve a specific purpose and give answers to specific management questions.

(7) When calculating the precision of estimates, all sources of error should be recognized and accounted for. There are errors associated with (a) the random location of sample units, (b) the transformation of primary set of plot and tree measurements (such as diameters, heights, quality, etc.) to secondary measurements (such as volume, quality, and quantity), (c) the physical measurement of various plot and tree characteristics, (d) the discrepancy between the real life entities of the inventory problem of interest and their counterparts in the statistical model of the sampling design used to represent them, and (e) the calculation of the forest areas.

(8) Great thought should be given to the problem of selecting precision requirements for the main estimators. To determine the precision requirements, one may rely on past experience with inventory data and their past uses. Or, one may determine first the amount of money that may be made available for sampling and then proceed with a sampling design that will optimize the precision of estimates. A more common approach is to reach a compromise between the desired precision and the costs of sampling; it costs money to obtain data with high precision, it costs money also to make poor decisions based on data of low precision. All these methods rely heavily on common sense, intuition, and subjective judgments by both resource managers and statisticians.

A much better approach may be to construct a mathematical model that combines the costs of obtaining inventory data with the expected loss when certain courses of action are taken. However, this assumes that the management system is already expressed in mathematical terms and that the expected loss for various courses of action can be accurately determined; something which is seldom, if ever, the case.

(9) To improve the efficiency of the sampling design, one should consider using remote sensing techniques. It is well known that aerial photography can be efficiently used in forest inventory. Much less known, however, is the fact that with the advent of high altitude aircraft and spacecraft and the development of new forms of data acquisition such as infrared sensors, multispectral scanners or side-looking airborne radar (SLAR) new avenues are open to the problem of remote sensing applications to forest inventory. The cost per unit of measurement is low, the data acquired may be made compatible with computer processing and the forest area of the entire country can be covered at regular intervals at relatively low costs.

(10) To improve the data analysis and facilitate the presentation of the inventory results, one should use computers. It may sometimes be advantageous to write custom-made programs to serve the specific needs of a particular inventory. However, national forest inventories are large systems with large data processing problems where one may not know at the time the computer program is being written the type of data and reports required by the management. Consequently, one would need flexible and powerful computer programs to generate all kinds of reports. As several such generalized programs have already been written, it may be advantageous to select one and adapt it to one's own inventory system.

(11) When designing a national forest inventory system, one must seek the advice of a professional statistician with advanced specialized knowledge in statistical sampling methodology. The statistician should be well aware of the methodology used today in the national forest inventory systems currently in existence, the advantages and disadvantages of their main sampling designs, and possibly, he should acquire sufficient knowledge from the fields of forest mensuration, remote sensing and computer science as related to forest inventory. Finally, he should get deeply involved in all phases of inventory, starting with the definition of the main objectives and finishing with the final applications of the inventory data.

RESEARCH NEEDS

The basic principles above can be used to devise efficient sampling techniques. Because research may still be needed to fully apply these principles, let us identify some of the areas where research may be required.

(1) Research is needed to develop management models that formalize the decision making process and study the impact of these models to the basic objectives and intensity of the national forest inventory systems. Research is also needed to identify the various forestry problems at the national level as well as the resource data that are needed to solve them.

(2) It is important to have a capability of predicting the reaction of the forest to various management activities. Much research has been done in order to determine relationships predicting the evolution of the forest, either unmanaged, natural forest, or forest subjected to standard silvicultural treatments such as thinning or fertilization. But much more research is needed to investigate many types of forests as they react to a much wider spectrum of management activities and courses of action. Finally, research is also needed in the methodology of projecting forest inventory data at various points in time with or without any management interference.

(3) Research is needed to determine the best level of precision in forest inventory estimates. The basically intuitive methods used until now should be replaced by methods based on mathematical cost functions which combine costs of sampling with costs incurred when decisions are made based on these estimates.

(4) The problem of best shape and size of fixed area plots or best basal area factors of variable radius plots has received a lot of attention in the past and for all practical purposes no large scale research is needed. However, because ground plots are normally selected in clusters, research is needed to identify the best combination of sample plots in clusters, their size and shape, as a function of forest conditions and objectives of inventory.

(5) It has been generally assumed that variable radius plots are more efficient than fixed area plots. While this may be true for most inventory conditions where estimates of current resource values are required, it does not necessarily follow that this will also be true when estimates of growth are derived from permanent plots. Research is needed to determine and compare the relative cost-effectiveness of fixed and variable radius permanent plots when estimation of growth components such as mortality, in-growth, growth on survivors, and cut are required.

(6) The problem of expressing the error in volume tables in a form in which it can be combined with the error in the other sources is largely solved if the regression function is linear, the method of estimation is the weighted least squares and the method of selecting trees is random. As many inventory systems use volume tables based on non-linear regression functions, research is needed to find ways to express their error in a suitable form and ways to combine it with the error from other sources. Research is also needed to show ways to measure and account for the measurement bias and the error in the forest area estimation.

(7) Because field measurements are taken in units which are independent of current utilization standards and management requires estimates using these standards, ways should be found to transform data to estimates expressed in a currently meaningful form. For example, if we refer to wood volume, one can select by sound statistical techniques a set of sample trees that are completely described in terms of many diameter measurements along the main stem from the ground level to the tree top, weight measurements of all tree components (such as sections of main stem, branches, roots, and leaves) and all defects outside or inside the tree. These sample trees could serve as a permanent sample tree data basis that can be used by computer to generate all kinds of regression functions or converting factors every time utilization standards change.

(8) Research is needed in the area of devising new sampling designs or improving the old ones by addition of new statistical concepts or technological advances. For example, the SPR concept has been in use for almost 20 years. However, research is needed to extend its use to sampling designs other than DFI or double sampling for stratification techniques. Similarly 3P Sampling or sampling with probability proportional to size are two similar concepts which are potentially much more efficient to use than the usual random sampling with equal probability. Furthermore, research may be needed to combine the effectiveness of SPR with that of sampling with probability proportional to size and, thus, define sampling designs using both concepts.

(9) Great developments have occurred lately in the extra large or ultra small scale aerial photography and multispectral scanning from earth satellites that can provide a practically continuous coverage of the forest resources of the entire earth. These new methods of data acquisition can provide us with successive sets of measurements of the same forest area taken at very short intervals. Many of these measurements are correlated with measurements as taken in the field and research is needed to (a) investigate the nature and strength of the relationship between remote sensing and ground measurements, (b) use this relationship to improve the sampling design (multi-stage or double sampling designs), and (c) efficiently apply computers to automatically process the enormous mass of data provided by remote sensors and present the summary results in tabular or graphical form.

FINAL COMMENTS

The main objectives of the national forest inventory are to provide, on a continuous basis, estimates of the forest resources as they change over time. These estimates are made at the national level and refer to the entirety of forests in the country irrespective of ownership. They are used to define matters of national policy and translate this policy into appropriate forest legislation and national programs.

The presently used methodology for deriving resource estimates at the national level ranges from relatively inefficient to highly efficient. A set of general principles for designing cost-effective national forest inventory systems have been identified and the analysis of these principles can lead to improvements of the presently existing systems.

Further research in this methodology is, however, still necessary. To do all this research alone may prove to be too great a task for any one nation. Consequently, international cooperation between various countries is strongly recommended.

This cooperation may take the form of regular symposia or workshops sponsored and attended by the members of various teams in charge of national forest inventories, the purpose of these workshops being dissemination of information and sharing of experiences and ideas. Another more active form may be the creation of an IUFRO project group in the area of sampling methodology for national forest inventory including researchers from various disciplines, as for example, biometricians, mensurationists, computer science and remote sensing specialists, policy makers, operations research analysts, forest managers, economists, and, of course, forest inventory specialists. Regular international meetings attended by forest professionals engaged in national forest inventory work will prove extremely fruitful in improving the various systems already in use or defining new and more efficient designs.

DERIVING A LOCAL VOLUME TABLE FROM A STAND AND STOCK TABLE

by

Harry V. Wiant, Jr.[3/]

ABSTRACT

A local volume table is easily derived from a stand and stock table using a weighted regression. This technique is especially useful when predicting growth by the stand table projection method.

Results of a timber cruise are often given in a stand and stock table, indicating the number of trees and volume in each diameter class. If sufficient increment borings have been taken, a future stand and stock table can be developed by the stand table projection method outlined in most mensuration texts. To do this a local volume table is needed, and that is easily derived from the stand and stock table using a weighted regression to give more weight to the diameter classes for which more trees were measured. The technique described here can be used if a plot of average volume per tree (Y) by diameter class over diameter-squared (X) indicates a straight-line fit is appropriate. A simple example will be used to illustrate this procedure (Table 1).

Once the appropriate equation is derived, per-tree volume for a given diameter class is easily calculated. For the 14-inch class, for example:

$$Y=0.772(14)^2-51$$

$$=100$$

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Table 1. Example of a weighted regression used to derive a local volume table from a stand and stock table produced from a fixed-area plot cruise.

Diameter class (D)	Number of trees (w)	Volume (V)	Volume per tree (Y)
12	60	3600	60
13	40	3200	80
14	30	3000	100
	Σ 130		

D	X	wX	wY	$w(X^2)$	wXY
12	144	8640	3600	1244160	518400
13	169	6760	3200	1142440	540800
14	196	5880	3000	1152480	588000
	Σ 509	21280	9800	3539080	1647200

1. $\bar{y} = (\Sigma wY)/\Sigma w$
$= 9800/130$
$= 75.385$

2. $\bar{x} = (\Sigma wX)/\Sigma w$
$= 21280/130$
$= 163.692$

3. $$b = \frac{\Sigma wXY-((\Sigma wX)(\Sigma wY)/\Sigma w)}{\Sigma w(X^2)-((\Sigma wX)^2/\Sigma w)}$$
$$= \frac{1647200-((21280)(9800)/130)}{3539080-((21280)^2/130)}$$
$$= 0.772$$

4. $Y = \bar{y}+b(X-\bar{x})$
$= 75.385+0.772(X-163.692)$
$= 0.772X-50.985$ or $0.772D^2-51$

Notes: $Y=V/w$ $X=D^2$
w for a point-sample-derived stand table with n trees in a given diameter class = nD^2
w can be reduced by dividing by a constant (e.g., 1000) to prevent calculator overflow

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MEETINGS

1980

February 21-23	19th Annual Meeting, Western Regional Science Association. Location: Doubletree Inn, Monterey, California. Contact: Lay James Gibson, Department of Geography and Regional Development, University of Arizona, Tucson, Arizona, 85721.
March 4-5	Conference on Aerial Photo Timber Volume Tables. Sponsors: EROS Applications Assistance Facility, National Space Technology Laboratories and School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University. Location: NSTL Station (near Bay St. Louis) Mississippi. Contact: Pat O'Neil, EROS Applications Assistance Facility, U.S. Geological Survey, Building 3101, NSTL Station, Mississippi, 39529.
March 17-21 June 16-20 August 18-22	The Application of Remote Sensing Techniques to Environmental Resource Problems. Sponsors: Remote Sensing Laboratory, Indiana State University and Laboratory for Application of Remote Sensing, Purdue University. Location: Terre Haute Indiana. Contact: Paul Mansel, Department of Geography and Geology, Indiana State University, Terre Haute, Indiana, 47809.

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