TREE MEASUREMENTS ON LARGE-SCALE AERIAL PHOTOGRAPHS

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SYNOPSIS

For ground determinations of timber stand volumes, a common procedure is to first obtain estimates of stem diameters at breast height, tree heights, and number of stems per hectare. Since stem diameters can often be predicted from measurements of tree crown diameters, it follows that the three required variables may also be determined from aerial photographs. With this possibility in mind, a study was initiated at Kaingaroa Forest, New Zealand, during 1970 with the following objectives:

(1) To determine the precision of photographic measurements of crown diameters, tree heights, and stem counts in thinned stands of radiata pine (Pinus radiata *D.Don).*

(2) To establish, for prediction purposes, a sample indication of the relationship between tree crown diameters and stem diameters.

(3) To serve as a training programme for several photographic interpreters employed by the New Zealand Forest Service.

(4) To develop from ground measurements, correlations between crown diameters, tree heights and tree basal areas for radiata pine.

Photographic measurements of individual trees were compared with ground measurements of the same trees. Large-scale, high quality aerial photographs on both black-and-white and colour film were specified to partially offset limitations arising from the use of simple photo interpretation equipment and relatively unskilled personnel. This approach, of course, is quite different from that employed in purely photogrammetric mapping where highly trained operators of sophisticated plotting machines delineate contours and make measurements on photographs of a much smaller scale.

REVIEW OF PREVIOUS WORK

In the United States and Canada, it has been conclusively demonstrated that reliable air photo measurements of tree

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heights and crown diameters can be made in even-aged, coniferous forests of merchantable size (Avery, 1958, 1968; Spurr, 1960; Zsilinszky, 1966). Accurate stem counts are difficult in young, dense stands, but estimates tend to improve as stands become older or for large trees and as the number of trees per hectare decreases to 500 and less.

Assuming reliable photographic estimates of tree crown diameters, it is often possible to establish high correlations between crown diameters and stem diameters. Minor (1960) and other investigators have shown the feasibility of this approach for North American conifers.

Investigations into the use of large-scale aerial photography (1:3960) for stocking assessments — *i.e.*, stem counts — have been made at Kaingaroa Forest (Wylie, 1967, 1969). Results were promising, but because of high densities (generally 1480 stems/ha or more), the photo counts had to be adjusted by a factor of "field estimated obscurity". Without this field adjustment, photo counts amount to only 70 to 80% of ground counts. The primary purpose of such photography was to estimate radiata pine stocking in stands up to 12 years of age. As might be expected, the precision of estimates improved as stands increased in height and decreased in terms of stocking.

André (1967) reported on a study designed to permit estimates of stand basal area from air photo estimates of crown canopy closure. However, because of erratic and inconsistent ocular judgements of canopy closure by untrained photo interpreters, the technique was not deemed sufficiently precise to have practical applications. André suggested that any future investigations be conducted by trained interpreters and that objective techniques be developed for measuring canopy closure. The use of stem counts in lieu of crown canopy closure is one means of achieving this objective.

THE STUDY AREA

Compartment 901 at Kaingaroa Forest was selected as the study area because several density classes in thinned stands of radiata pine were represented, the terrain was relatively level, and sample areas were easily accessible for collecting field data. Five 400 m^2 circular sample plots were placed in each of four density classes: 540, 370, 250 and 200 stems per hectare. These four stands were approximately 12 to 13 years old on the date of photography, and the most recent thinning had been made 6 to 12 months prior to photographic flights. Trees ranged from about 130 to 300 mm dbh and 12 to 20 metres in height.

To permit the precise determination of photographic scale and render the 20 ground plots visible on aerial photographs, a network of ground control and plot markers was established by the Senior Forest Surveyor from Rotorua Conservancy. Each plot was marked at the centre with a cross constructed from a 2 metre long, 230 mm wide radiata pine board painted white. A further board was laid along the radius of each arm with its outer edge 11.3 metres from the centre.

Locations of trees were plotted on special map forms for subsequent comparisons with photographic measurements; then, for each of the 304 trees tallied,* measurements of dbh, crown diameter, and tree height were recorded. Individual tree volumes were derived from radiata pine tables developed by Duff (1954).

Heights were measured with an Abney level and verified with a theodolite. It was found difficult to establish crown diameters to a similar accuracy but they were measured by plumb lines from the crown limits to the ground along the radius of each arm of the marker boards.

AERIAL PHOTOGRAPHY

Overlapping aerial photographs with a considerable degree of stereoscopic parallax are needed for measuring the heights of objects; conversely, a minimum of parallax or relative image displacement is desired for determining crown diameters and stems per hectare. Therefore, the necessity of measuring all three stand parameters must inevitably result in some degree of compromise in developing specifications for forest inventory photography. The objective is to obtain high-resolution photographs with a sufficient degree of relative image displacement to permit reliable measurements of object heights, but not enough displacement to interfere with linear measurements and object counts. Where large-scale photography of forest areas is planned, this objective is most likely to be achieved by using aerial cameras with lens angles of 60° or less.

A special test in 1970 offered an opportunity to compare parallax measurements on sequential photography obtained with both 30° and 60° camera lenses (Avery, 1970). It was found that exposures taken with the 30° lens and a "stretched" air base (minimum forward overlap) were preferable to those made with a 60° camera angle; hence the photography for the present study was taken with a Ziess RMK-A-60/23 aerial camera having a 30° lens angle and a focal length of 614.98 mm (24 in.).

Photographic coverage of the study area at a scale of 1:3000 was obtained by N.Z. Aerial Mapping Ltd on 18 October 1970. Exposures on both black-and-white and colour films were made at 10.30 and 10.40 a.m. N.Z. standard time, resulting in a sun elevation angle of 54°. Forward overlap for the exposures was held to a minimum (averaging 50 to 55%) to provide improved parallax characteristics.

PHOTOGRAPHIC INTERPRETATION

Six individuals, three from the Forest Research Institute and three from Rotorua Conservancy, served as photographic interpreters. Mirror stereoscopes having 4× to 8× magnifica-

*One tree in plot 4 was damaged by wind and broken off prior to photography. It has therefore been disregarded in recording height and diameter but not in the tree count.

tion and equipped with parallax bars (stereometers) were used for photo interpretation of both black-and-white and colour film transparencies; these instruments provided parallax readings to 0.01 mm.

Each interpreter made the following measurements, first on the panchromatic film transparencies and later on the colour film transparencies:

(1) Tree counts for each of the twenty 400 m^2 plots.
(2) Average parallax difference for all trees on each plot (total: 303 trees). Parallax readings were subsequently converted to tree heights.
(3) Average tree crown diameter for each tree. Crown measurements were made with a simple transparent "crown wedge"; two readings at right-angles were taken for each tree along the same lines as the ground measurement.

RESULTS

Tree Counts

Summaries of stem counts for each plot are shown in Table 1 (black-and-white photography) and Table 2 (colour photo-

TABLE 1: AIR PHOTO STEM COUNTS FOR TWENTY 400 m^2 PLOTS (black and white)

Plot No.	*Field Count*	*Stem Counts by Six Photo Interpreters* *A*	*B*	*C*	*D*	*E*	*F*
1	22	19	21	20	22	23	21
2	21	20	19	20	20	21	20
3	19	17	15	19	19	16	18
4	24	25	22	24	25	23	22
5	19	18	18	19	19	19	17
6	10	10	10	10	10	10	10
7	10	10	12	11	11	10	10
8	10	10	10	10	10	10	10
9	9	10	10	9	10	10	9
10	10	10	11	10	10	11	10
11	15	14	13	14	14	12	14
12	16	16	18	16	16	18	15
13	11	12	12	11	11	14	11
14	14	15	17	15	15	15	13
15	11	13	13	11	11	12	11
16	16	17	15	16	16	15	15
17	15	15	13	15	15	14	15
18	14	16	16	15	16	15	15
19	19	19	18	19	20	20	17
20	19	19	20	19	19	21	20
Totals	304	305	303	303	309	309	293
Diff. from field		+1	—1	—1	+5	+5	—11
No. of correct counts		8	2	14	12	5	8
No. of overcounts		7	9	3	6	10	2
No. of undercounts		5	9	3	2	5	10

TABLE 2: AIR PHOTO STEM COUNT FOR TWENTY 400 m^2 PLOTS (colour)

Plot No.	*Field Count*	*Stem Counts by Six Photo Interpreters* A	*B*	*C*	*D*	*E*	*F*
1	22	23	21	22	22	22	22
2	21	21	22	21	21	21	21
3	19	24	19	18	19	19	19
4	24	25	24	24	20	24	24
5	19	19	20	18	19	19	19
6	10	10	9	10	10	10	10
7	10	10	11	11	10	10	10
8	10	10	10	10	10	10	10
9	9	8	9	9	9	9	9
10	10	11	10	10	10	10	10
11	15	15	11	14	15	15	15
12	16	17	17	16	16	16	16
13	11	14	11	12	11	11	11
14	14	16	16	16	14	14	14
15	11	12	14	12	11	11	11
16	16	15	15	16	16	16	16
17	15	15	12	15	15	15	15
18	14	15	13	15	14	14	14
19	19	19	18	18	19	19	19
20	19	19	21	19	19	19	19
Totals	304	318	303	306	300	304	304
Diff. from field		+14	—1	+2	—4	0	0
No. of correct counts		10	6	11	19	20	20
No. of overcounts		8	7	5	0	0	0
No. of undercounts		2	7	4	4	0	0

graphy). Three of the interpreters were within two trees of the correct total on the panchromatic photography, while four interpreters achieved this level of accuracy on the colour photography. More important, the number of correct counts on individual plots improved considerably with the use of colour photography. As a general rule, individual plot counts that are within ± 1 tree of the correct value are regarded as acceptable for this type of inventory system.

Tree Heights and Crown Diameters

These results for six interpreters are summarized in Table 3. For such photographic measurements to be readily usable, heights should be within ± 1.5 m of the correct values, and crown diameters within ± 0.6 m. Experiments conducted on the photographs at a later date showed that the measurements were generally fairly accurate and could, for the purposes of this trial, be relied on to give a fairly good result. As these follow-up experiments may be considered the subject of a separate trial, it is not proposed to discuss them here.

TABLE 3: PRECISION OF TREE HEIGHT AND CROWN DIAMETER MEASUREMENTS (colour film)

Interpreter	Measured (Out of 303)	Heights Within ± 1.8 m		Crown Diameters Within ± 0.6 m	
		No.	%	No.	%
A	303	280	92.4	275	90.7
B	303	292	96.4	241	79.5
C	303	302	99.7	299	98.7
D	303	288	94	268	88
E	303	300	99	297	98
F	303	298	98	286	94

TABLE 4: PRECISION OF TREE HEIGHT AND CROWN DIAMETER MEASUREMENTS (black and white film)

Interpreter	Measured (Out of 303)	Heights Within ± 1.8 m		Crown Diameters Within ± 0.6 m	
		No.	%	No.	%
A	303	274	90.4	268	88.5
B	303	293	96.7	253	83.5
C	303	300	99.0	288	95.0
D	303	190	62.7	211	69.6
E	303	291	96.0	262	86.5
F	303	230	76.1	261	86.1

For the panchromatic photography (Table 4) four of the six interpreters were within acceptable limits for tree heights on at least 90% of the trees; however, only one interpreter had 90% of his crown diameter measurements within ± 0.6 m.

By contrast, the colour photography provided considerably better results for both measures; all six interpreters had at least 92% of their height measurements within ± 1.8 m, and four men had at least 90% of their crown diameter evaluations within ± 0.6 m.

Photo Interpretation Summary

Tables 5 and 6 permit a comparison of all major results obtained by each of the six interpreters. It can be seen that interpreters A, B and C required a considerably longer time to complete the measurements than interpreters D, E and F. This is largely due to the fact that the photo interpretation work had to be performed sporadically by the first group — by fitting it in with their regular job duties. Therefore, the time relationships shown here should be applied with caution.

Tables 5 and 6 also illustrate the tendencies of various interpreters to over-estimate or under-estimate the stand variables on aerial photographs. Such information is ex-

TABLE 5: SUMMARY OF PHOTOGRAPHIC MEASUREMENTS BY INTERPRETERS (colour)

Type of Estimate	*Interpreter Code* A	B	C	D	E	F
A. Time comparisons:						
Total No. of trees measured	303	303	303	303	303	303
Total time required (min)	2115	2923	3424	675	865	820
Av. time per tree (min)	7.0	9.6	11.5	2.2	2.9	2.7
B. Tree height comparisons:						
No. correct	35	30	45	38	56	56
No. of trees over-estimated	77	67	113	79	87	41
Av. positive difference (m)	0.56	0.58	0.58	0.82	0.52	0.64
No. of trees under-estimated	191	206	145	187	160	207
Av. negative difference (m)	0.91	0.91	0.67	0.85	0.64	0.73
Mean difference all trees (+ or —) Ignore signs (m)	0.58	0.27	0.24	0.73	0.24	0.58
C. Tree crown diameter comparisons:						
No. correct	71	33	83	79	104	110
No. of trees over-estimated	175	249	185	140	129	69
Av. positive difference (m)	0.49	0.61	0.42	0.51	0.39	0.46
No. of trees under-estimated	53	21	35	85	70	125
Av. negative difference (m)	0.45	0.27	0.30	0.55	0.36	0.45
Mean difference: all trees (+ or —) Ignore signs (m)	0.24	0.49	0.21	0.39	0.12	0.30
D. Tree count comparisons:						
Total trees counted	318	303	306	300	304	304
Difference from field count	+14	—1	+2	—4	0	0

tremely helpful in the selection and training of individuals for photographic interpretation.

The interpreters' readings were compared with ground measurements using tests for paired plots for both height and crown diameters. The differences were significant at the 95% probability level.

DISCUSSION OF RESULTS

Photo interpretation measurements clearly improved with the use of colour photography in lieu of black-and-white film. Since both sets of photographs were taken at the same hour and with the same camera, the inherent geometric characteristics are identical for both emulsions. Therefore, the improved measurements on the colour film, which was evaluated after the panchromatic film, can probably be attributed to three principal sources:

(1) The entire study was designed to serve as a training exercise for the six men who volunteered as interpreters. It can thus be assumed that they had become somewhat more skilled when interpreting the second set of aerial photographs.

TABLE 6: SUMMARY OF PHOTOGRAPHIC MEASUREMENTS BY INTERPRETERS (black and white)

Type of Estimate	*Interpreter Code*					
	A	*B*	*C*	*D*	*E*	*F*
A. Time comparisons:						
Total No. of trees measured	303	303	303	303	303	303
Total time required (min)	2920	2397	2556	985.5	926	1517
Av. time per tree (min)	9.6	7.9	8.4	3.2	3.0	5.0
B. Tree height comparisons:						
No. correct	42	50	81	17	41	30
No. of trees over-estimated	78	92	100	20	99	49
Av. positive difference (m)	0.61	0.61	0.46	0.73	0.61	0.91
No. of trees under-estimated	183	161	122	266	162	224
Av. negative difference (m)	0.79	0.85	0.53	1.64	0.82	1.34
Mean difference; all trees (+ or —) signs ignored (m)	0.67	0.67	0.36	1.49	0.61	1.16
C. Tree crown diameter comparisons:						
No. correct	72	56	90	41	63	88
No. of trees over-estimated	138	169	173	218	184	144
Av. positive difference (m)	0.46	0.54	0.46	0.67	0.52	0.60
No. of trees under-estimated	93	78	40	44	56	71
Av. negative difference (m)	0.48	0.55	0.27	0.55	0.52	0.49
Mean difference: all trees (+ or —) signs ignored (m)	0.36	0.46	0.30	0.57	0.43	0.40
D. Tree count comparisons:						
Total trees counted	305	303	303	309	309	293
Difference from field count	+1	—1	—1	+5	+5	—11

(2) Even though a time lapse of 30 to 60 days was enforced between the completion of the first phase (black-and-white film) and the start of the second phase (colour film), there was undoubtedly some "memory bias" — *i.e.*, certain individuals probably remembered some trees and their characteristics.

(3) The combination of resolution, contrast, and colour rendition on the colour film was greatly superior to that exhibited by the panchromatic emulsion. Thus the pointed tips (leaders) of radiata pine that were impossible to distinguish on the panchromatic film were easily seen and measured on the colour photographs. In like fashion, the obvious contrast between the tree crowns and lesser vegetation permitted easy ground parallax readings on the colour film, while such readings were difficult on the black-and-white film.

This study provided at least three important conclusions that will be useful in the future planning for air photo coverage and specifications in New Zealand forests:

(1) Kodak Aerocolor film, Type 2445, is the best emulsion for large-scale aerial photography of healthy stands of radiata

pine. (Kodak Aerocolor is the only type of negative film readily obtained through the contractors.)

(2) The Zeiss RMK-A-60/23 aerial camera with a 30° lens angle and a 614.98 mm focal length is suitable for large-scale photography, provided the forward overlap of successive exposures is maintained at around 50 to 54%. This minimum overlap assures a reasonable degree of vertical exaggeration in the stereoscopic model.

(3) Relatively unskilled personnel can be trained within 2 or 3 months to make reliable tree measurements on large-scale photographs with simple stereoscopic equipment.

ANALYSIS OF RELATIONSHIPS

From ground measurements, the relationships listed in Table 7 were tested.

TABLE 7: RELATIONSHIPS DETERMINED FROM GROUND MEASUREMENTS

Relationships	*Correlation Coefficient (r)*
dbh over bark/dbh inside bark (dbhob/dbhib)	0.994
volume/basal area inside bark (vol/BA)	0.976
dbh over bark/crown diameter × height (dbhob/(cd × h))	0.889
dbh inside bark/crown diameter (dbhib/cd)	0.847
dbh over bark/crown diameter (dbhob/cd)	0.843
basal area (inside bark)/crown diameter^2 (BA/cd^2)	0.828
volume/crown diameter (vol/cd)	0.796
volume/crown diameter^2 (vol/cd^2)	0.783
basal area (inside bark)/crown diameter^2 × height (BA/(cd^2 × h))	0.754
volume/crown diameter^2 × height (vol/(cd^2 × h))	0.751
height/crown diameter (h/cd)	0.499
dbh over bark/crown diameter^2 (dbhob/cd^2)	0.384
dbh over bark/crown diameter^2 × height (dbhob/(cd^2 × h))	0.178

The first two of the relationships listed in Table 7 use parameters not directly obtainable from photographic studies, but they are shown to illustrate the strong relationship that exists with parameters that are obtainable by this method.

The relationship dbhob (cd × h) was the strongest of those which could be obtained by photographic means, but group tests showed that though the slopes of the regressions carried out on each strata showed no significant difference the levels did differ significantly. This regression was therefore not used in this test. All the other regressions tested did conform for each of the four strata.

The stem volumes were calculated from volume tables for unthinned stands (Duff, 1954) and, although they showed a fair relationship, it was decided to use parameters that could be directly sustained by ground measurements. Of the two relationships, dbhob/cd and dbhib/cd, it was decided to use the former as this was more normally used in day-to-day work.

Crown Diameter/Stem Diameter Relationship

Field data from 20 sample plots in Compartment 901 provided 304 paired measurements of crown diameters and stem diameters (dbh) for radiata pine. When dbh values (d) were graphed over corresponding crown diameters (cd), a straight-line relationship was indicated. Therefore, a simple linear regression of the form $Y = a + bX$ was fitted to the plotted data by the method of least squares.

The resulting equation d = 8.56 + 0.1637cd demonstrates the feasibility of establishing such relationships for predicting stem diameters from crown diameters in thinned stands of radiata pine (Fig. 1). The shaded area of the graph encompasses the 95% confidence band when it is desired to predict an average dbh from a mean crown diameter based on 15 trees; in this case, the standard error of the estimate would be ± 12.7 mm. The outer limits of the graph depict the 95% confidence band when a dbh prediction is made from a single additional measurement of a tree crown diameter; here, the standard error of the estimate would be ± 45.7 mm. Assuming that tree crown diameters can be measured with an accuracy of ± 0.3 m to 0.6 m on large-scale aerial photographs, it should therefore be feasible to make predictions of dbh within ± 50.8 mm without difficulty. This level of precision should be quite acceptable for extensive surveys of large areas or relatively inaccessible stands.

The foregoing correlation is based entirely on ground measurements of the two variables; this was done purposely so that the aberrations of individual photo interpreters would

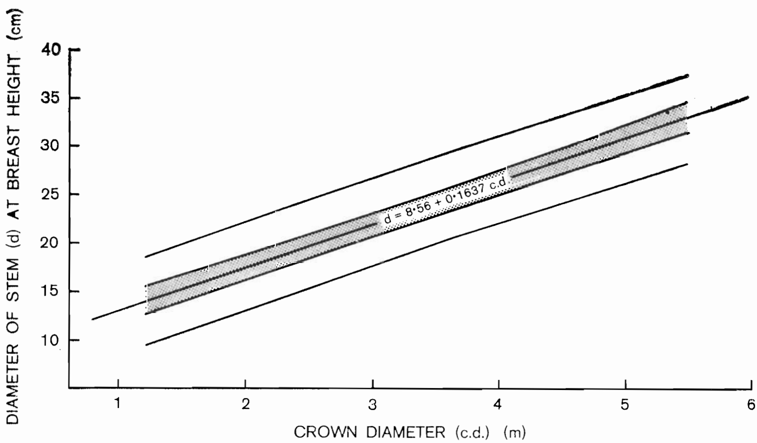

FIG. 1: *Relationship of crown diameter (cd) to diameter at breast height (dbh).*

not be incorporated into the relationship. The application of such correlations will merely require that each individual interpreter make the required adjustments in his photo-derived measurements of crown diameter before using prediction equations of the type shown here. Also, for the practical application of the technique, separate relationships may be needed for various site and age (or density) classes of radiata pine. Nevertheless, this sample correlation serves to illustrate the validity of the approach.

POTENTIAL APPLICATION OF RESULTS

Since stem diameters, tree heights, and crown diameters can be derived from measurements on large-scale aerial photographs, individual tree volumes can be assessed by the same procedures as used on ground inventories. Although photo-derived volume estimates will be slightly less precise than ground volume determinations, this limitation can be largely overcome by measuring greater numbers of photo plots than would normally be specified in a conventional ground assessment. Of course, the usefulness of a combined photographic-ground inventory approach rests on the assumption that New Zealand forest managers have a need for periodic volume estimates following major thinning operations — *i.e.*, when individual trees can be distinguished for measurement by photo interpreters.

Whenever aerial surveys are scheduled for thinned compartments, there must be some means available for determining the exact photographic scale and the height of the aircraft above ground. This required ground control could be obtained by establishing some combination of the following procedures:

(1) A permanent network of visible ground control throughout major forest areas. Such a network is now being planned for large sectors of Kaingaroa Forest.

(2) Temporary visible ground markers along roads, firebreaks, etc., following thinning operations and just before aerial surveys.

(3) A system of permanent sample plots in cluster patterns so that at least two plots would be visible on any selected stereo-pair of photographs. If used with contour maps, this network of visible permanent sample plots could provide both horizontal and vertical ground control for aerial surveys. Temporary (unmarked) photo plots could then be randomly located on those stereo-overlaps where adequate control is available.

If ground control is provided by a network of permanent sample plots (*i.e.*, as in item 3 above) a periodic inventory system might be designed along the following lines:

(1) Obtain large-scale aerial photography annually for those compartments that received their final thinnings in the previous 6- to 12-month period — *i.e.*, stands with 750 stems per hectare or less.

(2) For each age class, stratify the thinned compartments into two or three density classes (based on stems per hectare). There should be at least two permanent sample plots in each density class recognized.

(3) Determine the area of each density class.

(4) Within each density class (stratum) recognized, randomly locate a number of temporary photo interpretation plots (number of plots dependent on required probable limits of error) and derive volume estimates for each. Interpreters would also make volume estimates on the permanent sample plots as well.

(5) Use of relationships of photo to ground volumes based on the permanent sample plots to "adjust" volume estimates obtained on the temporary (non-visited) photo plots. (Each interpreter would probably require a different adjustment factor.) Then, following standard statistical procedures for two-stage or "double-sampling", volume estimates from the ground-measured permanent sample plots are combined with adjusted photo-derived volumes to provide an overall estimate of mean volumes and standard errors for each stratum recognized.

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REFERENCES

André, J. G. P., 1967. Assessment of stand density of *Pinus radiata* from aerial photographs. New Zealand Forest Service, Forest Research Institute, Production Forestry Branch, Management Report 3 (unpublished). 19 pp.

Avery, T. Eugene, 1958. Composite aerial volume table for southern pines and hardwoods. *J. For., 56*: 741.

——— 1968. *Interpretation of Aerial Photographs.* 2nd ed. Burgess, Minneapolis, Minn. 324 pp.

——— 1970. Height measurements on aerial photographs. *N.Z. For. Serv., For. Res. Inst., Res. Leafl. 31.* 4 pp.

Duff, G., 1954. Combined taper and volume tables for *Pinus radiata*. *N.Z. For. Serv., For. Res. Inst. Res. Note 1* (12). 39 pp.

Minor, Charles O., 1960. Estimating tree diameters of Arizona ponderosa pine from aerial photographs. *U.S. For. Serv., Rocky Mountn For. & Range Exp. Sta. Res. Note 46.* 2 pp.

Spurr, Stephen H, 1960. *Photogrammetry and Photo-Interpretation.* Ronald Press, New York.

Wylie, R. E. J., 1967. *The Potential Use of 5 chain Aerial Photography in Kaingaroa Forest* (unpublished).

——— 1969. *A Review of the Potential Use of 5 chain High Resolution Air Photographs* (unpublished).

Zsilinszky, Victor G., 1966. *Photographic Interpretation of Tree Species in Ontario.* Ontario Dept of Lands and Forests, Toronto. 86 pp.