TECHNICAL NOTES

THE ACCURACY OF TREE HEIGHT MEASUREMENTS
ON VARIOUS QUALITIES OF AERIAL PHOTOGRAPHS¹By George W. Allison²

ABSTRACT

Various qualities of aerial photographs were tested as a mechanism for estimating tree height. These tests covered only possible alternatives in aerial photographs immediately available to the Forest Service. In all, seventeen sets of photographs, each differing in one or more respects, were used.

During the past three years the Surveys and Inventory Division of the British Columbia Forest Service has made some attempts at timber volume estimating from aerial photographs. The attempts have been in the nature of trial applications of techniques and methods which have been developed and successfully used elsewhere. Briefly, various regression methods of sampling have been tried, wherein the relationships between volumes on a limited number of ground samples and photo measures of stand height and/or crown diameter and/or crown density for the same sample spotted on aerial photographs are first established; these relationships are then supplemented with large numbers of photo measures until desirable precisions in volume estimates for particular areas are attained.

Data were not immediately available for a comprehensive test of the utility of various qualities of aerial photographs as a mechanism for estimating timber stand volumes. However, it was possible to test various qualities of aerial photographs as a mechanism for estimating one factor which influences volume, namely tree height. These tests cover only possible alternatives in aerial photographs immediately available to the Forest Service.

The Air Division, Department of Lands, made several flights over a forested area on southern Vancouver Island. Three runs were made at 11,700 feet above sea level and three at 17,700 feet above sea level. On each run, two sets of photographs were taken, one using the Eagle 5 camera with 3¼-inch focal length, the other the Eagle 5 camera with 8-inch focal length. Prints obtained from these negatives were enlarged 1.85 times. In addition, prints enlarged 2.8 times were made from the 3¼-inch 11,700 feet photography. For each combination of flying height and focal length, the negatives were developed to give low, medium, and high contrast. In addition one run from each flying height using the 8-inch cone was printed on two different hardnesses of paper. All photographs were taken using a yellow filter and panchromatic film. In all, seventeen sets of photographs, each differing in one or more respects, were produced.

Twenty trees covering the range of heights (from 53 feet to 133 feet) found in the area were carefully measured on the ground, using a topographic chain

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and abney level. Trees were chosen which were easily identifiable on the aerial photographs. Tree heights were then measured on all seventeen sets of photographs using an Abrams pocket stereoscope and parallax bar. Repeat measurements were made on two sets. In order to control the human element as much as possible, all photo measures were made by a single operator (the author).

In Table 1 are presented the results of all 19 tests. For convenience they are grouped by classes having some major difference in either focal length, flying height, or enlargement. The photo measures in Groups 1 to 4 were made on prints enlarged 1.85 times; the photo measures in Group 5 were made on prints enlarged 2.80 times.

In general, there are no significant differences between any statistics within groups. Specifically, the minor differences of repeat tests (test 2 duplicates test 1 and test 17 duplicates test 16) or in printing (paper 1 vs paper 2) or in contrast (low vs medium vs high) are statistically of no account. In Group 1 for example, a mean difference in height between ground and photo measures of from 7.40 to 10.55 feet was recorded on the different tests. As far as this sample is a competent basis for judgement, all the data could be averaged and the conclusion made that 8-inch 11,700 feet photography is associated with a resolution loss of 9.0 feet.

In general, there are no significant differences between the tests of Group 1 and 2 nor between tests of Group 3 and 4. Specifically, the difference in flying height 11,700 vs 17,700 feet above sea level seems to be of no real importance *within the limitations of the test data*.

Significant differences exist in all other group comparisons. The utility of the photographs as media for height estimation deteriorates as the group number increases. Thus, there are much greater height losses associated with the 3¼-inch photography than the 8-inch, similarly the 2.80 times enlargements cause greater losses than any other type tested. The "b" values are particularly interesting. With the poorer photography (relative to these tests) many of the values are significantly different from 1.0, indicating correlation between the differences and actual height of trees—taller trees are underestimated by greater absolute amounts than shorter trees. While the "b" values for the better photography are not significantly different from 1.0, it is interesting to note that in all the tests run no "b" value equalled or exceeded 1.0. This would indicate that lack of significance in the better photography is perhaps due to the small unimportant differences and the small sample size. It is fairly safe to conclude that there is some differential factor which makes it more difficult to measure absolute heights of taller trees on all types of photography tested (2).

The variance values ($S^2_{p\bar{r}}$) provide a measure of "unexplained" variation in measuring heights on photos after the average effect of tree height has been eliminated. They are of major interest in that they indicate, in direct proportion, the relative numbers of samples required on the different types of photography to determine absolute average heights to the same precisions. Thus, to do a particular job on test 19 photographs would require $284/60 = 4.7$ times as many samples as on test 1 photography. Variance estimates are subject to considerable chance variation, hence individual comparisons as above are some-

TABLE 1
Summary of Results—All Tests—Photo Height/Ground Height Relationships

(Mean actual height $\bar{G} = 88.75$ ft; 20 trees ranging in height from 53 to 133 feet)												
Test	Group	Flying ht (ft) above sea level	Focal length	Photo scale	Contrast	$\bar{P}$	$\bar{d}$	a	$b_{p\ g}$	$\cdot p$	r	$S^2_{p\ g}$
1	7	11,700	8.0	1 9500	medium	79.30	-9.45	-5.1	.951		.948	60
2	7	11,700	8.0	1 9500	medium	78.20	-10.55	-3.0	.915		.915	97
3	1 8	11,700	8.0	1 9500	low	79.70	-9.05	-4.4	.948		.883	151
4	8	11,700	8.0	1 9500	low	81.35	-7.40	-2.2	.941		.876	160
5	9	11,700	8.0	1 9500	high	80.20	-8.55	-1.8	.924		.872	160
6	10	17,700	8.0	1 14,320	high	74.15	-14.60	+1.8	.815		.822	190
7	2 11	17,700	8.0	1 14,320	low	79.50	-9.25	+14.4	.734		.748	251
8	11	17,700	8.0	1 14,320	low	77.40	-11.35	+15.8	.694	.02	.813	147
9	12	17,700	8.0	1 14,320	medium	79.40	-9.35	+5.4	.834		.874	128

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10	7	11,700	3.25	1	medium	68.50	-20.25	-2.8	.804	.820	186
				<u>23,700</u>							
11	3	11,700	3.25	1	low	66.20	-22.55	+6.8	.667	.02	156
				<u>23,700</u>							
12	9	11,700	3.25	1	high	67.60	-21.15	+14.0	.605	.01	186
				<u>23,700</u>							
13	10	17,700	3.25	1	high	70.15	-18.60	+6.6	.716	.06	212
				<u>35,800</u>							
14	4	17,700	3.25	1	low	67.10	-21.65	+10.3	.640	.05	283
				<u>35,800</u>							
15	12	17,700	3.25	1	medium	68.60	-20.15	-10.9	.896	.820	232
				<u>35,800</u>							
16	7	11,700	3.25	1	medium	58.50	-30.25	+1.7	.640	.02	217
				<u>15,720</u>							
17	5	11,700	3.25	1	medium	66.20	-22.55	-7.4	.829	.06	239
				<u>15,720</u>							
18	8	11,700	3.25	1	low	60.95	-27.80	-7.5	.771	.03	139
				<u>15,720</u>							
19	9	11,700	3.25	1	high	59.30	-29.45	+5.2	.610	.662	284
				<u>15,720</u>							

$\bar{P}$ Mean photo measured height

$\bar{d}$ Mean difference between actual height and photo measured height

a The P intercept on the G equals zero ordinate

b_{pg} The slope of the regression line

$\cdot p$ The probability that b differs from 1.0—only significant values are shown

r The correlation coefficient

S^2_{pg} Standard error of estimate squared—A measure of the data about the regression line.

what unreliable. However, it is apparent the poorer photography will require considerably more samples than the better photography to arrive at equally precise average height determinations.

The foregoing analysis was concerned with the proposition—how well can actual heights be estimated on various kinds of photography. One point established was that there were larger average absolute errors associated with actual heights of tall trees than with short trees. The data for test 1 and test 16 (Table 1) were replotted with ground height over photo height to arrive at correction curves which could be used in problems of application. All the values shown at the foot of Table 1 were re-calculated (since Table 1 indicated values for photo height plotted over ground height). None of these relationships was significant; that is, as far as these samples are a competent basis for judgement, flat corrections applied to photo measured heights give the best available estimate of actual height on the photographs used. All other test runs are similarly not significant and a mean correction, $\bar{d}$, (ignoring the minus sign) of Table 2 is indicated.

The apparent contradiction—variable corrections are indicated but constant corrections are the best that can be arrived at from these data—need cause no confusion. It is quite usual that small quantities of data will indicate a need for and the nature of corrections, but that large quantities of data are required to establish the absolute values of the corrections.

Table 2 shows the mean corrections to be applied to the various types of photography ($\bar{d}$) and the variance (S_c^2) of each correction. The square root of variance (S_c) or standard deviation provides a measure of precision of individual height determinations. After having adjusted all photo-measured heights for the differences ($\bar{d}$) the following interpretation may be made: two out of three individual heights will be determined within $\pm 1 S_c$, 19 out of 20 individual heights will be determined within $\pm 2 S_c$.

Significant differences have been observed in the apparent utility of several kinds of photographs as media on which to measure tree heights. The tests have been grouped and the groups arranged from "good" to "poor" relative to the kinds of photographs tested. In order of preference the groups range from Group 1 down to Group 5.

Conclusions:

1. On the basis of twenty trees, there are no significant differences within groups of photography. That is, the minor differences in repeat tests, or in printing (paper 1 vs paper 2), or in developing (low vs medium vs high contrast), are statistically of no account.
2. On the basis of twenty trees, there are no significant differences between the tests of Group 1 and 2 or between the tests of Group 3 and 4. However, the trend present in analysis of all groups is so strong that it is valid to conclude that lower flying heights will give more precise measures of tree height.
3. There is a significant difference in all other group comparisons. That is, height losses increase and individual height determinations become less precise for increased flying height and/or shorter focal length and/or greater degree of enlargement.

TABLE 2
Summary of Results—All Tests—Ground Height/Photo Height Relationships
(Mean actual height $\bar{G} = 88.75$ ft; 20 trees ranging in height from 53 to 133 feet)

Test	Group	Run	Flying ht. (ft.) above sea level	focal length	$\bar{P}$	$\bar{d}$	S ^c	Sc
1		7	11,700	8.0	79.30	-9.45	58	7.6
2		7	11,700	8.0	78.20	-10.55	97	9.8
3	1	8	11,700	8.0	79.70	-9.05	144	12.0
4		8	11,700	8.0	81.35	-7.40	153	12.4
5		9	11,700	8.0	80.20	-8.55	155	12.4
6		10	17,700	8.0	74.15	-14.60	199	14.1
7	2	11	17,700	8.0	79.50	-9.25	192	13.9
8		11	17,700	8.0	77.40	-11.35	278	16.7
9		12	17,700	8.0	79.40	-9.35	137	11.7
10		7	11,700	3.25	68.50	-20.25	198	14.1
11	3	8	11,700	3.25	66.20	-22.55	210	14.5
12		9	11,700	3.25	67.60	-21.15	264	16.3
13		10	17,700	3.25	70.15	-18.60	246	15.7
14	4	11	17,700	3.25	67.10	-21.65	341	18.5
15		12	17,700	3.25	68.60	-20.15	226	15.0
16		7	11,700	3.25	58.50	-30.25	279	16.7
17	5	7	11,700	3.25	66.20	-22.55	243	15.6
18		8	11,700	3.25	60.95	-27.80	162	12.7
19		9	11,700	3.25	59.30	-29.45	249	15.8

4. The differences between photo-measured and ground-measured heights, on the average always negative, are apparently correlated with tree height, being greater for taller trees. That is, it is more difficult to measure the absolute height of taller trees on all types of photography tested (2). In any job concerned with determination of actual height it is thus not sufficient to apply the constant adjustments indicated by the mean differences between ground-measured and photo-measured heights for each kind of photography. A variable correction dependent on tree height would have to be applied—smaller for short trees, larger for tall trees.

5. In problems concerned with absolute average height determinations an operator must establish a "local" correction curve for each kind of photography on which he works. On the average, about twice as much ground measure-photo measure control will be required on the poorer photography to establish the correction curves with equal reliability.

6. In problems concerned only with relative average height determinations, no correction curves need be established; but about twice as much work is still required on the poorer photography to determine equally precise averages. Such extra samples are required on the poorer photography to take care of the greater unexplained variation in height measures associated with this quality of photography.

References

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