# *4 PHOTO-MEASUREMENT METHODS*

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## 4.1 Determining photo-scales

With fixed-base photography, two cameras are mounted in parallel on a rigid boom at a fixed and known separation and are fired simultaneously to obtain stereo photographs. The photographic representation of the air base is the photo base, which in this case varies with the scale of the photography. At low flying heights the photobase is large, whereas at high flying heights it is correspondingly smaller. The formula expressing this relationship is :

$$b = B.f/H$$

where $b$ = photo base (mm)
$B$ = actual air-base (m)
$f$ = focal length of camera (mm)
$H$ = flying height above the ground (m)

For example, with a boom of 7.5 m, a flying height of 100 m and a focal length of 100 mm, the scale of photography (f/H) is 1:1000 and the photographic air-base is 7.5 mm. At 500 m above the ground, the photo scale is 1:5000 and the photo base is 1.5 mm.

As it is not possible to guarantee that the cameras are perfectly parallel in flight, it is necessary to use calibration targets to determine exact flying heights and, if necessary, to calculate a linear regression of photo base versus the reciprocal of flying height to determine the relationship between them.

Using this procedure for the Vinten photography (Fig. 26) gives the following derived flying height function :

$$H = 1/(0.00318 + 0.00133\, b)$$

where $H$ = flying height (m)
$b$ = photo base (mm)

Hasselblad photography is a little more complex because daily reinstallations of the cameras cause slightly different relative orientations. Therefore, in order to determine the relationship between flying height and photo base for each day's photography, it is necessary first to calculate the camera orientations by reference to calibration targets.

The flying height of a stereopair can be calculated as :

$$H = Bf/(b + f\tan\theta) \qquad (1)$$

The value $f\tan\theta$ can be calculated from the photographs of calibration targets by rearranging equation 1.

$$f\tan\theta = Bf/H_C - b_C \qquad (2)$$

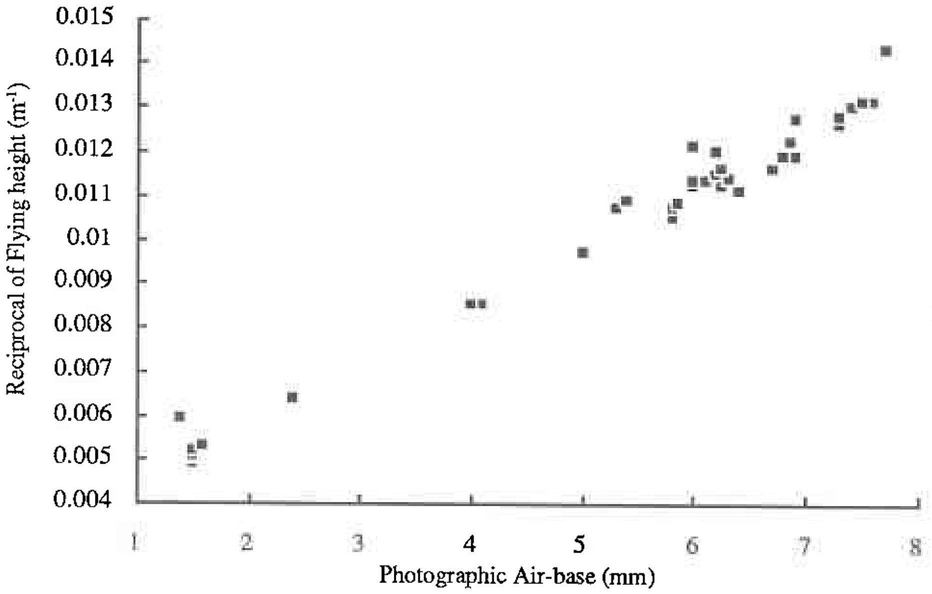

**Figure 26**

Flying height function. Reciprocal of flying height determined from ground-truth, was regressed against photographic air-base to develop a relationship for use in calculating the scale for photo-measurements. (Vinten photographs, 34 observations $r^2 = 0.988$.)

but $f/H_c = l_{pc}/l_{gc}$ (3)

so $f\tan\theta = (B\, l_{pc}/l_{gc}) - b_c$ (4)

Substituting equation 4 into equation 1 gives :

$$H = Bf/((b-b_c) + B\,(l_{pc}/l_{gc})) \quad (5)$$

where $H$ = flying height (m)
$H_c$ = flying height of calibration stereopair (m)
$B$ = airbase (m)
$b$ = photo-base (mm)
$f$ = focal length (mm)
$\theta$ = angle of convergence or divergence (degrees)
$b_c$ = photo-base of calibration stereopair (mm)
$l_{pc}$ = length of calibration target on photo (mm)
$l_{gc}$ = length of calibration target on ground (m)

## 4.2 Photo-measurement equipment

To obtain the maximum advantage from estimating timber volumes from aerial photographs, the measurement equipment should not only be capable of accurate measurements, it should also be quick to use. If possible, the instrument should have a facility to correct for distortions in the photography, such as from tip and tilt and lens distortion.

Equipment developed for the measurement of large scale photographs exhibits innovation and variety in terms of capabilities, cost, and speed of operation (Spencer and Hall 1988). The simplest systems for measuring height consist of a stereoscope and parallax bar, sometimes with an encoder for semi-automated recording of measurements.

Operational forest inventories, however, involving hundreds or thousands of large-scale sampling photographs, require better, more expensive instruments, preferably with built-in facilities for parallax measurement, tilt adjustment, and the automated recording and processing of coordinate data. These requirements have led to customized systems based on Helava's analytical plotter concept developed at the National Research Council of Canada (Friedman *et al.* 1980).

Analytical plotters use mathematics and computers to solve the relationships between photographic image coordinates in two dimensions and ground coordinates in three dimensions. They are, therefore, mechanically simpler and more compact than analog plotters and can readily accommodate the effects of different focal lengths, film formats, lens distortions, and shrinkage. Their major advantages are that they provide straightforward, semi-automated procedures for relative orientation and recording of digital data. They also allow the operator to read, record, and store ground or other coordinates and to recall it at any stage with the computer, which provides for immediate calculations and analysis.

The locally manufactured ADAM MPS-2 small format analytical stereo digitizer was favoured for these reasons (Fig. 27). However, the amount of distortion in the Vinten photography caused by the focal plane shutter could not be easily accounted for in the analytical instrument without large amounts of ground control, and that without correction,

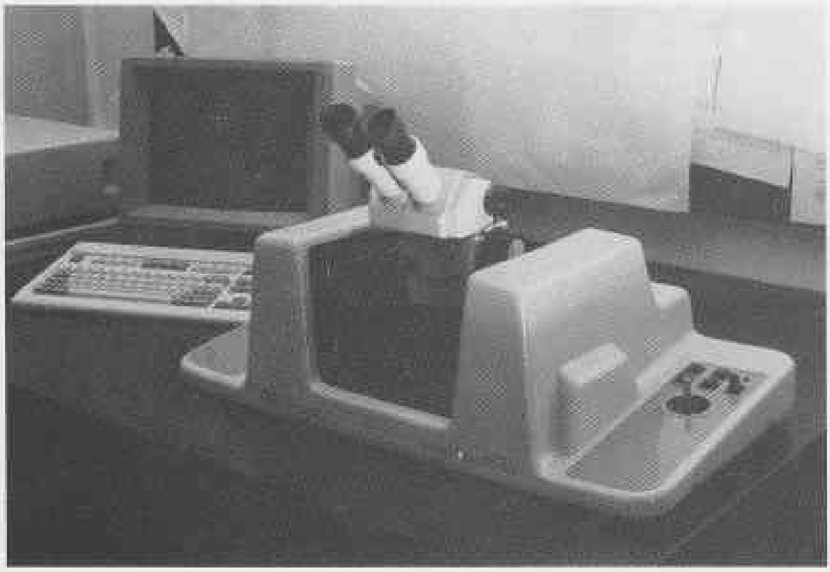

**Figure 27**
Adam MPS-2 analytical stereodigitizer.

relative orientations and parallax measurements could not be performed satisfactorily. This made the MPS-2 unsuitable for photographs from the Vinten cameras, but it was possible to measure photographs from the Hasselblad cameras.

As a result, alternative analog instruments in the form of modified Zeiss Stereotopes (Fig. 28) and Zeiss Jena Interpretoskops are being used to measure tree heights on the Vinten photographs. Modifications to the Stereotope facilitate the use of transparencies instead of prints. Although neither of these instruments is fitted with an encoder for the automated recording of parallax measurements, they are each supported by a microcomputer that accepts parallax readings keyed in by the interpreter and calculates and records tree heights.

The scale of each photo-pair, as described in Section 4.1, is calculated from a measurement of the photo base and a predetermined regression of photo base with flying height. This regression is checked by reference to calibration targets that are photographed at the beginning and end of each flight. The procedure estimates flying height to within ± 3 per cent of the true values at 100 m. The photo-base is determined from a simple procedure that involves measuring the difference between two corresponding images in a stereopair and their respective photo edges (Fig. 29) (Lyons 1964; Spencer 1979).

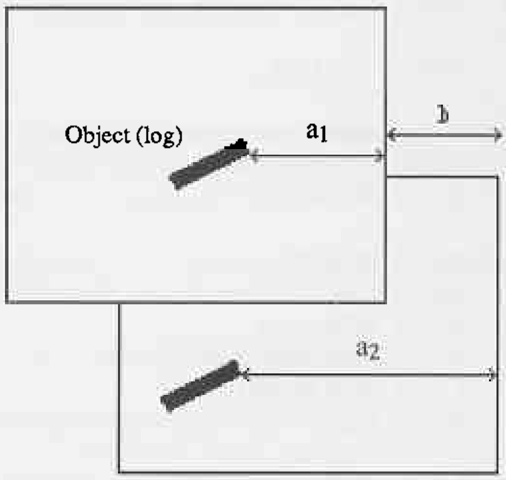

**Figure 29**
Measurement of photographic air-base(b) on 70 mm transparencies: $b=a_2-a_1$.

## 4.3 Selection and training of photo-interpreters

Photo-interpreters are selected for their ability to measure tree heights photogrammetrically. Experience in identifying tree species and forest types is also desirable, but as experienced forestry staff were not available for this part of the project, it has been necessary to implement a training

**Figure 28**
Zeiss Stereotope stereoplotter.

program in forest photo interpretation. Most staff employed in this area were either recent graduates or tertiary students in surveying or cartography.

Initial training involves one month's work in the field with ground assessment teams to gain experience in identifying tree species and stocking from the ground, and to develop a background knowledge of the forest. This is followed by one week of intensive training on species interpretation and stocking determination from aerial photographs, plus several days of training on tree height measurements.

Practice and evaluation then follow and interpreters do not start production work until they have obtained satisfactory test results, requiring a standard error of photo height measurement of less than 2 m and a species interpretation success rate of better than 75 per cent.

Each interpreter works on a single cell of photography at a time, with each cell being divided into smaller areas (subcells). Work on each cell begins with a reconnaissance of each subcell as a means of training the interpreter in the particular characteristics of that forest type and colour differences with different films.

## 4.4 Species identification

Tree species are differentiated on the basis of their geographic location and landscape position, the shape and size of the tree, branching pattern, colour, flowering and associated vegetation (Fig. 30, Table 3). As two major species, jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*), account for some 80 to 90 per cent of the trees in the jarrah forest, the interpretation process is simplified.

**Table 3**

Factors used in species identification

| Species | | Identification Keys |
|---|---|---|
| Jarrah *(Eucalyptus marginata)* | Crown | • dark shiny green<br>• leaves appear brown at times |
| | Branches | • red brown, gentle angles |
| | Flowers | • cream - early summer |
| | Location | • mid slope to ridge top |
| | Similar species | • pole sized trees similar to marri |
| Marri *(E. calophylla)* | Crown | • olive green, yellowish at times<br>• cauliflower appearance on pile sized trees |
| | Branches | • grey brown, twisted, sharp angles<br>• fine dead branches common<br>• often bent down by weight of capsules |
| | Flowers | • cream - later summer |
| | Location | • low to mid slope, less on ridge tops |
| Blackbutt *(E. patens)* | Crown | • olive green lighter than marri<br>• structure similar to jarrah |
| | Location | • gullies, moist sites |
| Wandoo *(E. wandoo)* | Crown | • structure & colour similar to jarrah but appearing very dark at times |
| | Branches | • and bole white to grey-yellow |
| | Location | • low rainfall zones |
| Karri *(E. diversicolor)* | Crowns | • spreading, very tall when mature<br>• regrowth in uniform, even aged patches |
| | Branches | • white |
| | Location | • high rainfall zones, gully sites in jarrah inventory area |
| Other eucalypts | | |
| Bullich *(Eucalyptus megacarpa)* | | • gully sites, white branches, |
| Flooded gum *(Eucalyptus rudis)* | | • larger creeks and rivers |
| Non-eucalypts | | |
| Sheoak *(Allocasuarina fraseriana)* | | • spreading crowns, grey branches |
| | | • light olive green, but brown when flowering |
| Banksia *(Banksia spp)* | | • large leaves in circular patterns large cylindrical flowers |
| Paper bark *(Melaleuca spp)* | | • gully sites, white boles and branches |
| Woody pear *(Zylomelum occidentalis)* | | • large ovate leaves, dense crowns white flowers, common in Collie area |

Shadows are sometimes an additional aid to interpretation because they can give a different perspective of the crown shape and structure and they can be a help in counting the number of stems in clumps.

Colour is of great value in interpretation but it cannot be used alone to separate species because colours vary considerably between different sites, as well as with different stages of flowering and fruiting and with different batches of film. Wandoo (*E. wandoo*), karri (*E. diversicolor*) and bullich (*E. megacarpa*) can be identified by their white bark (eg. Fig. 31).

Flowering is a characteristic that can be useful for separating species (Fig. 32) on small areas but its value varies widely over time and location. Where evidence of the stage of flowering at the time of photography is detected during a cell reconnaissance, it can only be used as a diagnostic feature in the relevant portions of that cell. Location, site and associated vegetation are used initially in conjunction with other observations during the cell reconnaissance to determine which species might be expected in each area. Other clues include the structure of the forest, symptoms of dieback, jarrah leaf miner (*Perthida glyphopa*), gumleaf skeletonizer (*Uraba lugens*)and management activities. When difficulties are experienced in the photo-interpretation, checks are made in the field.

## 4.5 Photo-measurement procedures

All photo plots within multiple-use State forest are measured, except plots within areas that are being logged, or that have been logged since the photographs were taken.

The first step is to measure the photo base of each stereopair using a glass scale graduated to 0.01 mm. This is done, as previously described, by identifying a point, preferably on the ground, which is visible on both photographs and measuring the distance from that point to the corresponding edges of each photograph. The difference between these measurements is the photo base (Fig. 29). This method, first suggested by Lyons (1964), avoids the tedious tasks of marking and transferring principal points.

The second step involves identifying the species and measuring the heights of all trees taller than 10 m that fall within a 20 m (0.125 ha) radius of the centre of the stereo overlap. This circular plot is defined by a transparent template positioned under the right-hand photograph (Fig. 33). A range of templates, in 1 mm radius gradations, is available to match the plot size approximately to the scale of each photograph. The analysis program calculates the exact scale and equivalent ground radius to ensure that the 'blow up' expansion factor for volume per hectare is used.

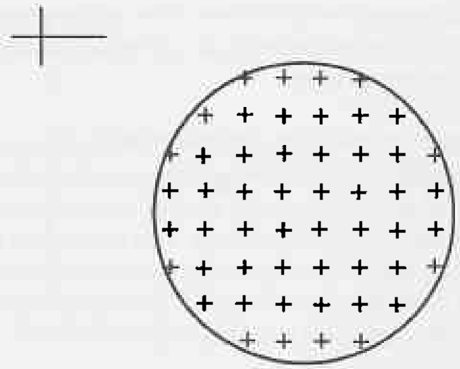

**Figure 33**

Photoplot template showing grid pattern to aid systematic measurement of all trees.

Photographs are scanned on a systematic pattern, with each tree being numbered, interpreted according to species, and measured for total height using the parallax method. A computer program is used to prompt the operator to record the appropriate photo data and to calculate tree heights.

## 4.6 Performance monitoring

Once a month, every interpreter is required to complete a performance test involving species identification and tree height measurements on a number of sample plots for which the heights and species have been checked in the field. A different set of photographs is used for each test to avoid the possibility of memory bias.

The following analyses are then made on the test data :

- mean error (photo-measured height-ground measurement);
- ratio correction factor (photo-measurement / ground measurement);
- standard deviation of the mean error;
- species interpretation accuracy;
- visual check on consistency of the height measurements.

The test results are used to monitor interpreter performance over time and to identify any problems. They are also used to calculate correction factors to be applied to each interpreter's measurements. Each plot is coded for the interpreter who measured it and the appropriate correction factor is included in the file to adjust the calculations in later processing. Typical results for species recognition are shown in Table 4a. Accurate species interpretation will affect the volumes estimated for species-specific products, but not the total volume.

Stem numbers for each species also affect the volume estimation and a series of test plots is used to check stocking accuracy. Finally, the easiest component to check is heighting accuracy, where the photo measurements are compared with ground measurements (Table 4b and Fig. 34).

**Figure 30**
Example of jarrah/marri crowns.

**Figure 31**
Example of white bark on karri.

**Figure 32**
Example of marri in flower.

**Table 4a**

Species interpretation tests - all interpreters, January to October 1989

| Ground truth | Photo interpretation | | | | | |
|---|---|---|---|---|---|---|
| | Jarrah | Wandoo | Blackbutt | Marri | Non-Eucalypts | Total |
| Jarrah | 533[a]<br>91.27<br>89.43 | 0 | 0<br>0.00<br>0.00 | 46<br>7.88<br>26.59 | 5<br>0.86<br>7.46 | 584 |
| Wandoo | 1<br>100.00<br>0.17 | 0 | 0<br>0.00<br>0.00 | 0<br>0.00<br>0.00 | 0<br>0.00<br>0.00 | 1 |
| Blackbutt | 2<br>28.57<br>0.34 | 0 | 5<br>71.43<br>100.00 | 0<br>0.00<br>0.00 | 0<br>0.00<br>0.00 | 7 |
| Marri | 54<br>39.17<br>9.06 | 0 | 0<br>0.00<br>0.00 | 124<br>69.27<br>71.68 | 1<br>0.56<br>1.49 | 179 |
| Non-eucalypts | 6<br>8.57<br>1.01 | 0 | 0<br>0.00<br>0.00 | 3<br>4.29<br>1.73 | 61<br>87.14<br>91.04 | 70 |
| Total | 596 | 0 | 5 | 173 | 67 | 841 |

(a) Values in each cell are respectively frequency, row per cent and column per cent.
For example the figures show that of 584 jarrah trees, 533 (91 per cent) were correctly interpreted as jarrah, 46 (8 per cent) were interpreted as marri and 5 (1 per cent) as other species (errors of ommission). In total, 596 trees were interpreted as jarrah of which 533 (89 per cent) were corrently identified while 63 were actually other species, mainly marri 54 (9 per cent) - errors of commission.

**Table 4b**

Height measurement tests - all interpreters January to October 1989

| | |
|---|---|
| Mean height - photo | 19.27 m |
| Mean height - ground | 19.65 m |
| Difference (mean error) | -0.38 m |
| Standard deviation of mean error | 1.71 m |
| Ratio Correction factor | 1.025 m |

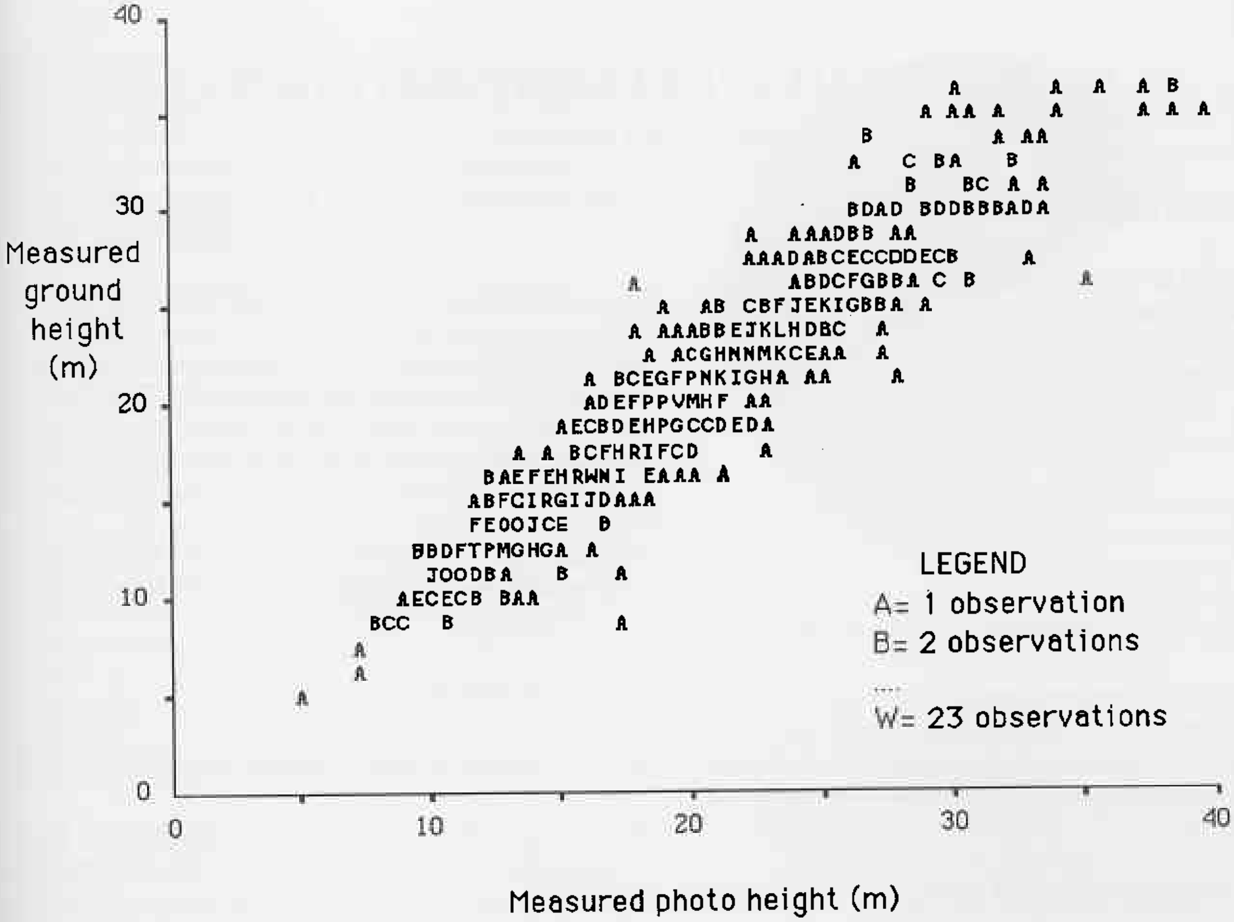

**Figure 34**
Comparison of tree heights measured from the ground and from aerial photos.