7 EVALUATION AND FUTURE DEVELOPMENT

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7.1 Evaluation

7.1.1 Photographic quality

Throughout the project there have been few problems with the exposure and processing aspects of photographic quality, though initially there were problems owing to incompatibility between the photography and analytical measurement equipment. These problems related to the lack of precise fiducials and problems associated with image distortions caused by the focal-plane shutters in the Vinten cameras. Expensive fully calibrated metric cameras are required to overcome these problems.

There were also some early occurrences of excessive image motion owing to excessive speed and large variations in scale, owing to turbulence and/or insufficient control of flying height, which made photo-measurement difficult. These problems have been reduced by using the GPS receiver to display the ground-speed to the pilot, by using the radar altimeter to help control flying height within tighter specifications, and by avoiding turbulent conditions.

Some loss of clarity was also noticed in the second season's photography when reseau plates were fitted to the Hasselblad cameras, which affected focusing but not to the extent that it affected measurement accuracy.

Photographs were taken in poor light on occasions to maintain production. One day photography was attempted with about two eighths cloud to judge the impact on photo quality, but the photographs taken in shadow were too dark because the Hasselblad cameras were used and they do not have remote aperture adjustment. This result highlights the advantage of remote aperture control on the cameras.

7.1.2 Navigation systems

The GPS navigation system provided accurate data on plot locations which facilitated an efficient link between the ground and photo samples and other geographic information. The precision of the plot locations was discussed in Section 3.4.

The main difficulty encountered with the GPS navigation system was the availability of the satellites. This restricted photography to the months of December, January and February in the first season, and limited the actual hours of the day during which photography could be carried out. This problem, however, is slowly disappearing as more NAVSTAR satellites are launched. It is expected that within a few years three-dimensional (i.e. 4 satellites) GPS navigation will be possible continuously.

The GPS navigator was cheap to run, since no ground transponders were required, as was the case with the microwave systems used previously within the Department. In addition, the positions obtained from the GPS unit were in latitudes and longitudes rather than coordinates referenced to local base lines. This made the connection of photo location data with existing map data very straight-forward.

Once the satellite constellation is complete, then field crews will be able to use hand-held GPS receivers to relocate sample plots throughout the year. This will overcome the problems experienced in registering the plot positions with existing printed 1:25 000 scale map sheets.

7.1.3 Photo and ground measurements

Photo measurements are constantly monitored for errors using a combination of regular field visits by the interpreters, plus monthly trials of height measurements and species interpretation.

These tests show that the standard error of height measurements is ± 1.7 m (p=0.68) compared with ground measurements and that species interpretations are correct 85-90 per cent of the time. These tests are used to determine the average bias in height estimation for each interpreter so that their measurements can be corrected to ground standards.

Ground measurements are monitored by regular remeasurement of a series of four sample plots. Analysis of these measurements shows that the variability of volume estimates between assessors is much less than the variability between plots (Fig. 46). Assessment of logs is much more variable compared with standing trees which could be attributed to the fact that logs are often severely burnt and rotten, making consistent measurements of length and diameter more difficult than on standing trees.

To evaluate the accuracy of volume estimations in relation to actual yields, two trial areas were subjected to intensive photography at 500 m x 100 m intervals and ground sampling at 500 m x 500 m intervals. These areas are being logged to obtain removal data for comparison with the sample estimates.

In the absence of these data, the only tests possible are comparisons between photo estimates and ground estimates. From one cell of photography 1202 photo plots and 100 ground plots (20 ground plots not measured owing to logging), it is evident that the estimates of gross bole volume from photographs underestimates the ground volume. A variety of factors have been identified as

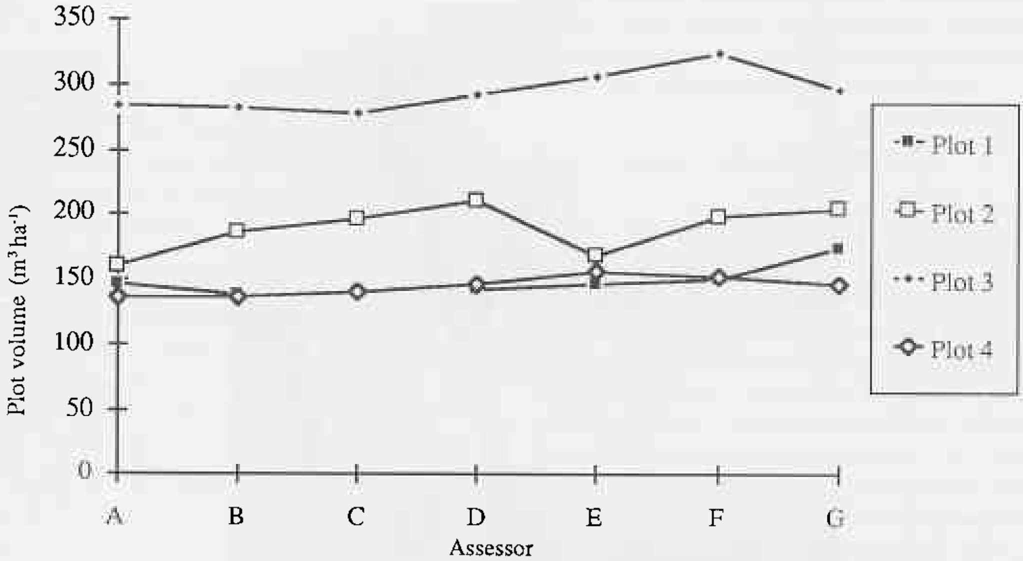

Figure 46
Variability between assessors compared with variability between plots.

contributing to this problem. The most common factor is the omission of trees from the photo estimates where crowns are close or interlocking and appear as one tree.

On several of the plots investigated, it has also been found that crown damage is common among large trees in some areas. In these cases the trees are relatively short but contain large bole volumes (Fig. 47). These trees are difficult to account for in the estimation process, but they can have a significant impact on results as shown in Figure 48. This demonstrates the relationship between the photo and ground estimates of gross bole volume.

From the example given, the estimate of gross bole volume from the double sample has a standard error of 4.1 per cent compared with 5.7 per cent from ground sampling only. The double sample involved 330 person days of work. To achieve a similar result from ground sampling would require 195 ground plots, nearly twice the number involved in the double sample: 195 ground plots would involve 380 person days, 18 per cent more than the double sample.

A full economic analysis of the method is not possible until more results are obtained, but it appears from these data that significant savings in labour and time are being made using aerial photo sampling.

7.1.4 Geographic Information System design and application

There are two questions to be considered when evaluating the GIS design: first whether the type of interrogation envisaged will be adequate to satisfy the information requirements of the end users, and second, whether the apparatus put in place to perform such interrogation can do so with sufficient speed and by enough different operators to be useful.

The first question will be answered only when the system has been in use for some time. The answer will almost certainly be *no*, as new possibilities become apparent for answering more complicated management questions and dealing with 'what-if' queries.

The second can be tested once there is sufficient data in the database for realistic interrogations to be tackled. Possible success criteria could be:

(i) a definition of window possible, based on geographical description;

(ii) generation of resource by products, in priority order;

(iii) facility for data to be corrected and updated routinely;

(iv) tabulations of resource figures available within, say one day of interrogation being received.

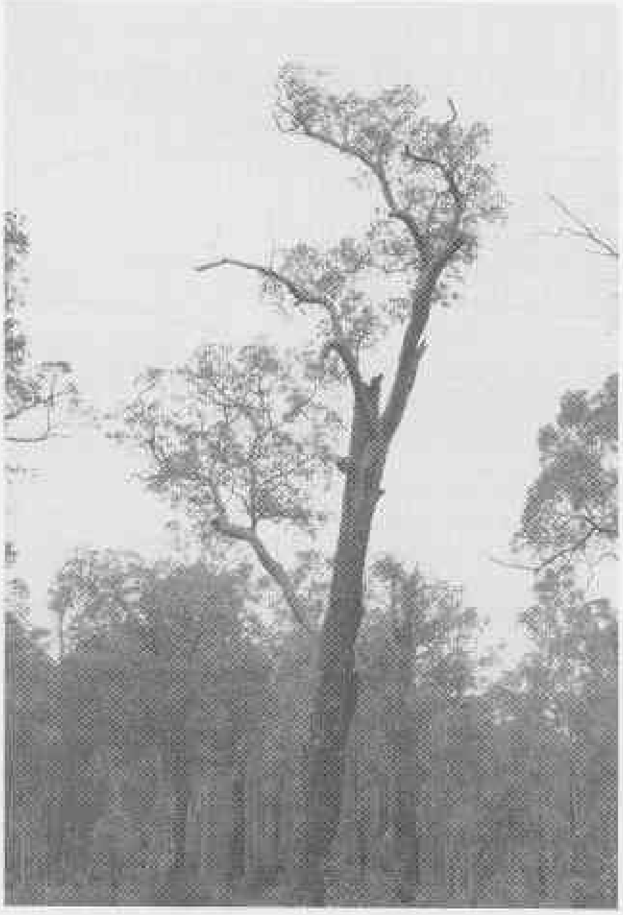

Figure 47
Crown broken out of large veteran.

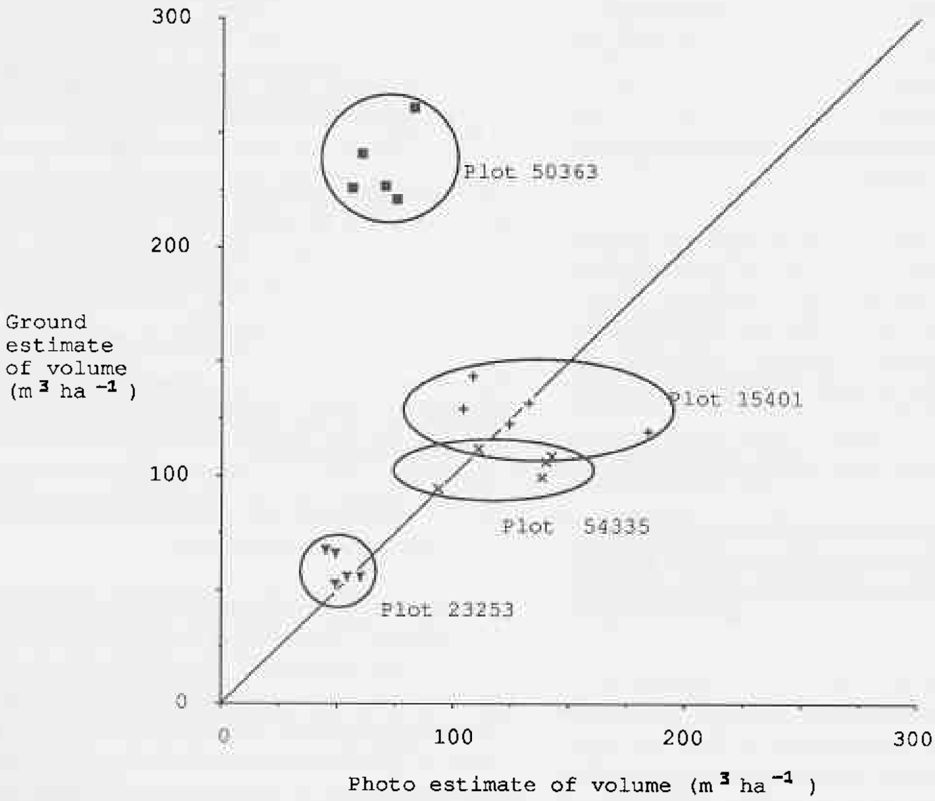

Figure 48
The effect of crown damage on photographic estimates of volume.
Plot 50363 was affected, the other three plots were not.

7.2 Costs

Data from two years of plot measurements have shown that photo samples obtained using large scale photography cost approximately one-tenth that of ground plots (Table 7). To derive the cost per plot, the fixed costs were apportioned out over the expected number of samples to be obtained to complete the initial assessment.

These costs will change slightly with different circumstances but in both cases, the variable costs are the major factors, and these will change little. In the case of the ground plots, the computer programming cost is high owing to the requirements of the quality assessment software. With the photo plots, the cost for the stereoscopes would be higher if all the instruments were purchased new. In this case, we are grateful to the West Australian MaritimeMuseum, the Department of Land Administration and The University of Melbourne for the loan of their stereotopes, which significantly reduced the cost of this project.

It should also be noted that more information was collected on the ground than from the photos. From Figure 35, it can be seen that an average of 131 minutes were spent on plot measurement. If gross bole volume only were assessed, and no wood qualities, this time could drop by at least half, reducing the total time per plot to 240 minutes, and the variable costs to $277. If the computer programming for quality sorting were not involved, then the total cost for the ground plots could be as low as $284 per plot. It may be more meaningful to compare this figure with the $38 per photo plot to obtain similar information.

7.3 Future developments

7.3.1 Continuous forest inventory

Data on growth and future predictions of short and long term yields are essential requirements for scientific forest planning and management. These requirements are usually met by establishing and measuring permanent sample plots within the forest at regular time intervals - called continuous forest inventory. Application of ground-based measurements to permanent sample plots is very expensive and slow and some times results in inconsistencies between successive measurements that result in costly rejection of results. Therefore, better measurement and recording systems are required.

Aerial photogrammetry, especially using photographs at very large scales, warrants closer attention in light of the recent technological advances described in this report. Their distinguishing characteristic is that they can provide a detailed permanent record of ground-quality measurements at the time of each measurement for quantifying and modelling growth and yield. These measurements could

Table 7

Costs of ground and photo plots.

	Ground plots (2600 samples)	Cost per Plot ($)	Photo plots (26 000 Samples)	Cost per Plot ($)
Fixed costs	Field equipment	4	Photo equipment	2
	Computer programming	23	Measurement equipment	2
			Computer programming and development salaries	4
		27		8
Variable costs	Salaries - crew	195	Salaries - aircrew and administration	2
	Salaries - administration	50	Helicopter hire	7
	Accommodation and travel	96	Film purchase and development	3
	Consumable equipment	3	Navigation and mapping	1
	Data processing	8	Accommodation and travel	1
			Salaries - measurement	16
		352		30
Total		379		38

include tree spacing and height, crown dimensions such as depth, area, and volume, and measurements for digital terrain modelling and three-dimensional modelling of trees and stands.

7.3.2 Applications to other forest types

The methods of large-scale aerial photography and geographically linked processing have the potential to be applied in many different forest types. For example large-scale photography procedures were developed in Canada in mainly coniferous forests, so the methods should be applicable in pine plantations in Australia. Indeed, Spencer (1972) has already demonstrated the potentials for applying large-scale photography over pine plantations in Victoria.

Thus, the advantages of this inventory system (particularly locational information and efficiency) prompted consideration for use in other inventories. The main areas of application would be for inventories in pine plantations, eucalypt plantations, karri regrowth and karri old-growth.

Measurement of the greater heights occurring in karri old-growth stands may be near the limits of the current photographic system geometry (see Section 2.4.2) but should still be achievable by experienced photo interpreters. Because of similar variability in forest type and log defects, the sampling intensities of the two phases would probably be similar and similar log quality assessment would be required.

In karri regrowth and other eucalypt plantations, however, the system is likely to be more accurate and straight-forward. With young eucalypts the height/volume relationship would be much stronger, requiring a lower intensity sample. The lower level of defect and smaller range of potential products would also mean that the second phase ground assessment could be made much simpler and faster.

One problem in these young eucalypt stands is the high crown cover densities which both obscure the ground and create darker conditions below the canopy, both of which can make height measurement difficult. Fortunately, there is little species variation in these stands so that species interpretation is not a problem and the canopy can be overexposed to allow better exposure below the canopy. The other alternative is to photograph under more limited full cloud conditions. These options are currently being tested.

The photomeasurement software does have a simple terrain model so that it is not necessary to see the base of each tree unless the ground is very uneven. The terrain model could be developed to handle more uneven surfaces, requiring ground readings only in open patches to establish the model. Tree height measurements then only require an additional reading at the top of each tree.

The second problem is where dense understorey obscures the ground, thereby making it difficult to obtain ground readings. Although this may sometimes be a problem in karri old-growth, it is almost always a problem in the regrowth forests where the understorey is usually 2 - 5 m tall, depending on age and site. Nevertheless, it is possible to measure heights above the scrub and then to add an allowance for scrub height to determine total tree heights.

In pine plantation inventories the height/volume relationship should be strong in stands with similar silviculture, thus requiring a lower second phase sample. Furthermore, as plantations are generally more uniform than native forest, the overall sampling intensity could be lower, although this would usually be negated by requirements for higher precision.

With current silvicultural practices in pine plantations, dense canopies would cause measurement problems on high quality sites prior to first thinning. Conversely, as the level of defect in pines is relatively low, the second phase ground measurements could be made very efficiently.

The wood quality assessment methods developed for the jarrah inventory have potential applications in other forest types where the patterns of utilization are changing because of the decreasing availability of old-growth resources. The concepts are also applicable to plantations where computer models based on taper functions and minimum diameter specifications are already used around Australia to predict grade recoveries. The addition of other quality data, covering factors such as sweep, branching, and forks, are merely extensions to these approaches.

Finally, the linking of inventory data with other geographic data through the use of a GPS and a computerized GIS has potential application in all forest types. Put simply, GIS provide forest managers with the tools required for more powerful and flexible planning of multiple forest resources.

7.3.3 New Geographic Information System developments

The incorporation of inventory data into the Department's corporate database and linking them to the GIS means that inventory results need no longer be a bewildering array of tables. Instead, the results can be accessed in a form that is 'presentable' and specific to areas relevant to a particular enquiry.

The inventory system will be made sufficiently user-friendly to allow dispersed interrogation at intelligent workstations in regional offices through the Department's extensive computing network. With plans for colour plotters at each regional centre, the GIS components of the system will be used for the production of high quality resource and planning maps.

Apart from tables of results and simple maps of the 'window' area, facilities are being developed for presentation of the data as elevation models of resource density. These would be three-dimensional graphic representations of volume data displayed over a background of topographic and management information.

A resource-seeking technique could also be developed in which the system searches the inventory data to determine an area from which a specified resource could be obtained. Spatial constraints would include haul distances and road networks classed according to road standards and economic factors.

The link to GIS will help to identify resources within different management categories, such as road and stream reserves and visual management areas. The effect of buffers of different sizes on the available resource could be modelled using the GIS.

As these applications are introduced, new possibilities will undoubtedly arise as management becomes more intricate and formally constrained.

7.3.4 Camera system developments

There is potential for significant improvement to the camera system described in this document and in the literature. To obtain the best quality photographs for detailed mensuration using analytical photogrammetric instruments, it is clear that metric cameras are required. The nature of aerial photography, however, places extra demands on the design of such cameras.

Especially for fixed-base photography, where the cameras are inaccessible during flight, the film capacity needs to be large (500 frames) and the aperture should be controllable from within the aircraft. Frame numbering (data imprinting) is necessary for efficient handling and cataloguing of the thousands of frames generated in a project of this size. Where the cameras are controlled by a computer/navigation system, as in this project, it is desirable for the film numbering unit to accept data directly from the computer, so ensuring exact correspondence between the computer records and film annotation.

Developments with forward motion compensation make it feasible that 230 mm (9 inch x 9 inch) cameras could be used for photography at this scale in a sequential, single camera arrangement with altimeter and tip/tilt recorder. The size and cost of the cameras would make them unsuitable for fixed-base photography. The advantages would be the increased area available for sampling at a given scale, but the benefit from this would depend on the application.

Video or CCD (charged couple device) cameras also have potential for future large-scale photography missions. Such cameras could reduce the cost of photography by removing the dependence on film, and open the way for automated measurement systems. These types of cameras are being implemented into industrial close-range photography (Fraser 1988) but in tightly controlled environments with regular targets which permit the use of image recognition to automate the digitizing procedure. It may be some time before this technology can be used in forest mensuration.

7.3.5 Refined photo-measurement systems and methods

To acquire the large quantities of photo measurements required in an inventory of this magnitude, it is imperative that the measurement systems are fast and efficient. This has only been partly achieved in this project by the computer programs written to accept parallax readings from the photo interpreters and calculate the tree heights. The next stage would be to fit encoders to the stereoscopes which would enable direct digital entry of readings to the computer without the operator having to look up from the image. X and Y encoders, as on the Zeiss Stereocord (Brun 1972), would also permit the digitizing of crown perimeters and other variables of interest.

The optimum solution with today's technology would be to implement analytical stereo digitizers (analytical plotters) which could correct for distortions in the camera lenses and could support more complex computations during the photo measurement process. This is slowly being achieved with the Adam MPS-2 instruments. Custom software has been written to model the ground surface in the sample plot, and to calculate the tree heights as the difference between the digitized tree tip and the ground model below it. The 20 m plot radius is also displayed on the computer screen, and a warning given to the operator if they move outside the plot area.

This is an improvement over the template method currently used with the older instruments, as it ensures that the plot radius is exactly 20 m. The most difficult step in implementing the analytical plotters is to ensure that the orientation of the photographs is calculated correctly from the fixed-base arrangement without reference to ground control. This needs to be done with the minimum orientation time since each photo pair involves only 30 minutes of measurements. Significant time must be spent with the programmers from the manufacturing company to ensure that all the requirements are met.

7.3.6 New applications of large scale photography and Geographic Information Systems

The potential applications for this photography are large - from simple stocking counts for regeneration and planting surveys (e.g. Hall 1984) to more complex measurements and interpretations for evaluating such things as site quality, growth, logging residues, fuel conditions (e.g. Morris 1970), species diversity and abundance, habitat characteristics, conservations values, stream conditions, erosion rates. Particularly in combination with the analytical machine, efficient measurement of many parameters in two or three dimensions is possible from the large scale photographs.

The linkage and processing of such photo data with geographic areas using GIS technology provides a powerful tool for wider application by resource planners and managers.