Methods for Study of Rate of Growth.

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The Research Division of the Forest Service of Canada has been conducting a series of surveys during the past few years to collect information relative to present growth conditions on timbered lands throughout Canada. Since growth on fully stocked virgin stands is offset by mortality, and since pure hardwood stands are of secondary consideration at the present, attention has been given entirely to cut-over and second growth stands of mixed woods and conifers. The guiding purpose of the investigation is to obtain:-

(1) Reliable information as to the average volume of pulpwood species left on cut-over lands and lands denuded by insects, fungi and fire.

(2) The periodic growth of these species for the past ten years from an analysis of the growth rings; and to predict the future growth for a like period.

(3) An estimate of the average mortality that has occurred during the past ten years, to be used in determining the net rate of growth.

With each survey, therefore, four distinct yet correlated investigations are conducted. A complete stand tally of main stand, saplings, and seedlings is required. A detailed study of increment is essential. A stand table of all trees that have died within the past decade must also be made. Since there is room for some irregularities in the increment measurements, and the mortality at best is but a conjecture, a series of permanent sample plots are finally being established. At each remeasurement period these should afford very reliable information on stand, increment, and mortality.

Although most European countries and some of the states to the south of us have at least a working knowledge of their timber resources and their rate of accretion, the figures for Canada's resources are more conjectures, while not even a conjecture is ventured for the rate of growth.

A complete survey of the forests of Finland has just been completed and reported in detail by Y. Ilvessalo in his publication "The Forests of Finland". He reports the average net annual increment over the whole country to be 25 cubic feet per acre. The best coniferous type produces 48 cubic feet per acre.

The yield of the entire state forest of Prussia is approximately 65 cubic feet per acre according to Botanical Abstracts, Entry No. 6227, July, 1925.

"The determination of increment in cut-over stands of western yellow pine", by Herman Krauch, Journal of Agricultural Research, March 15th, 1926, summarizes the results of data collected on sample plots. From large single-examination plots, stand tables of average conditions were prepared. For growth and mortality dependence was placed on small permanent sample plots.

"A study of the growth of spruce and balsam pulpwood on cut-over ridge land in New York" by Edward Richards, Journal of Forestry, January, 1925, gives the results of a stand and increment study. It purposes to give the present stand and the predicted volume ten years hence. However, details of how increment is determined are lacking.

"A study of current annual increment of red spruce and balsam fir in the western Adirondacks" H.C. Belyea, is reported in the Journal of Forestry, October, 1922. The investigation was made by growth studies covering a period of four years. They show growth rate to be 2.5 per cent to 3 per cent, or 35 to 40 cubic feet per acre.

"Growth of spruce and balsam in the Adirondacks", by A.B. Recknagel, Journal of Forestry, October, 1922, reports a study of "Current annual growth on cut-over lands. This, it was felt, is of more direct utility than figures of growth based on virgin stands". Work was conducted by means of increment borings. The growth is about 3 per cent or 0.6 cords on a stand of 19 cords per acre. No consideration is given to mortality.

"Volume increment on cut-over pulpwood lands" by E.F. McCarthy and W.M. Robertson, Journal of Forestry, October, 1921, is an article discussing the use of increment borings to determine growth, past and future.

T. Schantz Hansen made a line plot survey of cut-over lands in Minnesota to determine the stand and the condition of reproduction. Plots one square chain each at five-chain intervals were measured. He found reproduction much more satisfactory than anticipated. He made no attempt to determine rate of growth, however. His report is given as bulletin No. 203, University of Minnesota, Agricultural Experiment Station, May, 1923.

C.F. Korstian, Appalachian Forest Experiment Station, reports "Growth on cut-over and virgin western yellow pine lands in Central Idaho" in the Journal of Agricultural Research, June 14, 1924. This is the interim report of results of permanent sample plots to determine stands, increment and mortality. He shows virgin stands are at a standstill, while cut-over plots show net increment of 25 cubic feet per year.

"A study of mortality and recovery after logging", by H.C. Belyea, Journal of Forestry, November, 1924, was conducted by permanent sample plots. He concludes that mortality is surprisingly high, continuing for over ten years. The remaining stand shows little recovery, accretion being in the saplings and seedlings. Mortality is greatest in pine stands.

From the foregoing references it may be noticed that work in Finland and Prussia provides information relative to the stand, increment, mortality, and reproduction. Investigations in the United States, however, do not appear to have combined these four projects for any given area.

The forest Service of Canada has now undertaken such correlated studies, outlining which the writer read a paper entitled "Investigation of the Rate of Growth" at the Canadian Society of Forest Engineers, which was later printed in the Forestry Chronicle, February, 1927. The questions of stand tables, increment, mortality, and use of volume tables are discussed. Reference is also made to the value of permanent sample plots for future data.

The line-plot system of survey has been found well adapted to the requirements of rate-of-growth study such as the Federal Forest Service is conducting. Where the area is large and the number of type divisions small

there is no difficulty in obtaining enough sample plots in each type to furnish a stand table representative of average conditions. At the same time, since the tally of each plot is separate, it is possible to locate those plots that correspond most closely to the final stand table, and they may be established as permanent sample plots for detailed study and subsequent remeasurement. The line-plot system distributes the sampling of main stand, increment, and mortality more regularly than other methods of survey and, distributing mechanically avoids the element of personal judgment which usually tends to make selections in material better than average.

For small areas, or where it is desirable to subdivide into numerous types or sub-types providing comparatively few plots in any type, some other method than the line-plot system must be used. Under such conditions the strip system is probably the most satisfactory. Increment borings can still be taken at regular intervals on mechanically selected trees, e.g. by boring one or more trees of each species immediately following every tenth chain. However, the location of site for permanent sample plots must be left to personal judgment or to trial with a view to obtaining areas similar to the average stand table.

The general methods of procedure adopted by the Federal Forest Service follows one of two courses, depending upon the extent of the area and the time and funds available. Wherever possible, the entire area is covered by plots at ten or twenty-chain intervals. On this basis an area of thirty-six square miles is now being completed in cut-over and burned pulpwood lands of Ontario. In estimating the conditions of an entire watershed a complete cruise is impracticable. In such cases the method, then, is to select, after a preliminary examination, several representative sections of five or ten square miles each to be completely cruised.

Other variations may be found better adapted to the demands of a private corporation, whose most pressing requirement usually is a detail of the present stand existing on each sub-type. Possibly, then a complete cruise of the area by strip survey to furnish the stand table as required and a secondary survey of representative sections by line-plot system to produce figures of increment, mortality and reproduction, and to locate

sites for permanent sample plots may be found satisfactory under certain conditions. Immediate local conditions generally will dictate the procedure to be followed.

Except in determining the area to be surveyed, the Federal Forest Service methods are always very uniform. From the base line compass lines are run, usually perpendicular to the base, and lightly blazed. At ten or twenty-chain intervals a square chain plot is measured. Usually it is staked as well to ensure accuracy of the tally and to assist in relocating it should it be required for permanent sample-plot site. Since the plot is so small any inaccuracies are largely magnified in the final stand table. The interval adopted between plots should also prevail between lines, thus obtaining equal representation of the area in all directions, a feature not considered in the strip method. The interval between plots is based upon the size of the area and upon the regularity of the stand. In a pure, even-aged stand fifty plots may be found sufficient to furnish a stand table correct within $\pm$ five per cent. In other areas irregularities may demand several hundred plots to obtain equal accuracy. This can only be determined by an analysis of the data from time to time as the survey progresses. A discussion of the method of analyzing line-plot data is given in the Journal of Forestry, February, 1927, page 157. In general it has been found that at least 100 plots are required in each type.

Separate notes are recorded for each plot. For this purpose form 524 is used for the main stand. (Forms referred to by number throughout are those of the Forest Service of Canada). In the earlier surveys trees 4" D.B.H. and over were recorded here. Latterly, however, it has been deemed advisable to include saplings as well, since in predicting future stand many of them will have entered the main stand by the end of the period. Although separation into "free" and "suppressed" trees has been made in the field, no practical purpose has been served by this separation, the two classes being combined in the final stand table. Separation of dead into "standing" and "down" was made with a view to obtaining information valuable to the operator relative to salvageable material. However, these classes also have been combined in the final analysis.

Determination of mortality is perhaps the most

uncertain factor of the project. If there has been a logging operation from five to fifteen years ago it is often comparatively simple to determine the trees that have died since that date. Otherwise it becomes a matter of personal judgment after close observation of the stage of decay common to various species having been dead for a decade. To eliminate this feature of uncertainty is one purpose of permanent sample plots.

Record of seedlings as found on one square-rod sub-plot on each plot are taken on form 543. As already mentioned, the saplings are now recorded on form 524.

Since this investigation is primarily one of rate of growth the question of increment borings is highly important. Here, too, the "personal element" is liable to influence one in selecting trees for measurement, to avoid which some mechanical method of selection should be rigidly followed. The practice of this Service is to bore the first two trees of each species immediately beyond the plot. A recapitulation of the increment tally sheet from time to time as the work progresses indicates whether measurements are lacking for any diameter classes. Preference is then given to trees of the desired diameter-classes. Where growth is fairly regular, borings should be taken on at least fifteen trees of each diameter-class, species and type. Form 521 is our standard for increment-boring tallies. Incidentally the incrementometer, as described in the Forestry Chronicle of December, 1926, has been found a valuable asset in reading borings, and such an instrument even if only of wood, would be warranted for use on any rate of growth survey.

Field mapping is not essential for this project, although as in all other surveys, it is very desirable and adds but little to the cost.

Information necessary to prepare diameter-height curves for each species and type is necessary. For this purpose height and diameters of from fifty to one hundred trees in each species and type should be taken. If form-class tables are to be used in computation, the form of at least fifty trees in each species and type will be required. Measurements for form-class are D.B.H. outside and inside bark; height above breast-height; diameter outside and inside bark at half-height above breast-height. The same data may be used for diameter-height curves. An

conveniently ruled sheet may be used to record this data.

While too much care cannot be exercised in collecting field data for investigative work of this nature the work of compilation is quite as exacting and more time-consuming in its requirements. When conditions will permit it, a compiler should be attached to the field party so that the preliminary stages of summarizing may keep pace with the field data. As a matter of fact the final stand table must be prepared before it is possible to make selection of sites for permanent sample plots by means of line plots of similar stand.

Each day's tally sheets (form 524) should be posted the following day to a summary sheet separating each species in each type, and the living from the dead. If desired, further separation may be made for each crown class condition. Form 525 has been prepared for this summary. As soon as the tally for the last plot has been thus posted the summary sheets should be totalled and the average per acre obtained. This "average per acre" constitutes the stand table of numbers of trees and for convenience may be summarized on a single sheet. Form 526 is suitable.

The increment tally records (form 521) should be posted daily to separate species, type and diameter, and possibly to separate the free from the suppressed, (form 522). As already stated these sheets should be examined from time to time as the season advances to ensure sufficient measurements being taken in every diameter class.

This completes the field work as far as the line plots are concerned. Wherever possible, however, this investigation should be supplemented by a series of permanent sample plots, the only means of obtaining reliable information as to mortality and general behaviour of the stand from time to time. If possible, therefore, from two to ten one-acre standard permanent sample plots should be established in each type either at the time of the line-plot survey or before the following growing season has had an opportunity to influence the stand table. By comparing the line-plots with the average stand table (form 526 above) it is possible to select sites for the permanent sample plots that fairly closely represent conditions average for the type. For establishment of permanent

sample plots reference is made to Forest Service Research Manual.

Resuming the subject of compilation - to complete the stand table it is necessary to compute the volumes. This, in turn, calls for the correct form-class volume table and a diameter-height curve. To determine the form-class table desired, (60, 65, 70 or 75) determine the form-class for each tree by dividing the diameter at half-height above breast-height inside bark by diameter breast-height inside bark. The results, averaged, indicate the form-class for the type, and the standard table that corresponds within three units will probably be sufficiently accurate.

The diameter-height data should be averaged and graphically curved, and the table read in the regular manner. Since growth for a period of ten years usually will not be even feet in height or inches in diameter it is imperative to read the height curve to the nearest tenth of a foot. Most volume tables are prepared for height classes of ten feet; it therefore becomes necessary to interpolate values for the finer measurements.

In all research work this Service uses tables of total cubic volume, including stump and top, other tables making no provision for volume of small trees. There is also considerable variation in different localities in the height of stump and used top diameter. A ready converting factor from total cubic feet to cords is 100 cubic feet.

Having the form-class tables, height-class, diameter-class and number of trees, it is a simple matter to compute the volume per acre and thus complete the table for the stand as it is at present. It is usual to compile the volume for trees of 4-inch D.B.H. and over, assuming them to be of merchantable size.

The question of increment is the next concern. Form 522 should be totalled and averaged. For convenience of reference the averages for all diameter classes may be shown in a single table (form 523).

While interesting deductions and comparisons may be made from the data for each five-year period, particularly if some disturbing factor, as the budworm attack, has entered the field during the period, yet the

data of immediate concern to this investigation is the radial growth in the last ten years. Unless the number of borings has been very large, there is almost certain to be considerable irregularity in the growth figures from one diameter-class to another. In that event, therefore, it will be necessary to remove irregularities graphically. In many cases recourse will have to be had to the principles of "sliding averages" and "balanced curves" before a satisfactory curve can be obtained. From the curve a table may be read showing the average increment for each inch-class for the past decade. This table should show the growth in diameter instead of in radius.

Having the growth in diameter for the decade it is possible to reconstruct the present stand to represent the stand of ten years ago as follows:

(1) Reduce each diameter class by subtracting its diameter increment. In all probability the trees now in the 4-inch class were then in the 3-inch class (3.5 inches or less) and therefore must be withdrawn from the reconstructed table.

(2) Read from the height curve the correct height-classes for the reduced diameters.

(3) Compute the volumes interpolating for fractional measurements both in diameter and height.

The difference between this, the stand of ten years ago, and the present stand represents the net increment for the decade. Adding to this net increment the volume of material that has died during the decade, the gross increment for the past decade is given.

To predict the growth for the coming decade two assumptions are necessary; firstly, that the growth rate of the past ten years will remain constant for another decade, and secondly, that there will be no change in the rate of mortality. While it is rather unlikely that there will be any great change in the rate of increment unless the stand be recovering from logging operations, budworm attack, or suffers from some new attack, there is very little justification for the assumption that mortality will be constant. Lacking more reliable data, however, there is no alternative until results of permanent sample-plot studies are available.

To construct the stand of ten years hence, then

(1) Add to each inch-class the respective diameter increment. The trees of the present 3-inch class will probably become 4-inch trees (over 3.5 inches) and hence constitute part of the merchantable stand.

(2) Determine the height-classes to correspond to the new diameter-classes.

(3) Compute the volume for the new stand, interpolating both for diameter and height.

The difference between the future stand and the present stand represents the gross increment. Reducing this, the gross increment, by the amount of the assumed mortality, the predicted net increment will remain.

It is thus possible to predict what the present stand may be expected to produce in ten years; and, estimating the mortality that is likely to occur during the interval, the amount that will be available to the operator.

The data collected in reference to reproduction may be summarized to show the number of seedlings per acre, for each species and type by one foot classes. This summary might well be extended to include the saplings 1-inch, 2-inch and 3-inch. It is interesting to note the rate at which they decimate, class by class. It is also important to note the progressive change in relation between the numbers of spruce and balsam with increase in size.

On this basis, reports have been completed covering studies of rate of growth in Albert County, New Brunswick, and on the Nashwaak Drainage area, New Brunswick. A similar report is being prepared for Lake Edward district, Quebec. Data have been compiled for two other watersheds in New Brunswick. Field work has been collected this season for the Goulais River watershed in Ontario. It is hoped that reports covering these areas will be completed during the coming winter season.