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A FOREST SURVEY METHOD

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INTRODUCTION

Information on forest survey costs and methods was required for the Sault au Cochon Economic Forest Management Project (1) and a forest survey covering 186 square miles on the Sault au Cochon River, Saguenay County, Province of Quebec, was made by the Forestry Branch in co-operation with the Anglo-Canadian Pulp and Paper Mills Limited*. Special air photographs were taken in 1951 and field plots were measured during the same year. A method of forest survey was initiated which proved successful and has since been employed by the Forestry Branch for the Avalon Peninsula in the Province of Newfoundland and for areas covered during three years of work in the Yukon Territory. In 1953 a modification of the method was adopted by the Province of Nova Scotia in a forest inventory initiated under the provisions of the Canada Forestry Act.

The first step in the method is the classification or "stratification" of the forest stands by the air photo interpreter. Next comes the preparation of a provisional map showing all stands of the stratification delineated and marked with the appropriate symbols. The provisional map is taken to the field and sample plots are measured in sufficient numbers to provide adequate samples of the various strata. The plot data are computed in the office and are used to correct the original photo interpretation where necessary. The provisional map is then revised, the final map is drawn, map areas are planimetered, and timber estimates prepared.

The method is characterized by the avoidance of subjective alterations, in field or office, of the stratification of the forest stands prepared by the air photo interpreter. Accordingly, distribution of sampling units (plots) in the field is based directly upon the initial stratification. Although the random selection of sample plots in the field was not considered easily practicable in the areas surveyed, a field sampling procedure was nevertheless employed which probably goes a long way towards the prevention of personal or other bias. The method calls for the closest possible adherence to consistency in stratification.

The stratification is done directly from the air photographs and depends largely on the experienced interpreter's ability to distinguish *differences* in such values as the height of the stand, the forest type, and the canopy density. The interpreter's estimates of these values may be high or low but, if they are consistent, they do not prevent the satisfactory application of the sample plot data to the stratification. If, in extreme cases, the field work shows that certain stands of merchantable timber have been classified as marginal or unmerchantable, it will merely be necessary to secure an appropriate sample in the underclassified stands. Re-interpretation of the stratification is not done until the plot data have been computed and are available for use in a general and consistent raising or lowering of the stratification values if and where necessary. The plot data incidentally provide a most valuable means of checking the photo interpretation, with consequent improvement in the interpreter's work.

* Forest Inventories Project 10/1.

A single stratum comprises all those stands which are of the same class in respect to height, type or subtype, and canopy density. Each stratum containing merchantable timber is sampled by means of plots (sampling units), the number established depending on the variance encountered and the degree of accuracy desired in the volume estimates.

It is most advisable that no attempt be made to employ a stratification which requires the interpreter to make distinctions which cannot be secured with a suitable degree of accuracy. It may be mentioned that a project is to be undertaken in which field plots will be used to check stratifications made from photographs of two widely different scales in order to determine to what intensity a sound stratification can be made at each of the two scales, and to compare the number of plots required to provide equivalent samples of the two stratifications.

The method has not yet been fully tested in application to intensive surveys where volume estimates may be required for single stands or small groups of stands, but it seems probable that good results would be obtained although the number of plots per unit of area would be greatly increased.

Computation and tabulation of plot data from the earlier surveys, including Project 10/1, were completed by ordinary methods, but, through the courtesy of the Dominion Statistician, it has been possible to arrange for the use of punched cards and machine tabulation of results of a recent survey, with great savings in time and labour. (See punched card, Figure 2.)

PHOTO INTERPRETATION

It is most desirable that the initial photo interpretation be done as carefully as possible in order to provide a stratification which, because of its dependability, will require the minimum number of field plots.

For stratification purposes the interpreter usually determines the average height weighted by volume, the forest type or subtype, and the per cent of canopy density. A further subdivision based on the interpreter's estimate of the volume variance has been suggested in order that the stands having a greater deviation from the mean may be sampled separately. Sometimes the interpreter makes an estimate of site or age but this is not done as part of the usual stratification, which is directed towards the determination of volume. Otherwise height classes may be converted to age classes by height-age data obtained in the field for each site recognizable in the air photographs.

Diagrams are being prepared by the Forest Inventories Section to illustrate to the air photo interpreter the relation between the average height weighted by volume and the heights of the individual trees of the stand. Average height weighted by volume is found by multiplying the volume of the trees of each diameter class by the height for the diameter class and by dividing the total of all the products by the total of the volumes.

Stratification, in a survey controlled by air photography, is usually dependent on detail which can be interpreted from air photographs, ground observation alone being seldom of practical value in stratification because of the difficulty in securing comprehensive information. It may occasionally be found desirable, however, to delay the delineation of certain stratum boundaries until a better interpretation of the type or subtype can be made in the field, where identifiable species may sometimes be detected more easily in the air photograph by the aid of direct comparison with the actual stands.

The interpretation of the height and canopy density of the stand is based on differences determined by an experienced interpreter working as consistently as possible and is usually done satisfactorily before field work is commenced.

Re-interpretation is done following the office computation of the plot data, at a time when full information is available to indicate which, if any, stratum symbols ought to be changed. It is most important that alterations in symbols and stratum boundaries be made in a consistent manner in order to maintain the proper relation between the stratification and the sample. If the stratum boundaries remain intact a uniform change in the symbols is not accompanied by a change in the volume estimates but if the boundaries are altered some of the plots may no longer be retained in their original strata and may accordingly affect the average figures for the strata. Also the alteration of the boundaries may affect stratum areas, with consequent effect on the volume estimates.

The technique calls for consistency in the interpretation and thus demands the best possible approach to relative rather than absolute accuracy. Accordingly it will be found that stereograms of typical stands whose height, forest type, and canopy density have been established and agreed on by one or more experienced interpreters will be most useful as standards to maintain consistency. For the sake of consistency it is important to limit as far as possible the number of interpreters employed on a single project.

Forestry tri-camera photographs (2) taken under winter conditions, together with summer vertical photographs, were available for Project 10/1. The forestry tri-camera photographs were of an average scale of approximately 1:7,500 and the vertical photographs were of approximately 1:15,840. Recently taken vertical photographs of a scale of 1:15,840 were used for the survey of the Avalon Peninsula. For the work in the Yukon Territory the interpretation is being done from vertical photographs of scales varying from 1:15,840 to 1:35,000. The forestry tri-camera photographs, and Yukon photographs obtained in 1953 at the scale of 1:15,840, were taken specially for the Forestry Branch through the Interdepartmental Committee on Air Surveys; the other photographs had been taken for other organizations of the Federal Government.

The tree images in the oblique pictures of the forestry tri-camera photography provide the most accurate basis for the determination of tree heights, though shadows (3) in vertical photographs are also used to very good effect. Alternatively, the direct measurement of the tree image in the vertical photograph or the stereoscopic determination of parallax may be employed. Where tree images can be measured to advantage it is usual to accept the easily measurable trees as standards for stereoscopic comparison with the whole stand. Otherwise the interpreter may employ ocular estimating, particularly in small scale photographs. Estimates of the per cent of canopy density are at present largely dependent on the interpreter's experience and judgment but it is possible that large scale sampling photographs will provide the basis for a technique whereby the canopy density will be measured by an overlay containing regularly-spaced dots.

The interpreter marks the stratum boundaries and symbols on the air photograph and these are transferred to the provisional map, which consequently contains a representation of the stratification for use in the field.

In Project 10/1, which was governed largely by the working plan requirements of the Province of Quebec, the maps were prepared at the scale of 1:15,840. The final maps of the other areas were prepared at the scale of 1:63,360 (1 mile to 1 inch).

In Project 10/1 the interpretation was done in 10-foot height classes and 10 per cent canopy density classes expressed in terms of softwood alone, a procedure made possible by the availability of winter photographs for an area where softwoods were the only species of commercial importance. In addition to special classes of black spruce on poor sites, and jack pine, the stands were divided into six types on the basis of the percentage of hardwood, most of these types containing large quantities of spruce and balsam fir.

For the Avalon Peninsula the interpretation was done in 25-foot height classes, 25 per cent canopy density classes, and four types based on the percentage of hardwood. Most of these types contained large quantities of balsam fir and spruce.

The Yukon stratification is based on broader classes than those used in the other areas but as they are suitable for illustration purposes the Yukon classes are being shown below, together with the site classification which was employed.

Height

Up to 30 feet.....	1
31 feet to 50 feet.....	2
51 feet to 70 feet.....	3
71 feet to 100 feet.....	4

Type

Up to 25% Hardwood.....	S (Softwood)
26% to 75% Hardwood.....	M (Mixed)
76% to 100% Hardwood.....	H (Hardwood)

Canopy Density

Up to 30%.....	1
31% to 50%.....	2
51% to 70%.....	3
71% to 100%.....	4

Site

Well drained bottom lands.....	I
Moderate slopes and bench lands.....	II
Steep slopes.....	III
Poorly drained flats.....	IV
Hilltops and ridges.....	V

Example: 3S2—51 to 70 feet in height
 —Softwood
 —31 to 50% in density.

Minimum areas shown by the interpreter in drawing the stratum boundaries are related to the scale of the final map and vary with the importance of the timber. For instance, minimum areas for saw timber might be 20 acres, for pole wood 40 acres, and for young growth 80 acres. Where many stands are very small in area, as in a largely agricultural district, it might be found advisable to increase the volume estimates by a certain percentage in order to account for stands too small to show on the map. This percentage might be determined from the interpretation of photographs covering a typical part of the area being surveyed.

The stratification prepared by the photo interpreter is subject to errors caused by the following factors:

- (a) Inaccuracy in determining the scale of the air photograph and consequently in the determination of tree heights. The Inventories Section has undertaken a project which would provide a systematic procedure whereby all available ground control and altimeter readings would be employed to best advantage in scale determination.

- (b) Inadequate correction for fine detail not resolved in the air photograph and consequent inaccuracy in the determination of tree heights and canopy density. A research project is to be undertaken by which tables will be set up to indicate corrections to be applied under various conditions.
- (c) Lack of a good mensurational basis for the determination of canopy density. A promising approach may be forthcoming through the use of large scale sampling photographs, on which measurements of the per cent of canopy density may be made by overlays containing regularly-spaced dots.
- (d) Changes in the forest in the interval between the taking of the air photographs and the measuring of the field plots.

The above factors explain to some extent the reason for basing the technique on differences estimated by the interpreter rather than on absolute values difficult to determine. It may be mentioned that stand volume tables are being established by the Forest Inventories Section for use in preparing broad estimates of volume directly from the air photographs and these estimates will become much more dependable when the technique of interpretation has been improved sufficiently to counteract the above factors. It seems probable, however, that field sampling will always be called for in forest inventory projects of an intensive and exacting nature, except possibly for comparatively undisturbed forest of simple composition. Specific information regarding species composition, age class, and cull factors require field work and can be secured to advantage by stratification and field sampling.

FIELD SAMPLING

The chief of party will choose an identifiable point on the provisional map which may be used as the starting point of the forest survey line or as a reference point for locating the starting point. If the map lacks sufficient detail the air photographs may be employed to establish map features for use as starting points. The direction of the survey line, which will cross the stand or stands to be sampled, will usually be determined by a straight line drawn on the map from the starting point to some prominent map feature. In the lack of a suitable feature a bearing may be chosen to provide the direction of the line. It is important that the line be chosen without reference to the detail of the stands either in the photo or on the ground, thus avoiding personal bias. The fifth-acre field plots, usually 12 chains by 11 feet, will be centered longitudinally on the survey line. Possible inaccuracies in the provisional map will be guarded against by starting the first plot at a pre-determined distance well within the stand boundary except that where the position of the stand boundary is definitely known the first plot will commence at the stand boundary. Plots will be taken, usually not less than 6 chains apart, in various stands encountered on the survey line. The number to be taken in each stand or stratum will be governed, of course, by the requirements of the survey.

Widespread distribution of plots within each stratum is to be secured as far as possible. When the work is being done by contract it may be advisable to secure suitable distribution by stipulating that sample plots be placed consecutively in stands selected by reference to a table of random numbers. Nevertheless the method may be used successfully in regions where travel is extremely difficult because samples taken in easily accessible stands will have a practical application to unsampled remote stands of the same stratum.

Figure 1.

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STANDARD ERROR OF FIELD PLOTS

Stratum (Type Aggregate)—

Calculated by—

n	Plot No.	V	V ²	FORMULAE
1				$s = \pm \sqrt{\frac{\sum V^2 - \frac{(\sum V)^2}{n}}{n-1}} =$ $s_M = \pm \frac{s}{\sqrt{n}} \times t \text{ (from table below) } =$ <p>Expressing error in per cent:</p> $\pm s_M \times \frac{100}{M} =$ <p>Where</p> <p>s = standard deviation</p> <p>s_M = standard error of the mean</p> <p>V = volume of plot</p> <p>n = number of plots</p> <p>M = arithmetic mean volume</p> <p>t = a factor dependent on number of plots and the level of probability (68% or 95%) as specified for each particular survey (see table below).</p>
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
M =		ΣV =	ΣV ² =	

TABLE OF FACTOR "t"

No. of plots.....	2	3	4	5	6	7	8	9-10	11-14	15-29	30
Probability.....	68%	1.8	1.3	1.2	1.1	1.1	1.1	1.1	1.0	1.0	1.0
	95%	12.7	4.3	3.2	2.8	2.6	2.5	2.4	2.3	2.2	2.1

Procedures similar to this "selected line" technique of plot selection have been employed by industrial companies in eastern Canada for a number of years.

It is assumed that because the sample plots have not been chosen by personal selection some indication of the reliability of the volume estimates can be obtained by calculating the Standard Error of the Mean of the samples for each stratum. This is done for the individual strata and finally for all strata combined.

Often the instructions of the survey state that sufficient plots are to be taken to reduce the Standard Error of each stratum to a specified figure. When, however, the number of plots which can be taken is controlled by the time available in a comparatively short summer season the Standard Error is employed to indicate the most economical distribution of plots required to maintain an equivalent degree of accuracy throughout the strata. The Standard Error is calculated in the field by the aid of the best available multiple volume tables and is revised in the office following re-interpretation, at which time more suitable volume tables based on tree measurements made during field work are available. (See the Standard Error Calculation Sheet, Figure 1.)

STRATUM VOLUME TABLES

The estimates of timber quantities are computed from stratum volume tables, as illustrated by Table 1.

Table 1.

*Stratum Volume Table in Cords of Merchantable Volume for Softwoods in all Types
Sault Au Cochon Area, near Forestville, P.Q.*

Average Height of Softwoods	Canopy Density of Softwoods in Per Cent					
	5-15	16-25	26-35	36-45	46-55	56-65
36 - 45	4.7	10.1	13.1	14.4	16.9	19.3
46 - 55	6.7	12.7	16.2	17.8	21.7	25.2
56 - 65	8.0	14.3	18.3	20.2	25.0	29.5
66 - 75	9.3	15.8	20.1	22.4	28.0	33.7

Table 1 was derived by the aid of a three-variable solution (4) involving the following data obtained for each plot and averaged for each stratum:

- (a) Volume per acre, from the plot data. The dependent variable.
- (b) Average height weighted by volume, determined by applying the height-diameter measurements made in the field. An independent variable.
- (c) Canopy density in per cent. This is obtained by the aid of the ratio between the "interpreted" canopy density of the stratum and the average basal area per acre of the stratum. This ratio is applied to the basal area per acre of the individual plot to obtain a figure for the canopy density of the plot. An independent variable.

In the preparation of this table, plots were grouped in accordance with their incidence in the areas covered by the stratum regardless of the composition of the individual plot, which may vary considerably from the average of the stratum.

The data of stratum volume tables conform to the pattern of the interpretation and the peculiarities of the individual strata shown by the map. Accordingly these tables may differ considerably from stand volume tables measured on the ground without regard to any plan of stratification and sampling.

It will be noted that the above table applies to softwoods in all types and it may be explained that, because of the lack of separate tree volume tables for each type there appeared to be little reason for the preparation of separate stratum volume tables.

In the construction of subsequent stratum volume tables it was found that broad stratum classes were not accompanied by improved results from the application of the three-variable solution. Unless a sufficient number of points could be plotted to warrant the drawing of the curve between the points instead of from point to point it was preferable to use the unmodified field data.

The use of the Dot-Reading Planimeter or "Moosehorn" (5) in a small number of the sample plots of the Avalon and Yukon areas has provided more specific data on canopy density and has permitted a more definite determination of the ratio of canopy density to basal area per acre, with consequent improvement in the stratum volume tables.

CHECK OF INTERPRETATION

The field data provide a means of checking the accuracy and consistency of the interpretation. The methods of calculating the average height weighted by volume and the per cent of canopy density for each field plot have been indicated in the above description of stratum volume tables. These field values may now be compared with the interpreter's estimates of height and canopy density to determine the extent to which they may be high or low. Also some indication of the consistency may be secured by assuming that the mean of the field plot volumes of each stratum provides a suitable measure of the interpreter's estimates, and by calculating the Standard Deviation of these estimates.

It was found that in Project 10/1 the interpreter had given undue weight to differences of height and canopy density and had failed to maintain a sufficiently wide range for each class. As a result of the accumulation of error many stands were shown erroneously in very high or very low density classes. A similar but much less exaggerated result was found in the height classes. The forest of the project averaged about 50 feet in height and about 40 per cent in canopy density. The great bulk of the stands, which did not depart very far from these average figures, was accurately interpreted.

For the Avalon Peninsula, where the height of the trees is comparatively low, excellent results were obtained in the interpretation of height classes; fairly good results in the canopy density of trees 1 inch D.B.H. and greater; but very erratic results in the canopy density of trees 4 inches D.B.H. and greater because of the difficulty of distinguishing their crowns from those of the smaller trees.

The field plots measured in the Yukon Territory in 1952, in which the tree heights averaged about 65 feet, indicated that the photo interpreter's estimates of height were about 10 feet too low but that his estimates of canopy density were reasonably accurate. It may be mentioned that one of the research projects of the Forest Inventories Section calls for the investigation of lack of resolution of slender tree tips in small scale photographs. The Yukon plots of 1953 have indicated that the interpreter's estimates of height were remarkably good although his estimates of canopy density were affected by extensive stands of lodgepole pine in which it was difficult to distinguish the canopy density of the larger trees from that of the smaller ones.

COMPARISONS

About 20 per cent of the area of Project 10/1 had been covered by a contractor in the employ of the Anglo-Canadian Pulp and Paper Mills, Limited. For the most part the contractor had spaced his lines at regular 20-chain intervals and had recorded trees throughout an $8\frac{1}{2}$ -foot strip. Thus the sample measured was fifteen times as great as in Project 10/1, in which some 240 fifth-acre plots were measured in an area of 186 square miles.

Project 10/1 was done to forest management standards but, in order to increase the value of the maps for operating purposes, the volume per acre of each stand was shown in two of the eight map sheets. As the Project had been carried out to provide data applicable to a whole stratum instead of to individual stands, it was necessary to adopt the expedient of examining the individual stands on the photographs in relation to the above stratum volume tables as shown in Table 1. The work was facilitated by reference to the sample plots as marked on the photographs.

More conclusive results would have been obtained if the area of overlap of the two surveys had been larger. Table 2 indicates a fairly close comparison between the results of the two surveys.

Logging operations are proceeding on the area covered by Project 10/1 and a comparison of the inventory estimates and the scaler's returns will be of considerable interest.

Stand and stock tables compiled by the contractor were compared with similar tables prepared by the Forest Inventories Section from 71 fifth-acre sample plots measured for Project 10/1. The contractor's stand tables showed 256 trees per acre in the Softwood Type, and 267 trees per acre in the Mixed Type, as compared with 319 and 237 respectively in the tables of Project 10/1. The percentage of spruce to fir was considerably lower in the contractor's tables for the Softwood Type, but higher in the Mixed Type. A larger proportion of trees of 12 inches d.b.h. and greater appeared in the table of Project 10/1. Similarly, the contractor's stock tables showed 1,375 cubic feet per acre in the Softwood Type, and 1,416 cubic feet per acre in the Mixed Type, corresponding to 1,706 and 1,539 cubic feet in the tables of Project 10/1. The comparisons, based on a limited number of sample plots, are accordingly not conclusive.

A method which appears to have considerable merit in preparing estimates for individual stands, particularly when the photographic detail is good, is based on the selection of plots which are considered by a competent photo interpreter to be representative of the stand or stratum. It is possible that this method will be particularly suitable for intensive work on small areas.

A project is being conducted by the Forest Inventories Section on an area of about 140 square miles to compare the results of various sampling techniques, including the random selection of plots, the above-mentioned selected line procedure, and sampling by personal selection. Accordingly it is expected that more definite information will soon be available regarding the comparative effectiveness of various methods in application to intensive surveys.

As mentioned above, the subdivision of the strata in the method which is the subject of this Technical Note conforms largely to specified minimum areas which are decreased in size in accordance with increases in the intensity of the survey and the scale of the map. This reduction of the minimum area makes possible to some extent the exclusion from the stratum coverage of certain small extraneous portions comprising non-forested land or land supporting stands which do not properly belong to the stratum. A balance should, however, be maintained between the increased cost of the interpretation and draughting of small areas on the one hand, and on the other hand the increased cost of extra field plots required to cope with the increased amount of extraneous ground.

As Bickford (6) of the Northeastern Forest Experiment Station, Upper Darby, Pennsylvania, points out, there is more variation from one fifth-acre to another when the minimum area is five acres than when it is one acre. Incidentally, consideration might be given to the investigation, in application to Canadian conditions, of techniques of plot selection comparable to those employed in the forest survey work of the Northeastern Forest Experiment Station (7). The investigations would be directed towards the determination of:

- (a) The comparative degree of accuracy obtainable in the photo interpretation of one acre as compared to that secured when the minimum area is 10 acres or 20 acres.
- (b) The difficulty arising because plots chosen at random or systematically will sometimes fall on stratum boundaries, where they are difficult to classify.
- (c) The disadvantages which occur when the minimum areas become too small, as with one-acre stratification, to permit the drawing of stratum boundaries in accordance with the grouping of the stands as made possible by the comprehensive view afforded by the air photograph.

See the last three items (8), (9), and (10) in the list of references.

Table 2.

*Softwood Estimates in Areas where Intensive Surveys Overlap,
Sault au Cochon River, Saguenay County, P.Q.*

(Discrepancies in areas of compartments arise from differences in delineation of heights of land)

Compartment	Forest Inventories Project 10/1		Anglo-Canadian Pulp and Paper Mills, Limited	
	Acres	Cords	Acres	Cords
BX 1.....	997	13,706	899	11,065
BX 2.....	1,647	23,522	1,646	20,522
BX 3.....	1,133	16,072	1,160	15,854
BX 4.....	927	13,880	917	12,439
BX 5.....	856	11,624	877	11,849
BX 6.....	1,483	18,680	1,454	18,466
BX 7.....	1,026	13,968	1,026	12,429
BX 8.....	1,015	11,454	1,074	12,772
BX 9.....	1,497	20,016	1,493	20,136
BX 10.....	2,017	28,956	2,025	25,695
BX 11.....	1,102	14,314	1,129	14,923
BX 12.....	1,218	16,922	1,206	17,140
BX 13.....	1,858	21,392	1,834	22,847
BX 14.....	1,222	15,030	1,231	17,212
Totals for Bouleaux Watershed.....	17,998	239,536	17,971	233,349
T 10.....	1,927	26,752	2,162	25,712
T 11.....	1,670	15,362	1,806	20,295
T 13.....	1,869	27,448	1,738	23,591
T 15.....	1,024	14,176	974	13,683
Totals for part of Truchon Watershed..	6,490	83,738	6,680	83,281
Grand Totals.....	24,488	323,274	24,651	316,630

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