THE USE OF AERIAL PHOTOGRAPHS IN THE ESTIMATION OF SOME FOREST CHARACTERISTICS

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SELOSTE:

ILMAKUVIEN KÄYTTÖ ERÄIDEN METSÄN TUNNUSTEN ARVIOIMISESSA

HELSINKI 1968

Suomalaisen Kirjallisuuden Kirjapaino Oy Helsinki 1968

Preface

This paper is the fifth and last in the series of papers reporting the results of studies on forest survey methods, financed in part by a grant from the United States Department of Agriculture, and made at the Institute of Forest Mensuration and Management, University of Helsinki, mainly in 1961—65.

Of the authors, Nyyssönen is responsible for the overall planning and initial work in the study. Although the bulk of the field work had already been done by May 1962 when Poso started working on the project, and although he and Nyyssönen cooperated closely all the time, the progress made in the work during a three-year period should be attributed mainly to Poso, who was also engaged, rather independently, in preparing his extensive thesis. From this, Keil made a shorter report in English, and also discussed the methods applied in some sections. New data were added at this stage. After some lapse of time, which made it possible to receive a few comments from abroad, the final manuscript for this paper was written by Nyyssönen. Mr E. Mikkola, M.S., helped in the elaboration of the methods described in section 321. The authors greatly appreciate the help provided in various forms by several other persons.

Helsinki January 1968.

Contents

1. Introduction

The use of aerial photographs is often an essential part of a modern forest inventory. However, in the northern European countries Finland, Norway and Sweden, where national forest inventories have already been carried out for almost fifty years, forest survey work is in general effected on the ground. Only in certain types of inventory, such as that in which stand boundaries are delineated, have aerial photographs gained importance, and then for the main part in map-making.

The rather limited utilization of aerial photographs in the geographical area mentioned is explicable in many ways. First of all, it has been the custom to require the inclusion of many kinds of information, along with growth and treatment needs, in an inventory, and some difficulty has been experienced in perceiving whether photographs provide any assistance. With a relatively high percentage of forest land in existence almost everywhere, little travelling time is wasted in preparing an inventory, even if the information which photographs might offer in regard to forested areas is unavailable. Furthermore, the making of ground inventories is a long-established practice.

Apart from these reasons, and others, the scantiness of studies concerned with the application of aerial photographs in forest surveys may prevent their being employed to the best advantage. This does not imply that no more than slight attention has been paid to the photographs. Various tests have been made in the countries in question, training and education in photo interpretation is given in forest schools, in Sweden, for instance, there is a permanent board concerned with aerial photo techniques in forestry, etc. Nonetheless, inadequate knowledge is possessed of the opportunities offered by aerial photographs for selection of the survey procedure.

With respect to the point last-mentioned, tests relating to the application of aerial photographs were included in the research project when it became possible to us to begin a series of studies on the efficiency of forest inventory methods in 1960. These tests, and their results, are described in this paper.

Primarily, the aim of the present investigation is that of studying, for north European conditions, some overall standards of accuracy attainable in the estimation of a number of forest characteristics from aerial photographs. These characteristics are: land use class, main tree species, treatment class, dominant height, and the volume of the growing stock. It can be assumed that all of these may be estimated more or less immediately from the photographs, as opposed to such factors as site class, age, growth, etc., which may be estimated mainly through correlations. In selection of the characteristics, one important point was that they should be of significance in study of the application of stratification to tree volume inventory, which constitutes the second main part of the present study. In particular, inclusion of the estimation of treatment class, dominant height, and volume must also be viewed against this background (cf. Nyyssönen, Kilkki and Mikkola 1967, pp. 21—24). The study is further characterized by photographs taken on a generally obtainable scale and film, and the use of rather simple equipment in photo interpretation.

2. Experimental procedures

21. Characteristics tested

The characteristics tested in this study and their mode of estimation on the ground were as follows:

A. Land use classes

1. Forest land. The annual average increment under the most favourable conditions, and with a rotation of 100 years, is more than 1 cu.m./ha. incl. bark.
2. Poorly productive land. The increment of tree stands under similar premises is 1.0—0.1 cu.m./ha.
3. Waste land. The increment is less than 0.1 cu.m./ha.
4. Agricultural land.

(5. Water surfaces.)

Special interest in this investigation has been devoted to the estimation of forest land. In the main, ocular estimation was applied when making ground checks in regard to land use class.

B. Main tree species

1. Scotch pine
2. Norway spruce
3. Deciduous species (mainly birch)

The main tree species is that species of the dominant stand which is higher in volume than any other species. In a large proportion of the test material, the decision as to main species was based upon detailed tally of the trees; in the other part, the relascope count was employed.

C. Treatment classes

0. Open areas and seed-tree stands
1. Seedling and sapling stands
2. Stands in the thinning stage
3. Older stands not yet mature for felling
4. Mature stands to be regenerated
5. Shelter wood stands
6. Low-yielding stands

A more complete explanation has been given in an earlier paper (Nyyssönen, Kilkki and Mikkola 1967, p. 6).

The function of the treatment class system in Finland is the classification of stands of different sites with respect to their phase of development within the framework of the rotation applied. The classification also provides indications as to cutting and treatment needs. For these purposes, mere quantitative stand characteristics are inadequate. Cutting classes, as described by Ray (1964), have a very similar significance. The system is also related to the »area condition classification» applied in the United States (Forest survey . . . 1963).

Treatment classes are determined by means of ocular estimation. Some subjectivity is inherent in the treatment class concept, particularly as the assumption of well-marked cutting practices in the past does not hold under average forest conditions in Finland. Consequently, difficulty is frequently encountered in assigning a particular stand to a particular treatment class; there may instead be several choices available. Undoubtedly, there appreciable variation occurs from person to person, as has been found from experiments in Norway reported by Seip (1957, p. 73).

D. Dominant height

Dominant height, indicated in metres, refers to the arithmetic mean height of the 100 trees per hectare with the largest D.B.H. and forming part of the main story. Dominant height was estimated in general by means of height measurements; in part, ocular observations were made.

E. Volume of the growing stock

The volume of the growing stock (including bark, in cubic metres of solid measure) was assessed by two methods. First, in sample plots by recording diameters by species, and arriving at the plot volume by measuring the height and taper of sample trees (cf. Ilvessalo 1947). Secondly, in stands, by making use of a relascope and a height finder for derivation of the volume from stand volume tables in existence for different tree species (Nyyssönen 1954). In the former case the standard error of estimate is approximately ± 3, and in the latter ± 10 per cent of the mean volume.

22. Test areas

The information for this study was compiled from three different forest regions referred to as test areas; two of them (Toivala and Vesanto) are situated in the southern half of Finland, and the third (Meltaus) in North-Finland.

The location of the *Toivala* test area is 63° N.lat. and 27°40′ E.long. The entire area was about 1,400 ha. More than 80 per cent of these stands represented good sites of moist mineral soils. Consequently, Norway spruce was the main species, accounting for more than 70 per cent of the entire volume. The treatment class distribution was irregular, as no more than 7—8 per cent of the stands represented open areas or seedling and sapling stands, and there were relatively many stands in treatment classes 3 and 6. The average volume somewhat exceeded 100 cu.m./ha.

The objects of test comprised both whole stands and sample plots of square form. There were 60 sample stands of relatively large size; these were chosen to represent as much variation as possible in the pertinent stand characteristics. The ground information from these stands is rather reliable, as some re-checking was also effected. The stands concerned appear in Data 1.

The sample plots were established in the field in a systematic manner, with a rectangular pattern of N-S and E-W lines at intervals of 120 metres. At each line intersection, an area of 30 × 30 m., divided in nine plots each of 10 × 10 m., was measured. There were 173 intersections that fell on forest land. First, there were excluded all the intersection plots that fell on a stand border line. Secondly, 60 plots were selected from the remainder to encompass as nearly as possible the entire range of variation exhibited by the stand characteristics under examination. These plots appear in Data 2.

In addition, a number of stands from Toivala and from the other areas were estimated for the preparation of model stereograms, as will be described later on.

The location of the *Meltaus* test area is 67° N.lat. and 25°20′ E.long.; it is about 900 hectares in size. The area is characterized by its poor sites, which contain a large proportion of both poorly productive land and waste land. On more than 90 per cent of the surface, pine is the main species; the rest is dominated by spruce. With regard to treatment classes, the bulk of the stands are forests of mature age. Stands of treatment class 6, low-yielding stands, appear frequently. The average volume on forest land slightly exceeds 70 cu.m./ha.

From the Meltaus area, the subsequent test objects were examined for ground-airphoto comparisons:

Data 3: 59 stands
Data 4: 60 square plots of size 1,296 sq.m. (divided in nine sub-plots of 144 sq.m. each)

Rather small variation is present in Data 3 and 4, which are thus of more limited use than Data 1 and 2.

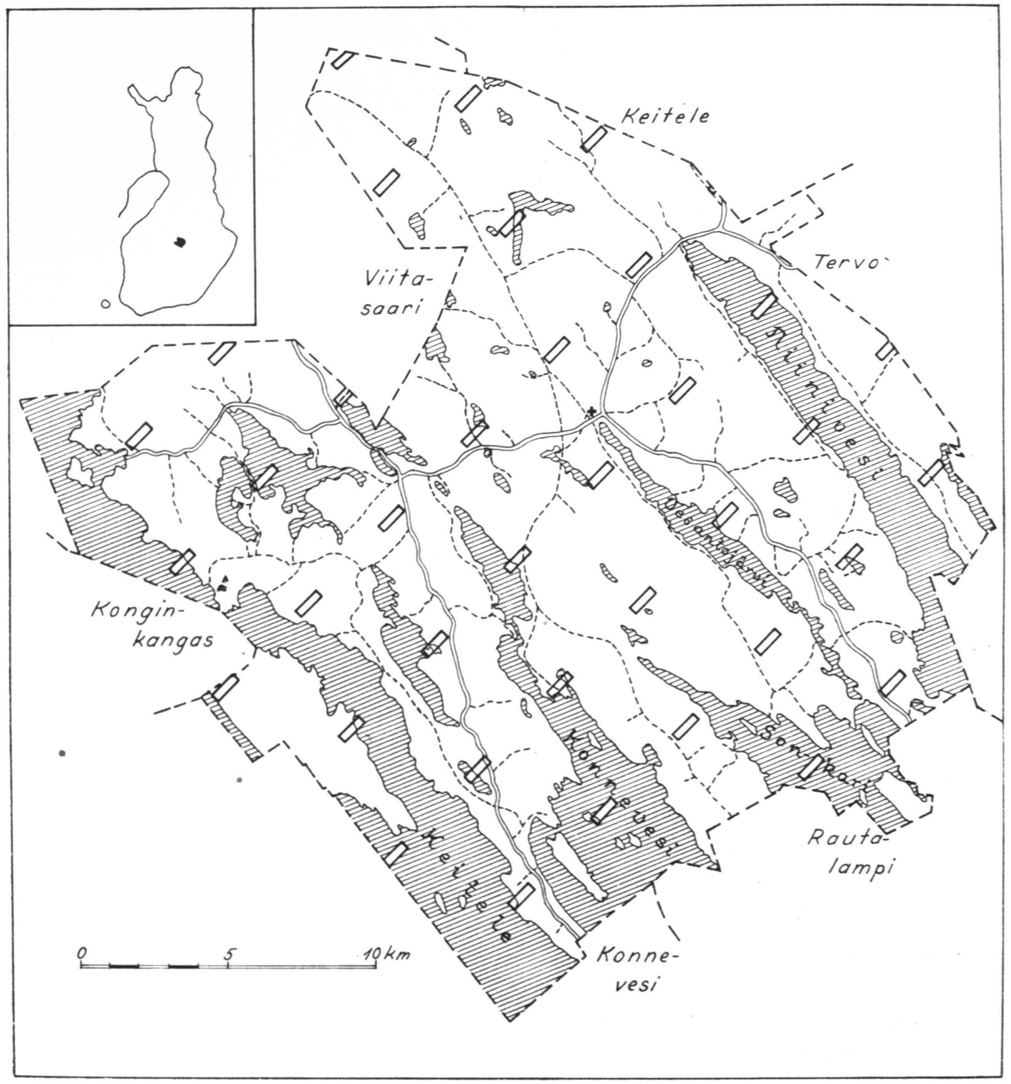

Fig. 1. Location of the survey tracts in the Vesanto test area. Water surfaces hatched. Scale 1 : 250,000.

Additional material, estimated in Meltaus, was constituted by strip sections, as obtained from irregular line cruising, and intended for the examination of land use classes 1 to 3 (cf. p. 6).

The *Vesanto* test area, providing Data 5, is located at about 63° N.lat. and 26°—27° E.long. and coincides with the entire area of Vesanto township, whose size exceeds 40,000 ha. About 80 per cent of the experimental area is forest land with more than 60 per cent of it on moist mineral soils, and about 25 per cent on dry mineral soils. Expressed as percentages of the growing stock volume, spruce amounts to 40, pine 30, and birch and alder together 30 per cent. The mean volume on forest land is 80 to 90 cu.m./ha., and the respective mean height 16 m.

Open areas and seedling or sapling stands (treatment classes 0 and 1) occupy about 17 per cent of the forest land surface, with the corresponding figure for low-yielding stands (treatment class 6) amounting to 14 per cent.

The field work in the Vesanto area was effected in accordance with »rectangular tract design» (NYYSSÖNEN and KARVONEN 1964). The method is illustrated in Fig. 1. The inventory area was systematically covered by cruising rectangle perimeters 300 × 1,000 metres in size at regular intervals of 4 km. The long sides of the rectangular tracts were placed in the SW-NE direction, with a view to reducing bias attributable to the systematic pattern of topography in the area. This pattern was clearly recognizable, running from NW to SE.

In all, 33 tracts were laid out. The combined length of their sides was approximately 70 kilometres excluding water surfaces.

The field work consisted of cruising along the sides of the tract, with a record being kept of the stand information. Variable relascope plots with a basal area factor 2 (sq.m./ha.) were measured in detail at intervals of 100 metres. Provided all four sides of a tract fell on forest land, 26 such plots would thus be measured on one tract.

In addition, to procure standwise information on the ground otherwise than with ocular estimation alone, 4 to 10 variable plots were established in each stand delineated beforehand on the aerial photographs, with the number of plots dependent on the stand dimensions. The SE tract sides, each of which was 1,000 metres in length, were used for this purpose; these sides were referred to as »base lines».

23. Photo interpretation

The scale of photography employed in all the test areas was 1 : 30,000, i.e. that generally applied in photographs taken in Finland during recent years. The film was panchromatic. As a rule, the photographs were of double-weight and semimatt type, except for one part in which glossy prints were used. The photo quality was rather good elsewhere than in Vesanto, where about one half of the photographs covering the area were foggy. Fig. 2 gives a rather good example of the general nature of the Vesanto test area.

For Toivala and Meltaus (Data 1 to 4), the time difference between photography and field work was in general one year, and that for Vesanto (Data 5) three years. Accordingly, the photographic material is more recent than the average material available for an inventory, unless new photography is used.

Fig. 2. An example of the photographs of the Vesanto test area. Scale 1 : 30,000. Aerial photo: National Board of Survey in Finland.

For interpretation, either contact copies or 1 : 20,000 enlargements were used, in conjunction with a 2-power lens-stereoscope. The necessary illumination was provided by two directional lamps or daylight.

The interpretation was aided by model stereograms as interpretation keys. The file of stereogram record cards was procured for each area by measurement in the field of a sufficient number of stands which covered the range of variation of each characteristic analysed in this investigation. The stands measured were located on the same aerial photographs, or ones similar to those used for compilation of the interpretation data.

In Toivala, 28 sample plots of a minimum size of 0.2 hectares were accurately measured for the preparation of model stereograms. In Meltaus, the file contained 20 stereograms for forest land, and 24 stereograms for poorly productive and waste land. The volume estimates were founded upon basal area and height observations. This also applies to the Vesanto test area, where the number of stereograms available was 23 for forest land, and 11 for other lands.

Throughout the interpretation phase, these model stereograms, with their respective volume and other determinations derived from field measurements, were continuously consulted by the photo-interpreters. Prior to photo-interpretation, an attempt was made to acquaint every interpreter with the nature of the forests in the respective test areas. This general knowledge of preparatory character was given by an explanation of the local conditions with respect to growing stock volumes, species relationships, treatment classes, etc. During photo interpretation, or even beforehand, the interpreters did not visit the test areas.

Since estimation by the utilization of model stereograms is far from being mechanical work, it is to be expected that the personal qualities of different interpreters greatly affect the results. For study of this point, in general 4 to 8 persons, independent of each other, interpreted the same plots on the photographs. In the tests made, they had all shown good capability of stereoscopic vision, and had also passed a basic course in photo interpretation and gained practical experience in a training camp for about 10 weeks. During this period, the interpreters had aerial photographs with them while they were engaged in a great deal of survey work on the ground for estimation of the characteristics employed in this study. Only three of the thirteen interpreters had made use of aerial photographs in their practical work for a number of several years.

As a general rule, no difficulty was experienced in locating sample stands on aerial photographs during photo-interpretation work. In the location of square plots of 900 or 1,296 sq.m., one corner of each plot was marked on an acetate overlay. The plot boundaries were then identified by means of a separate templet designed to mark out the exact area of a plot to the scale of the photographs. A templet was also used in a standwise interpretation along lines in the Vesanto area.

3. Discussion of the results

31. Different characteristics

311. Land use classes

Data from Vesanto and Meltaus provide a basis for comparison of the degree of concordance between field-cruising and photo-interpretation results in regard to the land use classes, particularly with reference to the proportion of forest land.

For the Vesanto data, on setting the total land length of the base lines of survey tracts, 26.89 km., as equal to 100, Table 1 indicates the percentage distribution into land-use classes (p. 6) arrived at. The photo-interpretation was effected by one person.

It should be mentioned that in the interpretation a very small amount of land, falling within classes 1 and 3, was classified as water. Since no water was interpreted as land, and the water surface represented 24 per cent of the total land area, the water surface was very successfully photo-interpreted.

In respect of the proportion of forest land (Class 1), the field estimate was 79.0, and the photo-interpretation result 77.6 per cent. The difference, 1.4 per cent, may be considered to be a systematic under-estimate. Provided this assumption is correct, any estimate of the percentage of forest land based on photo-interpretation within the same area of inventory is adjustable by multiplication with a correction factor. In the above case, this is 79.0/77.6 = 1.018.

For further examination of the corrections, the total line length of forest land from all base lines, 26.89 km., was systematically divided into four groups roughly equal in length. The correction could be calculated for each of these which can be regarded as separate samples. The corrections are given in Table 2 with other relevant information.

The total length of survey line classified on the basis of photographs was 151.5 km. This total includes both the sum of tract perimeters and all the additional section lines (three line segments of 1 km. length each for every tract,

Table 1. Percentage distribution of land use classes (cf. p. 6) in Vesanto.

Land use class by photo-interpretation	Land use class by field-estimates				All classes
	1	2	3	4	
	Per cent				
1	*77.0*	0.2	0.2	0.2	77.6
2	0.8	*0.3*	0.1		1.2
3	0.2		*2.7*	0.1	3.0
4	1.0			*17.2*	18.2
All classes	79.0	0.5	3.0	17.5	100

Table 2. Percentages of forest land from field estimates and from corrected photo estimates in Vesanto.

Item	Line length on the ground, km.	Correction factor K	Percentage of forest land	
			From field estimate	From corrected photo estimate (79.4 × K)
Group 1	6.99	1.026	84.8	81.5
» 2	7.42	1.023	65.2	81.2
» 3	7.61	1.002	78.8	79.6
» 4	4.87	1.025	91.6	81.4
All base lines	26.89	1.018	79.0	80.8

placed at equal distances). On these 151.5 km., the percentage of forest land was 79.4 in photo interpretation. To indicate the importance of aerial photographs for assessment of the area of forest land, this percentage was multiplied by the correction factors given in Table 2. The results are included in the same table.

A great deal of interest is attached to the percentages of forest land indicated by the four groups. Although the amount of ground work is the same for both procedures in each group, the results achieved through the agency of corrected photo estimates exhibit but little variation if compared with those derived by pure field estimates. For the former, the largest difference in percentages existing between group 1 and 3 is only 81.5—79.6 = 1.9, whereas for the latter it is 91.6 (group 4) — 65.2 (group 2) = 26.4. The importance of these findings with a view to estimation of the total volume of the growing stock will be discussed later on.

The comparison data of the Meltaus test area displayed a more even distribution of the proportions of lines for each of the land use classes 1 to 3, partly as a result of the method of placing the lines on the photographs. Of the 119 air-photo-ground comparison pairs, for five different interpreters the number of correct estimates varied from 71.4 to 76.4 per cent; the average was 73.2. As the results were so close to each other, the data for the different persons have been combined in the form of Table 3.

Table 3. Percentage distribution of land use classes in Meltaus.

Land use class by photo-interpretation	Land use class by field-estimates			All classes
	1	2	3	
	Per cent			
1	*48.1*	7.2	1.3	56.6
2	6.2	*17.3*	8.6	32.1
3	0.3	3.2	*7.8*	11.3
All classes	54.6	27.7	17.7	100

The percentage values indicate that there existed a general inclination to overestimate land productivity. For forest land, the overestimate was 2.0; for poorly productive land it rose as high as 4.4 percentage units, whereas the waste land percentage was underestimated by 6.4. The total of erroneous determinations amounted to 26.7 per cent; compared with the corresponding percentage for the Vesanto data, only 2.8 per cent, this is rather large.

In regard to the factors which may have contributed to this outcome, it is noticeable that in general the timber productivity of forest lands in northern parts of the country is lower than those in the south. Consequently, in Meltaus a narrower range of variation than that in Vesanto had to be divided in an equal number of classes. Moreover, as the percentages of classes 2 and 3 were essentially higher in Meltaus, and the photo-interpreters' experience of north Finnish conditions was less, the larger deviations in Meltaus become understandable.

It can be concluded that notwithstanding the likelihood of a systematic error in estimation of the area of forest land from aerial photographs, the bias can be eliminated to a large extent by corrections derived from ground checks, as was demonstrated with the Vesanto data. Accordingly, the use of aerial photographs conduces to reliable results, even with a comparatively minor amount of control effected on the ground. The adjustment of area estimates has been discussed more in detail by LOETSCH and HALLER (1964, pp. 333—347).

With respect to the results obtained elsewhere in determination of the area of forest land from aerial photographs, for example in the Pacific Northwest of the United States, an experiment made by MACLEAN (1963) showed that combined field and photo surveys were from 6 to 15 times more efficient in the estimation of commercial forest land area than surveys based upon field plots alone. Good results have also been reported from some earlier Swedish and Finnish experiments (e.g. TÖRNSTRÖM 1960; NYYSSÖNEN and POSO 1962).

312. Main tree species

Data 1 from the Toivala test area have been used here for indication of the success in tree species identification. The results derived by six interpreters in estimation of the main species are given in Table 4.

On the average, three quarters of all stands were interpreted correctly. This approximate proportion, varying from 63 to 85 per cent, also holds good for

	Field estimate, per cent	Photo interpretation, per cent
Pine	48.4	57.4
Spruce	42.7	34.6
Deciduous	8.9	8.0
Total	100	100

Table 4. Results arrived at by six interpreters in estimation of the main tree species for Data 1, Toivala.

Main tree species by photo-interpretation	Main tree species by field-estimates							
	Pine	Spruce	Decid-uous	Total	Pine	Spruce	Decid-uous	Total
	Number of stands							
Pine	*11*			11	*10*	5		15
Spruce	4	*34*	1	39	7	*27*	1	35
Deciduous	3	6		9	1	8		9
Total	18	40	1	*45*	18	40	1	*37*
Pine	*15*	3		18	*13*	11	1	25
Spruce	3	*35*	1	39	5	*28*		33
Deciduous		2		2		1		1
Total	18	40	1	*50*	18	40	1	*41*
Pine	*13*	3		16	*13*	7		20
Spruce	5	*34*	1	40	4	*30*	1	35
Deciduous		3		3	1	3		4
Total	18	40	1	*47*	18	40	1	*43*

The stand total equals 59. The number of correctly estimated stands is in boldface.

the other data analysed in this investigation. However, Table 4, based only on Data 1, does not reveal the fact that in general the proportion of pine-dominated stands was overestimated, mostly at the expense of spruce stands. This bias is numerically illustrated below by average figures, based upon all data.

On closer examination of the results, it seemed as though the percentage of species identified correctly was dependent upon the distribution of main species over a specific area. The more the area is dominated by a particular species, the better is the coincidence between the airphoto and field estimates. For further analysis, the data were divided into two rough volume classes, which were separately examined by χ^2 contingency tests. Inspection of the scores of the test data, both observed and expected, suggested that the interpreters were inclined to err particularly with respect to low-volume spruce-dominant stands, and to identify them, incorrectly, as pine-dominated stands.

Generally speaking, it can be concluded that the main species were determined with no more than moderate success from the aerial photographs employed in the present study. Since the material includes mixed stands of various stages, and the estimates for these have been found to be noticeably inferior to those for pure stands (cf. also Spurr 1960, p. 303) there are natural reasons for error. Furthermore, the field estimation of main species was based upon stem volume, but by reason of the nature of different species, the dominance in the crown canopy may not be the same.

»The type of photograph is of the utmost importance in the identification of species» (Spurr 1960, p. 297). Consequently, film and filter type, scale and time of photography and photo quality, in addition to the interpreter's familiarity with the local conditions, are important factors not dealt with in this study, which provides only a picture of the results achieved by the use of a certain type of photograph commonly available in Finland.

313. Treatment classes

In this study, considerable attention has been devoted to the determination of treatment classes, a problem which does not figure so largely in the literature as, say, questions concerned with tree species and growing stock volume. Practically taken all the data were used for the analysis. Interpretation was effected

Table 5. Results arrived at by six interpreters in estimation of the treatment class for Data 1, Toivala.

Treatment class by photo-interpretation	Treatment class by field-estimates											
	1	2	3	4	5	Total	1	2	3	4	5	Total
	Number of stands											
1	*8*	1	1	3	2	15	*6*	3	1		1	11
2	1	*9*	3	3		16	1	*7*	10	3		21
3		2	*8*	4		14		4	*4*	3		11
4		1	2	*2*		5			2	*3*		5
5		2	4	2	*1*	9	2	1	1	5	*2*	11
Total	9	15	18	14	3	*28*	9	15	18	14	3	*22*
1	*7*					7	*7*		2	2		11
2	1	*10*	9	6	1	27	1	*7*	4	4		16
3		5	*6*	2		13	1	7	*10*	4	1	23
4			3	*6*		9		1	2	*3*		6
5	1				*2*	3				1	*2*	3
Total	9	15	18	14	3	*31*	9	15	18	14	3	*29*
1	*8*	1				9	*7*	2	2			11
2		*3*	3	2		8	1	*6*	6	5	1	19
3		6	*9*	6	1	22		5	*5*	6		16
4		2	4	*4*	1	11		1	5	*2*	1	9
5	1	3	2	2	*1*	9	1	1		1	*1*	4
Total	9	15	18	14	3	*25*	9	15	18	14	3	*21*

The stand total equals 59. The number of correctly estimated stands is in boldface.

by 4 to 8 persons, except in regard to Data 5, which was interpreted by one person alone. Altogether, there were 31 series of observations. These were separately arranged in the form of contingency tables; a sample is provided in Table 5. Class 0, which was small in number, was generally combined with Class 1. Thus, six treatment classes were used for all the data except Data 1 (Table 5), in which Class 6 was non-existent. According to field stratification, in some cases the treatment class distribution was relatively even, although Data 3 and 4 are characterized by the small number of stands in Classes 1 and also 2, and by the large number of stands in Class 6. In a way, this was disadvantageous to the analysis.

In regard to the results, it can be stated that in only about one-third of all cases was there agreement between airphoto and field estimates. The total range of correct interpretations was from 21 to 56 per cent, or 35 percentage units. Both the range between interpreters, calculated for each data and then averaged, and the range between data were about 16 percentage units. The best average estimate was that of Data 1, Table 5.

χ^2 tests were applied to test the null hypothesis of independence between airphoto and field observations. In addition, contingency coefficients P, and their standard deviations, were calculated to find a measure of correlation. In all cases, χ^2 was clearly significant, which means that the field and airphoto estimates were correlated. Interpretation of the P-values led to the same result. Nevertheless, the results emphasize that as a rule the bulk of the stands was badly confused with respect to treatment class, as deduced from aerial photographs.

In study of the relationship between treatment class and volume estimates upon the basis of Data 5, it appeared that in the main low volume and high volume treatment classes could be separated more reliably than treatment classes of approximately equal volume. A closer correlation was apparent between treatment class and volume in airphotos than that found in ground estimation.

The present findings strongly indicate that aerial photographs do not constitute a satisfactory solution for arriving at estimates for treatment classes as viewed on the ground (cf. also MacLean 1963). One obvious reason for the low degree of concordance between airphoto and field estimates is the subjectivity inherent in the treatment class concept, especially in present-day forests (cf. p. 7). Special difficulty arises in respect of stands with more than one story in the canopy, with the main story not always discernible in the photographs.

314. Dominant height

The dominant height was estimated for different materials by different interpreters. Some examples of the two-way distribution of height observations are given in Fig. 3. In view of the large number of stands included in Data 5, only one-fourth of them were systematically selected for Fig. 3. This also applies to the volume indicated in Fig. 4, p. 21.

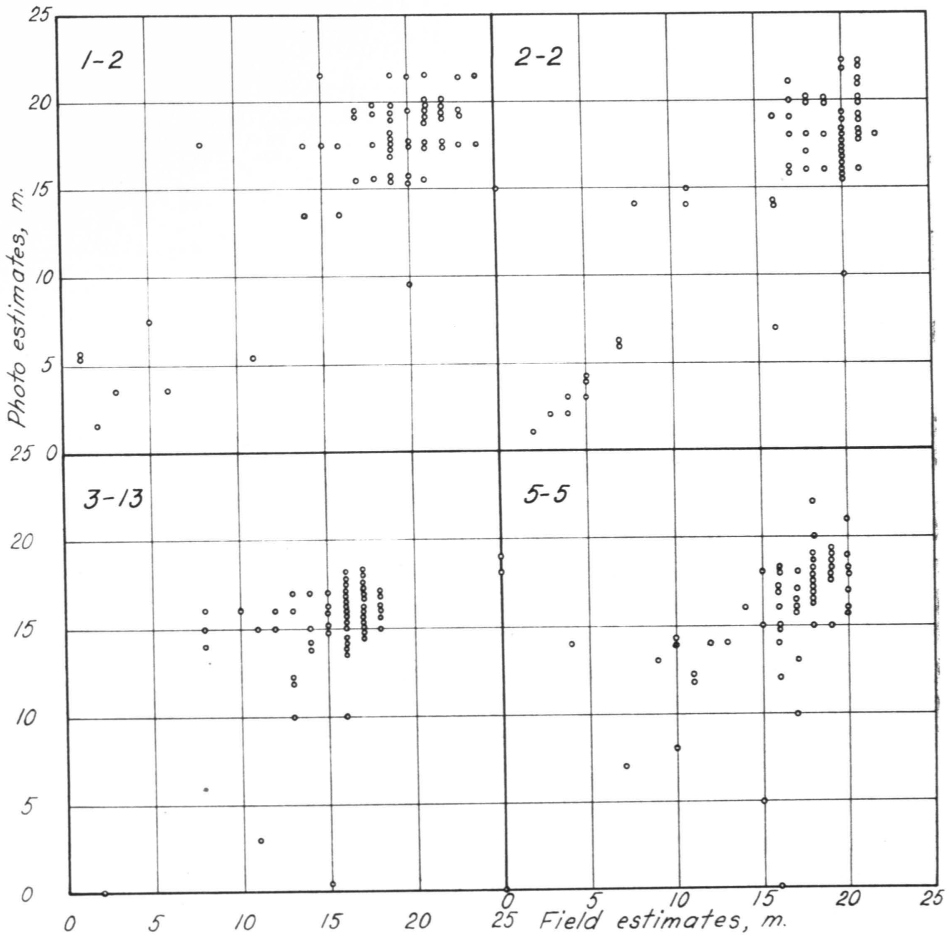

Fig. 3. Examples of the two-way distribution of dominant height observations. In ecah case the data and the interpreter have been indicated.

One rather common means of expressing results of this type would be in the form of correlation coefficients. However, it was realized that the data at hand did not fully comply with all the assumptions which underly the correlation analysis, such as that random pairs of observations should be obtained from a bivariate normal distribution. It is evident from Fig. 3 that most of the observations accumulate in the upper part of the range of height; this violates the assumption of normality. In its turn, randomness was in most cases violated by the purposive selection of stands. Nevertheless, the magnitude of the coefficient of correlation r is still of interest, since it provides a means for comparison of the

Table 6. Results in estimation of the dominant height by photo interpretation. Data 1, 2 and 4 combined; averaged over all interpreters.

Dominant height on the ground, m.		Number of comparison pairs	Dominant height by photo interpretation, m.	
class	mean		Mean bias	Standard error of difference bias included
0—15	9.0	39	+ 0.6	± 3.8
16 or more	18.8	141	— 1.8	± 3.3
Total	16.8	180	— 1.3	± 3.6

different data, classification systems, effect of corrections, and so on. It may consequently be mentioned that in the majority of instances *r* varied for Data 1, 2 and 5 between 0.7 and 0.8, but was clearly lower for Data 3 and 4 in respect of North Finland where the total variance was less; for example, in Data 3 the average *r* of four interpreters was 0.47 (cf. Fig. 3).

The standard error of difference, Table 6, was computed by taking the square root of the average of squared differences between photo and field estimates. Systematic error, or bias, is thus included here. The table shows that photo interpretation resulted in slight overestimation of the dominant height in small stands, but underestimation in high stands and in general. A bias of this nature has been found to be common. With this in mind, Pope (1962) recommended the construction of aerial photo volume tables based upon field-measured rather than photo-measured height.

The standard error of difference, including bias, varies from ± 3.3 to ± 3.8 m. If the deviations had been calculated from the regression line (i.e., excluding bias), it is likely that the standard error of estimate would be ± 2.5 to ± 3.0 m. Since some earlier results (Nyyssönen 1955, pp. 28—37; cf. also Axelson and Möller 1962, p. 413) arrived at on the measurement of height by the differential parallax method do not exceed ± 2 m. or about 10 per cent of the mean, the present results achieved by the use of stereograms are inferior. Moreover, the nature of the stand material may add to the errors. If the main tree story consists of a seedling or sapling stand below an upper canopy, the estimation of dominant height may in such cases be seriously wrong (cf. Fig. 3: Data 5, Interpreter 5).

315. Volume of the growing stock

The same data, compiled standwise or plotwise, applied for estimation of the dominant height, were also used for determination of the volume of the growing stock. The estimation followed a 10 cu.m./ha. classification. The samples illustrated in Fig. 4 illustrate the distribution of different data.

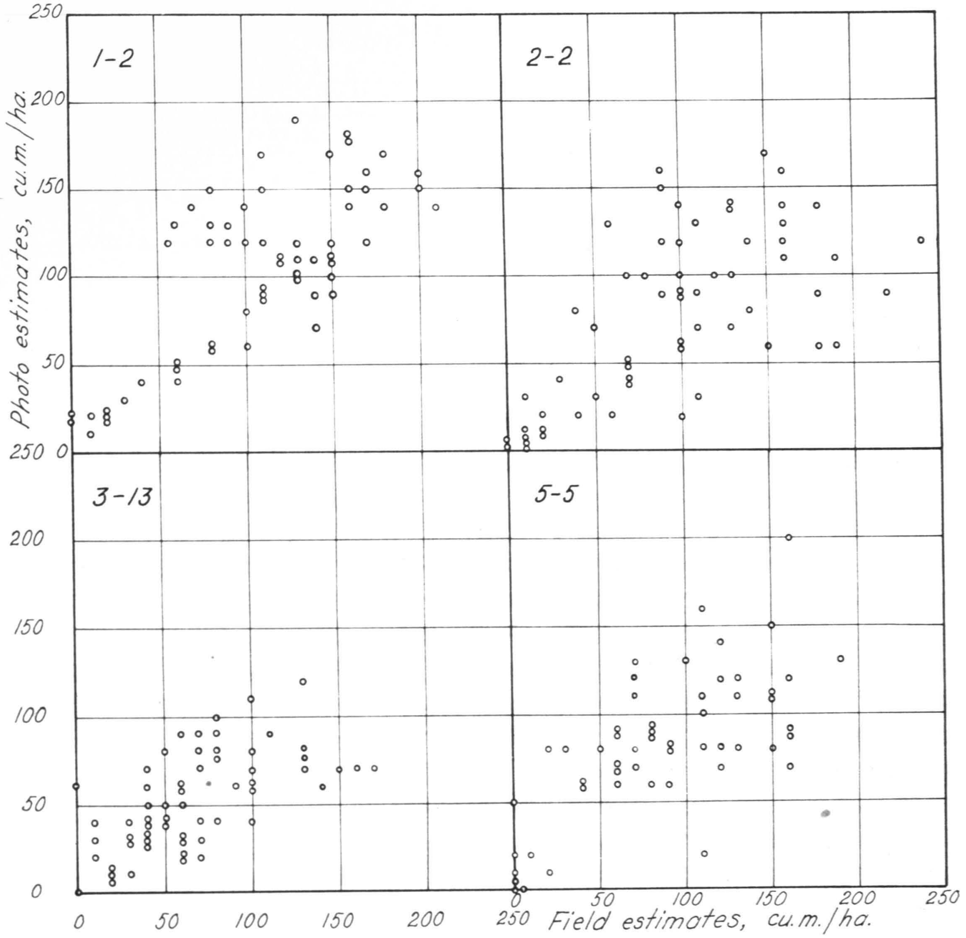

Fig. 4. Examples of the two-way distribution of stand volume observations.

The assumptions and limitations concerning normality, bivariateness, and randomness of the data are the same as those already discussed in regard to dominant height. Nevertheless, some indicative values of the coefficient of correlation *r* may also be of help in this case. For Data 1, 2 and 5, the value of *r* often varied around 0.7, and was almost the same as for the dominant height. For Data 3 and 4 from North Finland, *r* was clearly less, although in these compilations it was somewhat higher than that for the dominant height.

Computations made by classes in Table 7 indicate that there was a considerable overestimate for the low-volume and medium-volume classes, while there was a large underestimate for Class 120 cu.m./ha. and above. These systematic deviations were significant in the first case, and highly significant in the latter two cases. No more than a negligible deviation was apparent for the unclassified data.

Table 7. Results in estimation of the growing stock volume by photo interpretation. Data 1, 2 and 4 combined; averaged over all interpreters.

Volume on the ground, cu.m./ha.		Number of comparison pairs	Volume by photo interpretation, cu.m./ha.	
class	mean		Mean bias	Standard error of difference bias included
0— 20	11	19	+ 8	± 16
30—110	82	98	+ 17	± 36
120 or more	154	63	— 33	± 39
Total	100	180	— 1	± 43

The standard error of difference, including bias, both in cu.m./ha. and as percentage, is ± 43. If the percentage were based on the deviations of regressed means of ground volume from their respective airphoto volume observations, the corresponding percentage would be about ± 33 (cf. NYYSSÖNEN 1967). This result is slightly inferior to that arrived at in a survey of pure pine stands, i.e. ± 28 per cent (NYYSSÖNEN 1955); approximately the same degree of precision has been obtained elsewhere (cf. NYYSSÖNEN 1967). The difference in magnitude is rather easy to understand, by reason of some sources of disparity in the data and the methods applied: the scale of photography was larger in the earlier study, the data consisted of pine stands only, for which somewhat more reliable results are obtainable than for spruce stands, stereograms have now been used instead of volume tables and measurements from an earlier study, and so on.

A comparison between stand estimates and estimates from sample plots (maximum size 900 and 1,296 sq.m., respectively) revealed a slight tendency towards better correlation for the stand estimates although it was still not significant statistically. The reverse had been true for dominant height. Furthermore, it should be noted that the results of airphoto estimation of volume from survey line strips in the Vesanto test area, Data 5, were rather better than the other data (cf. also NYYSSÖNEN and POSO 1962). The material at hand does not suffice for a more exhaustive examination of these questions. A factor which deserves attention in this context is the influence of the forest area immediately adjacent to the survey units. It would be interesting to know how elimination of this influence would affect aerial volume estimates.

Moreover, the comparisons drawn on the basis of Data 5 indicated that volume determination was not greatly affected by photograph quality, and that the practical value of aerial photographs in volume estimation seems to decrease rather rapidly with the elapse of time.

32. The use of photo stratification for volume estimation

Only in exceptional cases is the interpretation of aerial photographs alone sufficient to provide the information needed in forest inventory work. Consequently, if some idea is to be gained of the practical importance of aerial photographs, the combined use of photo and field estimates should be discussed. Here, this question will be dealt with from the aspect of volume estimation.

The combination of estimates from photos and from field observations represents a form of double sampling; it is applicable through stratification, and for the derivation of regressed estimates. Situations arise in which both of these forms lead to results which are equally applicable, but in what follows discussion will be confined to the application of stratification.

If a forest survey is effected in the form of stratified sampling, aerial photographs are used for definition of the forest area and the classes needed. Classes may be defined on a multitude of bases, although the most effective are those most closely related to the primary quantity to be estimated, and which can be ascertained precisely and easily from photos. As was noted above, the quantity here is the volume of the growing stock; i.e. the quantity in which we are interested most frequently (cf. MOESSNER 1963). Thus, the most efficient classification is apparently that based upon volume. It is to be anticipated that the use of volume classes will effect the most substantial reduction in volume variation within classes in respect to total variation.

In the double sampling employed here, it is assumed that a large number of photo sampling units are to be classified with regard to volume. A subsample of these units is determined by proportional allocation for field examination. This method permits of class averages based on field measurements being obtained. The total volume on the area is the sum of the products of area and mean volume for each class.

When stratified sampling is applied in this way, the question of whether or not this method is superior to simple sampling is dependent upon several factors, such as the existence of differences between volume class means, the degree of correlation between volume as measured on the ground and that determined from aerial photographs, the number of classes, the extent to which total variation is reducible by stratification, and the relative cost of photo and field plots. Of course, there should be borne in mind the skill of the interpreter, the recent nature and the quality of the photographs, the size of sampling units in different cases, and so on.

Many of these factors are interrelated. In what follows, special emphasis is laid upon variances within and between classes, and on the relative cost of photo and field plots. Double sampling with stratification will be compared with unstratified simple sampling in two ways. First, the method of comparing the efficiency of different approaches will be discussed, and the data available used for comparisons. Secondly, the results achieved by alternative sampling methods in the Vesanto test area will be compared.

321. Efficiency comparisons: approach and assumptions

For estimation of the variances, the following notations are used:

m = total number of photo-interpreted sampling units
m_h = number of units in stratum h
n = total number of sampling units measured in the field
n_h = number of units in stratum h
x_{hi} = a typical unit in stratum h
$w_h = \frac{m_h}{m} = \frac{n_h}{n}$ = stratum weight
$\bar{x}_h = \frac{1}{n_h} \sum_i x_{hi}$ = sample mean in stratum h
$\bar{x} = \sum_h w_h \bar{x}_h$ = overall sample mean
$s_h^2 = \frac{1}{n_h - 1} \sum_i (x_{hi} - \bar{x}_h)^2$ = sample variance in stratum h

If it is assumed that the sampling fraction is negligible in both samples, the variance of sample mean can be estimated by the formula (cf. COCHRAN 1963, p. 330; the last formula of Corollary 2)

$$V_{\bar{x}} = \frac{V_1}{n} + \frac{V_2}{m}$$

where (by the use of proportional allocation)

$$V_1 = \sum_h w_h s_h^2$$

$$V_2 = \sum_h w_h (\bar{x}_h - \bar{x})^2 = \sum_h w_h \bar{x}_h^2 - (\Sigma w_h \bar{x}_h)^2$$

Note that V_1 and V_2 are the so-called variances within and between strata, and that the estimate for the total variance of the population is thus $V = V_1 + V_2$.

After this comes the question of cost in double sampling. We denote the cost per sampling unit in field and photo work by c_n and c_m respectively. Then the total cost (= C) is[1]

$$C = mc_m + nc_n \tag{1}$$

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[1] In fact, the initial or fixed costs for both methods have been excluded here; these costs should be taken separately into account in order to derive the grand total of costs.

The problem is that of choosing m and n so that the sampling is most effective, i.e. it gives the minimum variance

$$V_{\bar{x}} = \frac{V_1}{n} + \frac{V_2}{m} \tag{2}$$

for a given total cost C.

Solving n from (1), substituting it in (2), and differentiating with respect to m, and setting the derivative equal to zero, we find after some manipulation that m and n must satisfy the equation

$$\frac{m}{n} = \sqrt{\frac{V_2 c_n}{V_1 c_m}} \tag{3}$$

Equations (1) and (3) determine the values for m and n[1]. The minimum value for variance (2) is (cf. COCHRAN 1963, pp. 331—332)

$$V_{\bar{x}\,min} = \frac{(\sqrt{V_1 c_n} + \sqrt{V_2 c_m})^2}{C}$$

There still remains the comparison between double sampling and simple random sampling. When air-photo stratification is not employed, the method is simple random sampling, and if there are n' units in the sample, the estimate of the variance of the sample mean is

$$\frac{V}{n'} = \frac{V_1 + V_2}{n'}$$

To obtain a variance which equals $V_{\bar{x}\,min}$ of the previous case, we must have

$$n' = \frac{C\,(V_1 + V_2)}{(\sqrt{V_1 c_n} + \sqrt{V_2 c_m})^2}$$

The total cost C' for simple field sampling is then $n'c_n$, and the cost ratio (»efficiency»)

$$\frac{C'}{C} = \frac{(V_1 + V_2)\,c_n}{(\sqrt{V_1 c_n} + \sqrt{V_2 c_m})^2} = \frac{1}{\left(\sqrt{g} + \sqrt{\frac{1-g}{c_n/c_m}}\right)^2}$$

where g is the ratio between the variance within strata and the total variance, i.e.

$$g = \frac{V_1}{V_1 + V_2}$$

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[1] A start could also be made from a given variance (2), and m and n chosen so that the total cost is at its minimum. In this case, the optimum ratio between m and n is again given by (3), and equations (2) and (3) determine their values.

In Fig. 5, C'/C has been plotted as a function of g for some values of c_n/c_m.

It has been seen above that estimates of efficiency presuppose knowledge of the relative costs of measurement of a sampling unit on the ground and on the photographs. In regard to field plots, travel time to and from the plot must be included. With photo costs, there often exist major differences, dependent upon whether the cost for a flight mission is included or not. The costs of this type may be negligible whenever the photographs are used for some primary purpose other than forestry (cf. Moessner 1963, p. 13). In most cases, forest survey seems to make use of photographs already in existence.

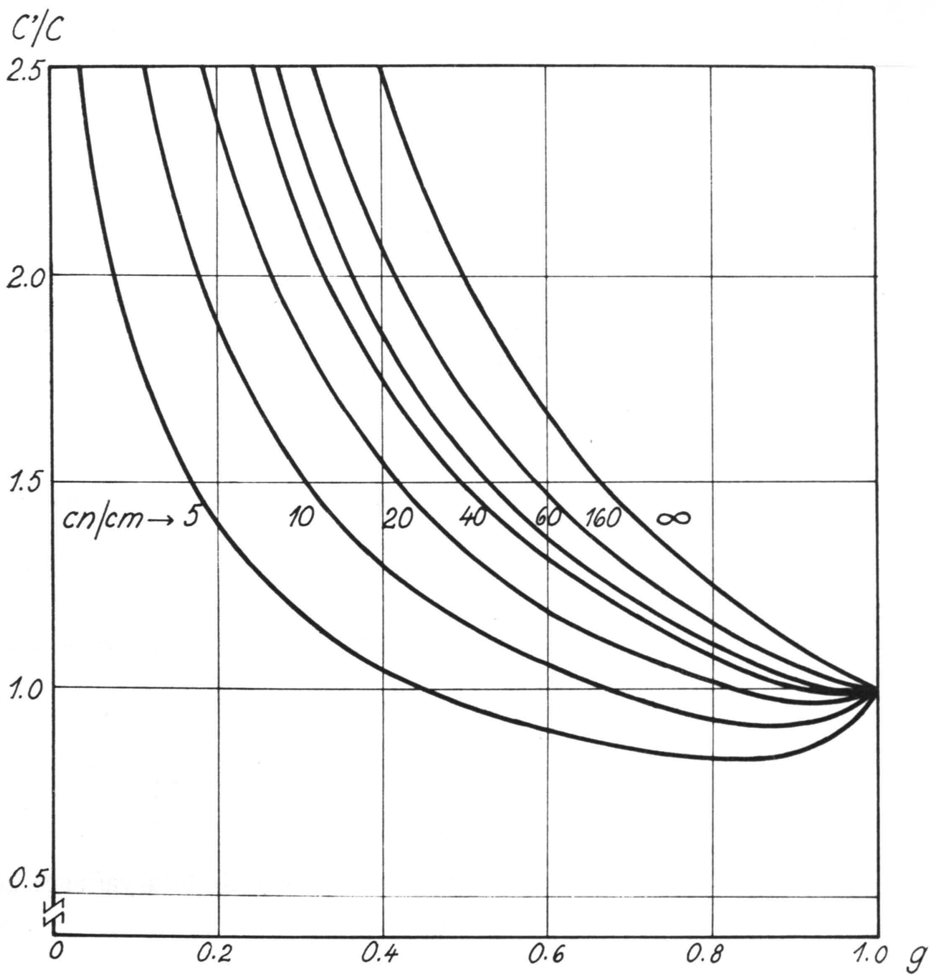

Fig. 5. The cost ratio (C'/C) between simple field sampling and combined airphoto/field sampling of the growing stock volume, as a function of the ratio (g) between variance within strata and total variance, for some values of the cost ratio (c_n/c_m) between field-measured and photo-estimated sampling units.

According to available information, the field/photo cost ratio varies considerably. If use is made of large-scale photographs, with precisely measured individual trees, the cost of the corresponding field plot may be no more than 3—4 times that of a photo plot (A. H. Aldred, of Canada, personal communication). In Sweden the ratio was found to be about 16 for plots with fixed diameters of 27—30 m. (Sandberg 1963). The attributes estimated were land use, treatment, and age classes, principal species, height, and crown closure. With these estimates as basis, the volume was obtainable from stand volume tables. In the United States, Moessner (1963, p. 13) gave a ratio of close on 100 for a fully proficient photo-interpreter. An even higher ratio, of more than 200, was mentioned by MacLean (1963, p. 514), whose photo plot costs comprised the time spent on photo preparation, field orientation, preparation of photo interpretation rules, plot interpretation, and associated office work, excluding the cost of photo coverage. The photo-interpretation of land-use, stand-size, and stocking classes was in question.

It may be concluded that on the assumption that the interpreter has had a reasonable of experience, and resorts to stereograms, as was the case in this study, a ratio of the magnitude of 40 or more can be considered fully attainable under Finnish conditions. An even larger ratio, although always desirable, raises the efficiency no more than slightly (cf. Fig. 5).

In making choice between alternative methods of forest survey, one may not be willing to introduce a method which calls for more complicated procedures, if despite these the efficiency remains at about the same level. Consequently, when looking at Fig. 5 one may require a cost ratio of about 1.5 or more before the application of photo stratification is considered. In addition, if a cost ratio of 40 between field-measured and photo-estimated sampling units is assumed, the variance within strata should not exceed about one half of the total variance if photo stratification is to be justified. It is thus of interest to attempt to discover, from the data available, the relationship of the variances »within» and »total».

Nyyssönen, Kilkki and Mikkola (1967, p. 23) published figures on the effect of stratification on the variances. In general, three strata were applied. By the use of 400 sq.m. plots in Evo and Toivala, the average variances within strata were found to be about 49 and 56 per cent, respectively, of the total variance. For the 576 sq.m. plots in Meltaus, where the total variance was smaller, the corresponding percentage was 70. To all these cases is attached the provision that the stratification has been effected correctly. Since this is unattainable in practical photo-interpretation, the real percentages are somewhat higher.

For calculation of the variances for the present data, the following three volume classes were chosen as the basis: 55 and less, 56 to 105, and 106 and more cu.m./ha. As there were only a few low-volume observations, the upper limit of Class 1 was put rather high. Moreover, some tests made with various class-limits favoured this classification. As for the results achieved in regard to the percentage ratio of within and total variance, two interpreters had the values 30 and 44 for the stands of Data 1. For 100, 250, 500, and 1000 m. strips of Data 5, the respective results were 43, 48, 54, and 43, and for BAF 2 (in sq.m./ha.) variable plots of the same data 64.

The above-mentioned percentages provide a basis for the conclusion that under some conditions photo stratification within forest land seems to improve the efficiency of volume estimation, whereas in some other cases stratification is hardly an economic proposition unless the information is wanted classwise. From the point of view of stratification, the use of stands or survey strips as sampling units seems to lead to better results than the application of small-size sample plots; however, in these cases the cost ratio between field-measured and photo-estimated sampling units may be different, and thus affect the comparison.

322. Results of the alternative procedures

The results achieved by alternative methods in the Vesanto test area still need to be compared. Pages 13—14 contain a discussion of how the percentage of forest land, arrived at from field measurements alone, accords with the estimates in which these measurements were utilized for correction of the results derived from aerial photographs. Altogether, 151.5 km. of tract lines (excluding water surfaces) and supplementary lines had been photo-interpreted, and 26.89 km. of base lines surveyed in the field. This latter distance had been systematically divided into four groups, ranging from 4.87 to 7.61 km. each.

These four groups and their total sum provided a foundation for calculation of the estimates of the mean volume of the entire land area in three different ways. For each of these three ways, the same amount of field work had been done: variable sample plots with the BAF 2 and at 100 m. spacings had been measured. The results are indicated in Table 8. A description of the methods of computation follows. In each case, the mean volume of forest land was multiplied by the proportion of forest land; the sum of proportions of all the land-use classes was 1.

Table 8. Dispersion of volume estimates for entire land area by simple field sampling and combined airphoto/field sampling.

Item	Simple field sampling	Combined airphoto/field sampling	
		Photo estimate of the percentage of forest area	Photo estimate of the percentages of forest and volume-class areas
	Mean volume of the entire land area, cu.m./ha.		
Group 1	71.8	69.0	63.6
» 2	50.9	63.4	61.0
» 3	66.6	67.2	69.1
» 4	75.6	67.2	66.2
All the groups	66.3	66.7	65.0

The left-hand column of Table 8 contains the results arrived at by simple field sampling. The mean of plot volumes in cu.m./ha. was computed for each group, and this mean volume of forest land was multiplied by its field-estimated proportion. Estimates of mean volume of the entire land area were thus derived; their dispersion simultaneously also provides that of total volume.

In two other methods, aerial photographs were employed. First, the mean volume of forest land was calculated in the manner outlined above. In computing the mean volume for the entire land area, the multiplier was the proportion of forest land, as obtained by photo-interpretation of the total of 151.5 km. line, and corrected after a field check on the base lines in the group concerned.

In the second method with aerial photographs, the proportion of forest land was a corrected photo-estimate, as explained above. In calculation of the mean volume of forest land, the proportions of three volume classes were estimated by photo-interpretation. In each group, the length of survey line classified for this purpose was about 5.6 times that of the base lines, i.e. in each group, a total of 35 to 40 km., or about one quarter of the total line length classified on photos. The percentages of volume class areas ranged as follows:

Class 1	12.5—15.8 per cent
» 2	56.4—66.9 » »
» 3	18.9—30.5 » »

The mean volumes of these classes were based on all the field plots which had been established in these photo-interpreted classes. In view of the small number of plots, the class means did not always remain within the class limits mentioned earlier, as can be seen from the following figures of the range of mean volumes in different cases:

Class 1	8.7— 55.4 cu.m./ha.
» 2	60.0— 93.9 »
» 3	95.2—127.1 »

On multiplication of these class volumes by the class proportions mentioned above, the mean volumes of forest land were arrived at. After this, the means for the entire land area were computed; they are indicated in the right-hand column of Table 8.

Although the three over-all means of all the groups differ by an insignificant amount only, the group means in simple field sampling display rather large variation. The range, that is to say the difference between the extreme values of four estimates, is 24.7 cu.m./ha., or 37 per cent of the average of these estimates.

With supplementary information derived from aerial photographs in respect of the proportion of forest land, the range of four estimates is 5.6 cu.m./ha., or

8 per cent. This clearly indicates the importance of improved results in the determination of land use classes, for the purpose of volume estimation, achieved by the use of photo interpretation (cf. p. 13—14).

Finally, the question arises whether the additional utilization of photo-interpretation in the form of volume class stratification leads to improved precision. The range is now 8.1 cu.m./ha., or 12 per cent of the overall mean, i.e. slightly but insignificantly more than without stratification within the forest. It thus appears that no gain would have resulted from the additional use of photos; this result could be anticipated from the earlier discussion on within strata and total variances in terms of BAF 2 plots. The reason for this is to be discovered in the forest conditions; inadequate differences existed between the mean volumes of the classes, which reduces the efficiency of double sampling in comparison with simple sampling. There should be noticed, too, that the distribution of field plots into photo volume strata was determined on the basis of standwise photo estimates.

As the alternatives in which airphotos were applied entail somewhat higher costs, the comparisons made here may not be considered fully conclusive from the aspect of efficiency. In any event, the results seem to indicate adequately overall relationships. They also are in accordance with those arrived at by MacLean (1963) in the Pacific Northwest of the United States; he indicated the advantages of photo interpretation in the estimation of forest land area, but found that supplementary photo classification of stand-size and stocking class was of limited utility.

4. Summary and conclusions

This paper reports on tests, made with Finnish material as basis, for study of the reliability of estimation of a number of important forest characteristics from aerial photographs. Field data were acquired in three areas, comprising whole stands, fixed and variable size sample plots, and sections of survey strips. Comparisons between field and airphoto observations provided the basis for analysis. The method of photo interpretation was ocular in nature, guided by comparison with specially prepared stereograms. In each case, the photographs, which were either 1 : 30,000 contact copies or 1 : 20,000 enlargements of panchromatic film type, were examined by 1—8 interpreters through a simple lens stereoscope.

Land use classes, with particular interest attached to forest land, could be estimated to a rather high degree of precision from airphotos. Although a likelihood of bias in fact existed in determination of the area of forest land from photographs, this deviation can be corrected by means of a relatively minor amount of ground control.

The main tree species could be determined with no more than moderate success: three quarters of all stands were interpreted correctly from the present photographs, the alternatives being pine, spruce, and deciduous. The estimates with respect to pure stands were noticeably superior to those for mixed stands. In the lower volume classes, the proportion of stands in which pine predominated was systematically overestimated at the expence of spruce.

In general, the agreement between treatment class stratification in the field and from airphotos was poor, as in only about one-third of all cases was the class the same in both instances. However, this result may to a large extent be attributable to the subjectivity inherent in the treatment class concept, and also to the large number (5 to 7) of treatment classes.

The dominant height was estimated with a relative lack of bias for small stands, but a systematic underestimation of nearly 2 m. existed for high stands. The consistency of individual height determinations from aerial photographs was not good, as the standard error of difference, bias included, was around ± 3.5 m. and excluding bias between ± 2.5 and ± 3.0 m. Errors in recognition of the main tree story in stands of more than one story seriously impaired the results.

The emphasis in this investigation was laid upon determination of the volume of growing stock, the characteristic which is generally considered to be the most important. Stand volumes in the low and medium volume classes were overestimated, against a clear systematic under-estimation for high volume stands. The standard error of difference, including bias, was ± 43 both in cu.m./ha. and as a percentage. If the percentage were based upon the deviations of regressed means of ground volume from their respective airphoto volume observations, it would amount to about ± 33. This result is only slightly inferior to those achieved earlier by the use of stand aerial volume tables and photo measurements.

Particular attention has been paid to the combined use of photo and field estimates for volume inventory. The discussion is initially concerned with the method of comparing the efficiency of double sampling with simple sampling, the former with stratification from aerial photographs. The efficiency depends predominantly upon two factors: the extent to which the stratification can reduce the variance within classes as compared with the total variance, and the cost ratio of field-measured and photo-estimated sampling units. It appeared that the variance within strata should not exceed about one half of the total variance if photo stratification is to be justified.

The variance data available provide a basis for the conclusion that under some conditions photo stratification within the forest land seems to improve the efficiency of volume estimation, whereas in some other cases the stratification is hardly an economic proposition. Alternative computations made from the data of an experimental survey indicated the likelihood that no gain was derived from the use of aerial photographs for volume class estimation, despite the great improvement in the results ascribable to photo interpretation of the area of forest land.

The underlying forest conditions provide a partial reason why double sampling with stratification into volume classes by the aid of ocularly-interpreted aerial photographs is not consistently more efficient than simple sampling. Due to the lack of well-marked cutting practices in the past, there may also be a lack of distribution into clear classes in present-day forests; this fact further makes itself felt in treatment class determination.

To increase the efficiency of double sampling, improvement is necessary in the correlation between airphoto and field estimates. Attention could be paid to several points in which the results achieved in photo interpretation might be better than those of this study. Since the recent nature of photographs exercises a positive effect, the time lapse between photography and field control should be avoided; in the present study, this lapse of time was 1 to 3 years. Another factor which needs to be mentioned is the quality of the photographs. Although the variation in this respect was not found to affect ocular volume estimates, it markedly affected the precision of height estimation. In particular, higher requirements in regard to the type of photography might have guaranteed better results in tree species identification. With respect to treatment classes, it may be worthwhile to attempt the development of a simpler system of classification, derived from the features which are more easily distinguishable from aerial photographs. Instead of the sole reliance being placed upon ocular interpretation aided by stereograms, a system which involves objective measurements of aerial photographs may prove more efficient. Moreover, the element of interpreter experience should be accorded more attention. Finally, the size and the form of sampling unit need to be considered; for instance, the photo interpretation of volume on sections of survey strips proved here rather successful, on comparison with other data.

The future will show the extent to which the overall picture obtained here will be changed by studies of the items mentioned above, and other points. Nonetheless, it must be remembered that all kinds of information generally needed in forest inventory have not been discussed; these include such essential factors as the site quality, the volume increment, and the extent of various silvicultural measures; their estimation may call for a great deal of field work. When attention is paid to these factors as well, a more complete picture of the share of aerial photographs in forest inventory will be achievable.

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SELOSTE:

ILMAKUVIEN KÄYTTÖ ERÄIDEN METSÄN TUNNUSTEN ARVIOIMISESSA

Julkaisussa selostetaan suomalaisiin aineistoihin perustuvia tutkimuksia siitä, miten luotettavasti eräät tärkeät metsän tunnukset voidaan arvioida ilmakuvilta. Maastoaineistoon, jota kerättiin kahdelta alueelta Etelä-Suomessa ja yhdeltä Pohjois-Suomessa, sisältyy sekä metsiköitä että erilaisia koealoja. Ilmakuvatulkinta suoritettiin silmävaraisesti käyttämällä apuna stereogrammoja eli mallialoja sekä tavallista linssistereoskooppia. Kuvauksessa oli käytetty pankromaattista filmiä ja mittakaavaa 1 : 30 000. Kuvat olivat joko pinnakkaiskopioita tai mittakaavassa 1 : 20 000 olevia suurennoksia puolikiiltävällä paperilla.

Maiden pääryhmät, joista erityistä huomiota kohdistettiin metsämaahan, voitiin arvioida ilmakuvilta varsin luotettavasti. Vaikka ilmakuva-arvioissa esiintyykin systemaattisen poikkeaman mahdollisuus, virhe on oikaistavissa suhteellisen vähällä maastotyöllä.

Metsikön pääpuulaji voitiin nyt käytettävissä olleilta ilmakuvilta selvittää vain keskinkertaisella menestyksellä: neljästä tapauksesta keskimäärin kolme oli oikein. Puhtaissa metsiköissä onnistuttiin selvästi paremmin kuin sekametsiköissä. Pienikuutioiset kuusivaltaiset metsiköt arvioitiin usein mäntyvaltaisiksi.

Metsikön kehitysluokka saatiin ilmakuvilta ja maastossa samaksi vain yhdessä tapauksessa kolmesta. Tähän tulokseen on vaikuttamassa kehitysluokan arvioinnin subjektiivisuus; jo maastossakin tehdyissä arvioissa esiintyy todennäköisesti melkoisia eroja eri henkilöiden kesken.

Metsikön valtapituus aliarvioitiin ilmakuvilta varttuneissa metsiköissä keskimäärin vajaalla kahdella metrillä. Tulosten hajontaa kuvaava arvion keskivirhe oli ± 2.5 . . . 3.0 m. Kaksijaksoisissa metsiköissä aiheutti vallitsevan puujakson virheellinen määritys suuria poikkeamia.

Päähuomio tässä tutkimuksessa on kohdistettu puuston kuutiomäärän arvioimiseen. Metsikön kuutiomäärä yleensä aliarvioitiin runsaspuustoisissa metsiköissä ja yliarvioitiin muissa. Arvion keskivirhe suhteellisena oli noin ± 33 %. Tämä luotettavuus on miltei yhtä hyvä kuin se, johon aiemmin on tultu ilmakuvien käyttöä varten laadittujen metsikön kuutioimistaulukoiden avulla.

Erityisenä tehtävänä oli selvittää ilmakuva- ja maastoarviointien yhteiskäyttöä metsän puuston määrän inventoinnissa. Aluksi selvitettiin teoreettisluonteisesti sitä menetelmää, jolla voidaan verrata kaksivaiheisen, ilmakuvaluokituksia soveltavan otannan ja yksinkertaisen otannan tehokkuutta. Tehokkuus on pääasiallisesti kahdesta tekijästä riippuvainen: miten suuri on ilmakuvilla erotettujen luokkien sisäinen varianssi verrattuna kokonaisvarianssiin, ja mikä on maastossa ja ilmakuvilla mitattujen näyteyksiköiden kustannusten suhde. Käytettävissä olleen aineiston perusteella osoittautui, että metsän jakaminen kuutioluokkiin ilmakuvien avulla parantaa kuutiomäärän arvioimisen tehokkuutta joissakin tapauksissa, mutta ei ole kannattavaa toisissa. Vaihtoehtoiset laskelmat, joita kokeiltiin Vesannon pitäjässä suoritetun arvioinnin nojalla, viittasivat siihen, ettei ilmakuvilla suoritetusta kuutioluokkien pinta-alan määrityksestä ollut hyötyä, mutta osoittivat toisaalta ilmakuvilta suoritetun metsämaan pinta-alan määrityksen suuren merkityksen myös kuutiomäärän arvioinnissa.

Metsien tila on osasyynä siihen, ettei ilmakuvia käyttävä kaksivaiheinen otanta ole aina tehokkaampi kuin yksinkertainen otanta. Metsien aiempi epämääräinen käsittely aiheuttaa toisistaan selvästi erottuvien luokkien puutteen, minkä seuraus on edellä nähty myös kehitysluokkien arvioinnissa.

Tulevat tutkimukset saattavat muuttaa tässä tutkimuksessa ilmakuvien merkityksestä saatua yleistä kuvaa. Voidaan viitata useihin kohtiin, joiden huomioon ottaminen voi johtaa parempiin tuloksiin ilmakuvien tulkinnassa: kuvien tuoreus, kuvien laatu, luokitustapojen kehittäminen kuvatulkintaa silmälläpitäen, mittausten käyttö, tulkitsijain kokemus, näyteyksiköiden koko ja muoto jne. Toisaalta on muistettava, ettei edellä ole käsitelty kaikkia niitä tunnuksia, joista metsän inventoinnissa yleensä tarvitaan tietoja. Tarkastelun ulkopuolella ovat olleet sellaiset tärkeät tekijät kuin kasvupaikan laatu, kuutiokasvu ja erilaisten metsänhoitotöiden tarve, joiden selvittäminen voi vaatia huomattavasti maastotyötä. Kun huomio kohdistetaan myös näihin näkökohtiin, on mahdollista saavuttaa täydellisempi kuva ilmakuvien osuudesta metsän inventoinnissa.