A TEST OF THE EFFECTIVENESS OF AIR PHOTO STRATIFICATION

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SUMMARY

A test of the efficiency of different systems of air photo stratification was conducted for an area near the Petawawa Forest Experiment Station. While stratification, particularly by cover type, height and canopy density, increased the precision of the estimated total volume and mean annual increment, this increase was not as large as had been hoped for. The main value of air photo stratification may lie in providing a forest type map for management purposes.

There is no intention to generalize from the results obtained. They are valid only for the particular forest where the test was carried out.

INTRODUCTION

The intention of the experiment to be described is to determine to what extent different systems of air photo stratification improve the estimates of present volume and past growth that are obtained from systematically established permanent sample plots.

DESCRIPTION OF THE AREA

The area of the test is located in the Middle Ottawa Section of the Great Lakes-St. Lawrence Forest Region (Rowe, 1959) at the Petawawa Forest Experiment Station in Ontario. The area is approximately equally divided between pure hardwood, pure coniferous, and mixedwood stands. The most common species are trembling aspen, white birch, white pine, red pine, and white spruce. The topography is gently undulating and predominantly covered by loamy sands of glacial origin, underlain by granites and gneisses. The forest was extensively cut over or burnt late in the 19th century and at the beginning of the present century.

As a result of these disturbances, and because of the relatively homogeneous topography, the various cover types are not clearly differentiated, and frequently merge imperceptibly one into the other. The shapes and patterns of the different strata are to some extent illustrated by Figure 1.

PROCEDURE

The ground survey

Ground plots were located in the pattern of a systematic grid, with intervals of 10 chains between plots and lines. The plots were square, one-fifth acre in area, and their corners were permanently marked with aluminum stakes. The plots were established in 1947 and 1948 and were remeasured 10 years later. A total of 353 plots were available for the test.

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Figure 1 on page 338

FIGURE 1. Air photograph showing part of the test area. The right portion of the area shown is stratified by sub-type, 10-ft. height class, and 10% canopy density class.

Figure for page 350

Photo-interpretation and stratification

Experienced photo-interpreters subdivided the area into different strata on the basis of cover type, stand height, canopy density, age and site⁸. Vertical, panchromatic fall photographs of a scale of 4 inches to 1 mile were used, except for some of the height measurements, which were taken on oblique, tri-camera photographs. The smallest area normally separated on the air photographs was approximately 5 acres. This standard, however, was not rigidly adhered to, and sometimes smaller areas, such as clearly defined swamps and openings, were mapped.

A brief description of the 11 different systems of stratification that were employed follows. The number of strata that resulted from each system is shown in brackets.

(1) Cover (8 strata)

Sub-types were identified on the basis of the main tree species. A sub-type was named by listing, in the order of their importance, all species comprising 25% or more of the stocking. For example in the oak-maple sub-type, only oak and maple comprised more than 25% of the stocking, and there was more oak than maple.

(2) Height (7 strata)

The height value used was the estimated average height of the dominants and co-dominants. Stands were stratified into 10-foot height classes.

(3) Site (5 strata)

A soil survey was carried out in 1957 and 65 minor site types were recognized. These were later grouped in five main classes (very good, good, moderate, poor, very poor) which formed the basis for the site stratification. The interpreter, who did the site classification on the air photographs, had participated in the original soil and site survey.

(4) Age (4 strata)

The area was stratified into 20-year age classes. Even for such a rough classification it is very difficult to estimate age on air photographs. The photo-interpreter had to rely mainly on his knowledge of the forest sites, of stand history and the approximate growth rates. Age estimates could then be made by a vague combination of the determined species, height and canopy density. Other features used were the characteristic crown shapes of trees of different ages and the frequently irregular appearance of overmature stands.

(5) 10% Canopy Density Classes (7 strata)

The canopy density of the forest was ocularly estimated and the forest was subdivided into 10% canopy density strata.

(6) 20% Canopy Density Classes (5 strata)

The forest was stratified by 20% canopy density classes.

(7) Height/Canopy Density (19 strata)

Strata were delineated by using the combination of 10-foot height and 20% canopy density classes.

⁸ All interpretation, with the exception of site, was done by F. W. Kippen (Research Technician, Dept. of Forestry); site was interpreted by D. S. Lacate (Research Officer, Dept. of Forestry).

(8) **Age/Site (18 strata)**

Combinations of the age and site classes described above were used.

(9) **Cover/Height (14 strata)**

Strata were formed by combining sub-type and 20-foot height class.

(10) **Cover/Density (33 strata)**

Sub-type and 10% canopy density class were used to define strata.

(11) **Cover/Height/Density (56 strata)**

Sub-type, 10-foot height class and 10% canopy density class were used.

ANALYSIS AND RESULTS

A limitation of the data

From the preceding description it has become apparent that the plots constitute a systematic sample. The analysis that follows has treated this sample as if it were a random sample. While this procedure has numerous precedents, there are many statisticians who have condemned it.

Realizing that a convincing defence of this analysis is impossible, we shall nevertheless mention that there was no evidence of periodicity, one of the main threats to systematic samples. Patterns, such as periodic trends in vegetation, are features that show up particularly well on air photographs. No only are such trends absent, but one should also note the irregular shapes of the different stands and strata, as illustrated by Figure 1.

Calculation of relative efficiency

Using the 353 plots the standard errors of the mean volume and mean annual increment were calculated for the whole sample, treating it as if it were an unrestricted, random sample. Volume was total volume in cubic feet for all trees of d.b.h. 4 inches, and greater. Following this, the standard errors of the mean were calculated from the same data for each of the ten systems of air photo stratification described above.

The following formula, given by Quenouille (1950, p. 202) was used in this calculation:

$$\text{standard error of the mean} = \sqrt{\frac{n_1 s_1^2 + n_2 s_2^2 + \dots + n_k s_k^2}{N^2}}$$

where n_1, n_2, n_k = number of plots within each stratum

s_1, s_2, s_k = standard deviations within individual strata

N = total number of plots

The standard errors thus obtained are listed in Tables 1 and 2.

Using these standard errors the relative efficiency of different systems of stratification was calculated, based on the assumption that the efficiency of each system is directly proportional to the number of plots necessary to attain a fixed degree of precision. The standard for comparison was the precision obtained by the unrestricted random sample. The calculation followed the formula shown below:

$$\frac{\text{efficiency of stratified sample}}{\text{efficiency of unrestricted sample}} = \frac{(\text{standard error of unrestricted sample})^2}{(\text{standard error of stratified sample})^2}$$

It should be noted that, for a given number of plots, the degrees of freedom are reduced as the number of strata is increased. This becomes important with small samples.

CONCLUSIONS

The increase in sampling efficiency

The values of relative efficiency of the different systems of stratification (Tables 1 and 2) were calculated on the assumption that cost depends only on the number of plots. This assumption is of course valid in part only, for the cost of the air photographs and of stratifying is ignored and also it is not true that the cost of a ground survey depends only on the number of plots. A more detailed analysis was not possible because the necessary data were unavailable.

One can, however, conclude that the saving achieved through area stratification has not been spectacular and is disappointing when judged by Spurr's opinion (Spurr, 1952, p.337) that "The proper use of good aerial photographs . . . may well reduce by from one half to two thirds the number of plots to be measured in the field for a given standard of precision."

A low efficiency of air photo stratification could of course be blamed on the quality of the photographs or the photo interpretation. While the photographs used for this project were of only fair quality, these factors are still considered unimportant, because the work was done by experienced and frequently tested interpreters, who knew the area well. Also ground observations were available for checking.

The most important factor appears to have been that on the one hand there were insufficient differences in volume and increment between the different strata, while on the other hand the differences within strata remained large. This can be explained by the stand history of cutting and fire. Had the forest been composed of large, distinctly different strata, then stratification would undoubtedly have been most efficient.

The low efficiency of area stratification should not be surprising, particularly when one considers the essentially similar conclusions of Bickford (1952) who described how a system of double sampling with air photo plots was given preference over the use of delineated strata. The reason for this was the nature of the forest which is described as "composed of a dozen or more species, with several ages represented on most acres, in a crazy pattern of small irregular stands, merging from one class to another . . ." (Bickford, 1952, p. 293). This also describes very well the forest where our test was carried out, except that some of the stands were even-aged.

What variables are best?

The problem of deciding which variables should be considered in area stratification is made difficult by the fact that their efficiency values fall within a narrow range. In this experiment one is not justified in ascribing significance to differences of a few per cent in relative efficiency. A further complication is that practically all the variables are correlated. One would for instance expect that height and age would be very closely correlated, and indeed stratification by height and by age give almost identical values for relative efficiency.

TABLE 1
STANDARD ERRORS AND RELATIVE EFFICIENCY OF DIFFERENT
STRATIFICATIONS FOR ESTIMATING MEAN VOLUME PER ACRE¹

Stratification	Standard error of the mean (cu.ft. per acre)	Relative efficiency
none	61.7	100
site	59.8	106
canopy density (10% classes)	58.5	111
canopy density (20% classes)	58.4	111
height/canopy density (10 ft. 20% classes)	58.1	113
age (20 yr. classes)	57.8	114
height (10 ft. classes)	57.3	116
cover	57.0	117
age/site	56.2	121
cover/height (20 ft. classes)	55.3	124
cover/canopy density (10% classes)	54.6	128
cover/height/canopy density (10 ft. 10% classes)	54.1	131

¹In each case the number of plots used = 353 and the mean volume = 3024 cu.ft./ac. The standard deviation is 1159 cu.ft. and the coefficient of variation is 0.383.

TABLE 2
STANDARD ERRORS AND RELATIVE EFFICIENCY OF DIFFERENT STRATIFICATIONS
FOR ESTIMATING MEAN ANNUAL INCREMENT PER ACRE¹

Stratification	Standard error of the mean (cu.ft. per acre)	Relative efficiency
none	1.89	100
age (20 yr. classes)	1.87	102
height (10 ft. classes)	1.86	103
canopy density (20% classes)	1.86	103
site	1.84	105
canopy density (10% classes)	1.84	105
cover	1.81	109
height/canopy density (10 ft. 20% classes)	1.81	109
age/site	1.77	114
cover/canopy density (10% classes)	1.77	114
cover/height (20 ft. classes)	1.67	128
cover/height/canopy density (10 ft. 10% classes)	1.67	128

¹In each case the number of plots used = 353 and the mean annual increment = 72.36 cu.ft./ac. The standard deviation is 35.51 cu.ft. and the coefficient of variation is 0.491.

The generalizations that can be made are therefore few. Cover appears to be the best variable if only one variable is used. Cover combined with height or canopy density resulted in a significant gain in efficiency for estimating both volume and increment. The stratification: cover/height/canopy density gave a further slight improvement and was the best of the systems of stratification tested.

Other uses of stratification

Before becoming too critical of the value of area stratification because of its failure to sharply reduce the number of field plots required for a given precision, one should consider its other uses.

First, the area that each forest condition occupies can be more precisely determined by planimetry of the delineated air photo strata than by calculating it from the ground plots. This is, of course, subject to the somewhat unrealistic assumption that both methods are carried out without systematic errors or mistakes. The two methods compare with each other as the use of a planimeter to the use of a dot grid. Both give objective estimates of the same mean.

Because the smallest area stratified is usually many times as large as a ground plot, air photo stratification will give a less precise, but possibly more useful answer. Air photo stratification will ignore small, extraneous patches within the strata, and if a type map is drawn it will give a simplified and therefore clearer picture of the forest. Just where this simplification begins to become desirable is a matter of opinion.

Employing air photo stratification also has the advantage that a map showing the location of different stands and strata can be produced with little additional effort. It is suggested that if a map is required for forest management it should be the goal aimed for in air photo stratification. The map is needed anyway and the reduction in the standard errors of the estimated means is an additional benefit. Furthermore the stratification that will be arrived at by using this criterion will come very close to the statistically most efficient area stratification. Management is interested in only large differences between areas; separations on the basis of minor characteristics will not affect operations. At the same time it appears that only where large differences between strata exist is area stratification statistically effective.

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