A FOREST INVENTORY BY CONTINUOUS FOREST CONTROL¹

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INTRODUCTION

Continuous Forest Control is a forest inventory system used by Canadian International Paper Company on its leased and freehold lands. It may be described as a forest sampling technique involving the establishment of permanent sample plots and their remeasurement on successive occasions.

Senior Company foresters, Greg. Belcher and Ivar Fogh became acquainted with the concept of Continuous Forest Inventory and under the strong influence of Cal Stott became convinced that it could fill the gap and the imprecision left when estimating changes in the forest with the existing Company inventory methods. The idea of a permanent, accurate plot and tree record, remeasured in time, to estimate the current state of the forest and its rate of change was the strongest link in the chain reaction that followed.

In 1954, a CFI system was installed at the Company's Causapschal Research Station, situated in the Gaspé Peninsula. It consisted of a systematic network, with a random start, of 1/7 acre circular plots. 340 plots were established on some 6,500 acres. In 1955, the same plots were remeasured. The information from the two measurements was analysed in great detail. These studies resulted in a decision to extend this inventory system to all Company forest holdings. Statistical factors, limitation of forest travel, the amount of reliable work possible in a day's work in the forest, the precise data to be collected were fully considered in the design of a more efficient sampling plan. Credit must be given at this point to another Company forester, Henri Le Blanc for his valuable contribution to the writing of the technical field instructions and the thorough training of personnel.

1958 became the target date to start the five year plot establishment cycle. Some 17,500 sq. miles (11,200,000 acres) were earmarked to be sampled by randomly located groups of two 1/7 acre plots. During 1958 and 1959, as the data was being collected a forest statistician, Tiberius Cunia, analyzed the sampling design and showed that more efficiency would be achieved by changing to a group of three 1/10 acre plots. In 1962, Ware and Cunia published their theory of sampling with partial replacement of units. Further reductions in sampling costs were thought possible in determining in advance the proportion and the choice of the plots scheduled for remeasurement. The possibility of lower field work standard has resulted in the decision to establish all plots as if they were permanent. In 1963, the first remeasurement cycle started in the areas where the establishment was completed. Some

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overlapping of areas varied the interval between measurements from 3 to 5 years. In 1965 and 1966, CFC was extended to an additional 7500 sq. miles (4,800,000 acres) working up to a total of 25,000 sq. miles. We have collected data for 32,600 plot records, from the first or the second occasion and this number increases by 4,500 new or remeasured plots every year.

Following this historical sketch we will describe the general sampling procedure and the pertinent details concerning the data collected, our approach to tree studies or volume regression. The main characteristics of the system such as post-stratification, partial replacement of units will be treated in their concepts without going into their statistical backing. Interested parties may refer to the published papers describing the theory in detail. CFC data processing will lead to analysis of CFC data, its present and future uses in forest management.

PRESENT SAMPLING PROCEDURE

CFC may be further described as a forest inventory system based on cluster sampling with systematic sub-sampling and partial replacement of units.

1. Plot Establishment

The forest area of each division of the Company is sectioned into geographical units called blocks, varying from 50-200 sq. miles. These block boundaries are those of minor watersheds and they were determined long before for administration purposes. They are the basic units used to determine the sample size and their productive land areas are known. A grid equivalent to 60x60 chains is laid over 20 chains to the inch map and those clusters whose centers fall on productive land are numbered within each block. The number of clusters to be sub-sampled is determined by dividing the productive area by 2.2 sq. miles and a random selection made from the total number of clusters. The geometrical center of the cluster becomes the primary plot. A random choice from 10 directions (multiple of 36°) of the primary establishes the location of the satellite plots at 21 chains on each side. If one of the satellites falls on non-productive land a new random direction is taken. The group of three 1/10 acre plots, the primary and the two satellites is considered a normal work day under average conditions.

CFC personnel, both cruiser and assistant, are trained before every field season and must follow specific field instructions concerning the method of plot establishment and remeasurement. Once the plot periphery is determined, all the trees of 3.50 inches and over are measured and numbered. Within the 1/10 acre plot, sapling and seedling plots of 4 milacre are taken at separate locations.

2. Data Collected

The plots are well identified geographically within each division and area breakdown and a number of variables are measured and estimated according to field instructions.

a) *Plot Variables*

Plot cover type, plot history, stand type, age class, obstacles, slope, aspect, duff depth, soil texture & stoniness, topography, operating class, and total number of trees are recorded for each plot.

b) *Tree Variables*

Each tree within the plot contour is described in detail and recorded.

Particulars noted are: Species, crown class, branchiness class, defoliation, dieback, DBHOB, vigour, status, stem defects, external pathology, use class; breast height is exactly marked and measured with a diameter tape to the nearest .01 of an inch. Three trees in each plot are systematically chosen and measured for height with a hagameter (to the nearest foot). Coniferous trees measured for height are bored with an increment borer, age and growth for the last 5 and 10 yr. period are recorded. Rot presence is noted and its diameter measured.

3. Plot Checking

Checking crews for every 4 to 5 cruisers constantly verify the quality of the work, report and correct any deviation from the standard procedure. They also contribute to further the training of personnel to achieve the best possible field work. Random selection of the plots to be checked insures against possible sloppiness in out-of-reach plots. Approximately 10 per cent of the plots are checked. All plots are considered permanent and the random selection of the plots to be remeasured is made immediately before each field work season. The same standards are maintained for remeasured and new plots at second and subsequent occasions.

VOLUME REGRESSIONS

During the early part of the CFC program a method was devised to provide satisfactory volume tables for CFC volume computation. Tree studies were needed to develop tree volume regression formulae for each species by division where tree volume would be expressed as a function of DBH and height. Some 3,000 tree studies were taken in the logging area as trees were felled by cutters in the main species now utilized. Logging camps were chosen at random and all the trees cut in a day by a randomly chosen cutter were measured. These volume formulae will be later used in the data processing.

PRE-STRATIFICATION VERSUS POSTSTRATIFICATION

Concepts of merchantability and accessibility change. Trees of lower quality or of less valued species, until recently of minor interest or of no use, have become more important. Similarly, areas inaccessible in the past, because of topography or low economic value, acquire new significance in the light of improved logging techniques or the shrinking wood supply. A forest stratification also changes considerably with time. Fires, wind and insect damages, harvesting, and natural evolution in species composition continually alter the original stratification. The use of stratification with optimal allocation would be highly efficient in a one-shot forest inventory. The strata could be sampled more or less intensively according to their variations within.

In Continuous Forest Inventory with permanent sample plots pre-stratification becomes more cumbersome. Different types of strata may be required at the same time. The optimum allocation of plots for one defined set of strata will no longer be optimum for another set. Sampling will no longer yield unbiased estimates unless adjustments were made to the general stratified sampling formulae. With a large number of strata remeasured at several occasions the problem of obtaining unbiased estimates becomes practically, if not theoretically, impossible.

CFC permanent sample plots have been randomly located on the map and on the ground, independently of any strata definition. Consequently, if a post-stratification is superimposed, on the average, the number of plots in any stratum will be approximately proportional to its size.

Different management needs, such as working plans, would require a number of different poststratifications that could be overlaid on the plot location map and a regrouping of plots within each stratum would yield unbiased estimates of averages per acre or totals and their confidence limits. Poststratification assures a flexibility that is most desired in continuous forest management.

SAMPLING WITH PARTIAL REPLACEMENT OF UNITS

Ware and Cunia have shown that when a population is measured on two occasions and that when estimates of some current value and/or their change over a given time interval are required, the best method of sampling is with partial replacement of units (SPR).

The main feature of SPR in CFC is that part of the permanent plots will not be remeasured at the successive occasion but replaced by new ones. The application of the theory to our own needs in CFC has resulted in lower costs and the same precision in sample estimates. Their theory shows an incredibly low optimal proportion of plots to be remeasured for estimating current mean volume. This proportion depends only on the cost ratio of new plots to old plots and the correlation coefficient. In our system, cost of new plots and old plots being equal and the correlation coefficient slightly higher than 0.90 the proportion could be as low as 30% of the original number of plots. A conservative decision was taken to remeasure 50 per cent of the plots and establish 20 per cent new ones.

DATA PROCESSING

CFC data computation has evolved considerably from desk calculators, to electric tabulators, to electronic processors with punched card input. We are now moving to a larger computer with magnetic tape input. This evolution has created a programming problem further complicated by a large turnover of programmers. Several changes in card format through the years also increased the difficulties in programming and updating of programs. A recent decision to convert all data processing to a new computer IBM 360 model 40 brought about format standardization of all existing data to make an efficient use of magnetic tape. The newest and most promising programming language PL/I is being used for the program conversion. The flexibility and the additional processing speed will enable us to update CFC information more rapidly.

The field notes consisting of plot, tree and reproduction data are punched and verified on three distinct IBM card formats. Edit and sequence programs check each coded variable for validity, interrelationship and also against an admissible range of changes between two measurements. A volume regression program using the calculated regression coefficient from tree studies and total heights from sample plots convert the regression to a new one on DBH only. The new coefficients are applied to individual trees over large areas from 1000 to 2000 square miles, in all forest types and age classes.

A series of programs, in the present setup, calculates and lists the plot and tree merchantable and total volumes by species, species group and categories

such as survivors, ingrowth, cut, mortality or windfall. A second series of programs are a simplified application of SPR. The coefficients of a basic regression formula is calculated for each species group and for each combination of total and merchantable volume at first or second measurement time. This volume is then added to the plot record as if we had actually measured it in the field, and because it is statistically an unbiased estimate it can be satisfactorily used.

The new data processing setup will apply the general SPR formulae to obtain estimates by species for each area break or blocks and for several occasions. At present, the main CFC report is prepared from the updated records and basic statistical data are summarized by blocks, group of blocks or for an entire division. Averages, standard deviation, standard errors and confidence limits are listed for several series of estimates. The first series is derived from permanent plots only and establishes survivors growth, survivors growth and ingrowth, growth on growing stock, unadjusted and adjusted net growth for the period between measurements. The following series of estimates are derived from all the plots of the first or the second measurement. Other estimates including all sample plots, permanent and temporary where SPR was applied are given for the first and second measurement and their difference. Finally, a series of estimates gives totals per area break using productive areas and the preceding estimates of stand per acre.

Detailed stock and stand tables are prepared by species for total and merchantable volumes from first and second measurement data using permanent and temporary plots. They are also classified into cut, windfall, mortality, survivors and ingrowth.

DATA ANALYSIS AND USES OF CFC DATA

From the main statistical report (CFC-45), volume estimates per block, groups of blocks or an entire division can be analyzed by species group or species to provide, in addition to the content of the report itself, such information as the change in species composition of the forest during the interval between measurements. Allowable annual cut based on adjusted net growth can be determined for large areas or for the division. Relationships between stand per acre by species and related growth may be necessary to determine what accounts for a low or a high average rate of growth. A number of interrelation of variables can be calculated now from these basic CFC reports.

CFC data analysis may be considered at several levels such as the individual tree, the individual stand or the whole forest.

CFC data were used in the preparation of the periodical "Management Working Plan" required by the Department of Lands & Forests of the province of Quebec. The forest was poststratified in cover types by age classes. The sample plots were regrouped according to the stratum in which they were located. The areas of these strata were determined. The CFC data then provided unbiased estimates of average stand per acre or totals per stratum, with confidence limits. Stock and Stand tables for each stratum by diameter classes and species were compiled from the individual tree records.

Planning the development of new logging areas on a large scale, at the division

level, has been done from overall volume distribution by species and diameter limit classes coming from CFC information.

The proportional allocation of sample plots over large areas has made it possible to establish the percentage of the total area covered by wet or dry ground conditions, by classes of slope, or by classes of stand per acre.

The average tree diameter, the average merchantable length of trees, the average branchiness class and their variation have been also calculated to help in drawing up final specifications for the design of new logging equipment.

The tremendous source of information that exists in the CFC records will multiply its uses as it is further analyzed.

Among its possible future uses is the determination of cutting schedule per area break or blocks or even per forest stand per year. Operations research techniques such as linear programming and simulation can be used to achieve harvesting policies that would maximize yield while minimizing costs and maintaining or improving the forest stocking over a period of time.

CONCLUSION

We have merely outlined the general characteristics of our forest inventory system, Continuous Forest Control. We may recall the two main goals of our sampling method: 1) to estimate the general state of the forest and 2) to evaluate its rate of change. The pursuit of these objectives has uncovered a host of problems that were solved with the emphasis on a practical rather than theoretical aspect.

We have combined the recognized value of permanent sample plots and the economic effectiveness of the most advanced statistical sampling techniques as tools to better forest management. A look at the historical development of forest inventory methods would reveal the strong influence and almost parallel development of the mathematical statistics.

The total management concept of a forest enterprise requires from the industrial forest precisely defined information. Further influencing forest inventory methods are the advent of computers which made possible the use of complex statistical methods and analysis. The emphasis on rational work planning by management scientists leaves no choice but to be prepared and see the forest through the trees.

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