Multimillion Acre Forest Inventories Based on Airphotos

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Introduction

According to Behre (1949) there were about 660,000,000 acres of commercial forest land in the United States in colonial days; and this has been reduced to 461,000,000 acres due to agricultural and urban development. Government officials have estimated that the population of the United States, which amounted to 180,000,000 people in 1960, will increase to 300,000,000 people by the year 2000. With hundreds of pulpmills and sawmills in existence will there always be sufficient forests to meet the nation's wood requirements, and how will each mill fare in relation to its competing mill neighbors?

These interlocking requirements can be met in perpetuity by (1) forest research that will lead to greater productivity of forest land; (2) intensive forest management to achieve maximum productivity; (3) a high degree of utilization of each tree felled in the forest; and (4) long-range wood-procurement planning. This paper will be limited to the last named phase.

The McSweeney-McNary Forest Research Act of May 22, 1928 charged the United States Forest Service with the responsibility of making and revising a survey of the nation's forest resources. This is accomplished by individual states to permit state and national planning. By this compilation method it is difficult to use reports by individual mills for planning purposes as the variable radius from which pulpwood is transported to the mill cuts across watershed and counties—the basic areal units in the forest survey.

While the statistics furnished by the Forest Survey fill a need in our National inventory, they do not meet all of the needs of large industrial timberland owners. The methods described in this paper constitute an inexpensive approach to couple smaller than usual airphotos to a double sampling ground technique. Using this procedure, estimates of timber volume and locations of operable stands of timber can be arrived at with desired accuracy.

Methods

The described methods have been tested on four inventories in Maine and Nova Scotia involving a total of 16,100,000 acres that were similar but not identical. The particular pulpwood requirements of a mill and the total environment within which the mill is located will introduce some changes in the general methodology. A study involving 2,600,000 acres will be used as an illustrative model.

Photography

The airphotos were taken with a six-inch focal-length camera and a minus-blue filter at an altitude of 15,840 feet above the ground; this resulted in an RF of 1:31,680. A total of 962 pictures were taken between June 1 and August 3, 1953 with the photographic period beginning three hours after sunrise whenever possible.

Photo Interpretation

For the requirements of this inventory, experienced forest photo interpreters were of the opinion that essentially the same forest types could be delineated on airphotos with an RF of 1:31,680 as with using airphotos with an RF of 1:15,840. Therefore, the following types were recognized (1) softwood—operable; (2) softwood—nonoperable; (3) mixed growth with softwood predominating—operable; (4) mixed growth with softwood predominating—nonoperable; (5) mixed growth with hardwood predominating—operable; (6) mixed growth with hardwood predominating—nonoperable; (7) hardwood—operable; (8) hardwood—nonoperable; and (9) burned areas.

An operable stand was defined as one containing at least three cords of merchantable wood; a nonoperable stand would have less. To eliminate duplication of interpretation effort principal, conjugate and wing-points were located on every photo, and the portion to be examined for forest type boundaries was delineated by connecting appropriate photo points. The type boundaries were delineated with black ink to facilitate transfer of the detail in a later step. The minimum area recognized by the photo interpreters as a

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forest stand, was about ten acres and was somewhat less for nonforested land.

MAPS

Photo index sheets showing the location of every other photo principal-point were prepared on U.S.G.S. topographic maps. Each principal point was numbered and was connected to delineate the actual flight line. These index maps were reduced to two-inches-to-the-mile in the copying process to facilitate handling and storage.

Vertical sketchmasters were employed to transfer the forest type boundary lines from the 1:31,680 airphotos to the topographic maps; these were at a scale of 1:62,500. Orientation was achieved by superimposing recognizable terrain and culture features on the airphotos over the same features on the topographic map. These were traced in black ink to insure clarity of detail in the next step. The topographic maps were then photographed and positive prints were obtained in order to make copies on the ozalid machine. The forest stands on one complete set of topographic sheets were colored with each color representing a different forest type to facilitate use of the maps.

INVENTORY TECHNIQUES

Available funds indicated that 100 crew days (two men to a crew) would be available for field work. Therefore, maximum use of this limited time was essential to obtain results at some acceptable level of accuracy for this inventory. This acceptable accuracy, based on the estimate of the volume of all species combined in each type, was ten per cent at 2:1 odds.

Representative sampling of this large irregular area was achieved by use of the general highway atlas of the State of Maine. This atlas prepared by the Maine State Highway Commission includes lines of latitude and longitude at five minute intervals. By use of these lines, blocks approximately four by six miles are established. Tippetts random numbers were used to select a cruise line on the east-half and another on the west-half as the long axis of each block is in a north-south direction.

On each randomly selected line, a strip 50 chains (one chain equals 66 feet) long and one-third chain in width, the length of each forest type was recorded and all trees that were 6.0 inches or larger at breast height were measured or estimated. The cruisers were able to work from two to four strips per day so that all blocks were sampled in the allotted time.

STATISTICAL ANALYSIS

Statistical analysis was limited to the total volume of all species within a type, in preference to an analysis by individual species. Most of the forest types in Maine are composed of a number of tree species. Within a forest type the density and volume for each species may vary considerably from one acre to the next; however, as a rule, the variation in volume for all species within a forest type will vary much less from acre to acre. With such a small sample only large errors could be expected from an analysis of volume of individual species. So such an analysis was not made. Representative sampling of regular blocks as described by Schumacher and Chapman (1954) was employed to analyze the weighted data in the two-strips-per-block. The variation within and between blocks was calculated by forest types for each county, and for the entire study area by combining counties, and finally by combining all forest types.

RESULTS

The lengthy experience of the photo interpreters had been confined to airphotos at a scale of 1:15,840. So they were concerned with the accuracy of their interpretation at this smaller scale. Each interpreter was in charge of a field party; these interpreters found that the number of type designations that they believed should be altered, based on field examination on the measured strips, was less than one per cent. This strengthened their confidence in the overall accuracy of the forest type delineation for the entire area. Table 1 is a comparison of the standard dot grid method of acreage determination and the forest type acreage as determined by percentage of forest type encountered on the measured strips; these strips constituted approximately 00.02% of the entire study area. The comparison is extremely favorable thus indicating that the random sample is truly representative.

Table 2 summarizes the statistical results for all counties combined by forest types and for all types and all counties combined. There was insufficient data in Types 7 and 8 for statistical analysis and so little in Type 2 that the error exceeds the established standard. All three of these are in the nonoperable category so that the results of the study are not invalidated. All of the other types had errors of less than 10 per cent even at 19:1 odds. For all types and all counties combined the error was only 5.4% at 19:1 odds.

Forest inventory costs for large tracts are conveniently placed on a square-mile basis. These costs are dependent on (1) size and location of the area; (2) specifications of the inventory; and (3) the purchasing power of the dollar for the year of the study. In 1953 the costs for this particular study were approximately as follows:

Item	*Cost per square mile*
photography	$2.75
field work	2.00
office computations report, etc.	1.75
Total	$6.50

TABLE I

FOREST LAND AREAS BY TYPE AND COMPARISON OF THE DOT GRID AND LINE METHOD OF OBTAINING AREA

Forest Type (Coded)	*Acres*	*Per Cent of Forest Area*	
		Dot Grid Method	*Line Method*
1	106,385	6	7
2	194,672	11	9
3	193,383	11	13
4	623,683	35	35
5 & 7	223,489	13	12
6 & 8	437,578	24	24
	1,779,190	100	100

DISCUSSION

Airphotos are normally taken between midmorning and midafternoon in order to avoid long shadows. During the summer months in Maine it is quite common to have clear skies in the early morning and extensive cumulus cloud cover by midmorning. These clouds can be avoided by taking airphotos three hours after sunrise, to insure a minimum angle of the sun of 30 degrees, this is satisfactory for latitudes encountered in Maine. Longer shadows occur at this time of day but they did not present a major obstacle to the photo interpreters.

Government agencies and private concerns generally use relatively inexperienced foresters to do both the field work and the photo interpretation. These are two major sources of error in a forest inventory. Photo interpretation is an art rather than a science, and it requires a long period of time to develop and test this art. The forest measurements in an inventory are not difficult or complex, but it is a common observation that only men of considerable experience are sensitive to the importance of careful and accurate measurements. Another aspect of experience that is important in forest inventory is familiarity with the region, with regard to field work and photo interpretation.

Forest inventory—timber cruising as it is commonly called—has gone through three stages of development and is just entering the fourth. In the first stage men walked through the forest without any measurement and made an estimate. In the second stage men estimated or measured trees on a few plots to obtain an estimate. In the third and most lengthy stage, systematically established plots or strips were located on a predetermined percentage of the land. On these plots or strips all trees were measured, volumes were estimated from volume tables, and the estimated volume of the entire tract by species within forest type was calculated. By trial-and-error comparisons of timber inventories with actual harvesting after the inventory, rules of thumb were developed for the per cent of the total area on which trees were to be measured in relation to the size of the area. This ranged from a 100 per cent inventory on woodlots of 25 acres to about 0.5% on 22,000.

The fourth stage of inventory requires a statement of the allowable error of estimate in the planning stages leading to a sufficient amount of field work that will produce satisfactory results. Field work, therefore, is directly related to the amount of variation anticipated in the volume within forest types rather than a direct relationship to total area. The U. S. Forest Service has employed this concept in the National inventory on a state

TABLE II

STATISTICAL SUMMARY FOR EACH TYPE (ALL COUNTIES COMBINED) AND FOR ALL TYPES AND COUNTIES COMBINED

Forest Type (coded)	*Error of Estimate as a Per Cent of the Mean at Various Odds*		
	2:1	*9:1*	*19:1*
1	3.2	5.3	6.6
2	14.8	24.2	29.4
3	4.9	7.9	9.5
4	4.0	6.4	7.6
5	4.1	6.6	8.0
6	4.0	6.4	7.8
7 & 8	insufficient data		
all types combined	2.8	4.5	5.4

basis. It has not been extensively used by industry but when it properly exploits this procedure, it will find that field work, in general, will be reduced and that confidence can be placed in the results of the inventory which has been conducted to meet an established standard.

For the Forest Survey in the northeastern states the U. S. Forest Service uses a double-sampling procedure where a number of plots are interpreted on airphotos, and only a small percentage of these are examined in the field. In Maine the U. S. Forest Service examined 39,817 airphoto plots of approximately one acre, and 2,146 were actually examined and measured in the field in the form of fifth acre plots. Therefore, for 17,100,000 acres of forest land in Maine only 476 acres were measured. In sharp contrast is the method presented in this paper in which one acre was measured for every 4,650 acres as compared to one acre for every 36,383 acres in the Forest Survey.

The Forest Survey does not prepare a forest type map because reliable estimates of the area of each type can be obtained from the airphoto plots. This is satisfactory for State and National planning but is unsatisfactory when information is necessary for specific tracts of land. A forest type map was prepared in this industrial study for the dual purposes of (1) preparing volume estimates by forest types for the inventory; and (2) providing a basis for the field examination of specific stands that might be harvested.

In the ten year period following World War II a number of studies were made to evaluate photo interpretation at airphoto scales, both larger and smaller than 1:15,840. It was generally found that much larger scales were necessary to increase the accuracy of photo interpretation, and that essentially the same forest type information could be obtained at 1:31,680 as was being obtained at 1:15,840. This reduced scale contract flying costs, mapping costs and photo interpretation costs. The four large-scale industrial forest inventories have established the validity of forest type delineation at a scale of 1:31,680.

Acreage determination of forest types by the dot grid method has been described by Spurr (1948) with 25 and 36 dots to the inch suggested. Because of the number of topographic sheets involved, Tryon, Hale, and Young (1956) investigated the possibilities of using as few as 4 or 9 dots to the inch. Both of these were found to be satisfactory when determining the acreage of large areas. Nine dots per inch were used in this study to insure satisfactory results. The reduction from 25 to 9 dots per inch not only decreased the cost of this phase of the work but increased the accuracy as there was less chance for error.

None of the components of this study were entirely new. The contribution of the study is the manner in which comparatively small scale airphotos, simplified mapping and interpretation techniques and modern statistical methods have been combined to provide a tremendous amount of information in a short period of time at relatively low cost.

Summary and Conclusions

Multimillion acre forest inventories requiring considerable detailed information can be accomplished in an economical fashion by intensive use of airphotos combined with modern sampling and statistical methods. Aerial photography is kept to a minimum by utilizing a scale of 1:31,680. Index maps were prepared on topographic sheets reduced to half scale, and forest type boundaries transferred to similar sheets by vertical sketch masters were reduced in a similar fashion. Representative field sampling was accomplished by measuring trees on two strips randomly selected in each block with almost the entire study area divided into blocks of equal size. The method was planned to yield errors of estimate for volume of all species combined by forest types, of not more than 10 per cent at 2:1 odds. The results for each of the operable types and for all types combined were well within this standard.

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