The Application of Large-Scale Video and Laser Altimetry to Forest Inventory

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Abstract

Traditionally, forest inventory in Australia has relied on mapping from medium scale (1:25,000) aerial photography and limited ground survey, with often poor results. This study describes the first trial in Australia of a helicopter-based remote sensing instrument including a: differential global position system; digital video, and laser profiling device, aimed at bridging the gap between mapping and ground survey. Analyses were undertaken to compare laser estimates of tree height, projective foliage cover, crown cover and large-scale video estimates of: stocking, growth stage, and species, with the ground surveys of the same variables. Coefficients of determination (r^2) ranged from 0.82 for projective foliage cover to 0.97 for tree height. A Chi-squared analysis of species proportions found no significant difference ground and video data. This study demonstrates that the integration of these technologies has the potential to replace and or supplement some information currently collected from ground surveys. It also has the capacity to generate ground quality information across inaccessible areas at a fraction of the cost of traditional forest inventory in Australia.

Introduction

For decades in Australia, medium scale (1:10,000-1:25,000) Aerial Photo Interpretation (API) has provided the primary means of stratifying large heterogeneous forests based on attributes such as overstorey species, stand height, crown cover and growth stage. Typically these photo interpretation strata are labeled through rapid ground reconnaissance surveys and then detailed plots are established within a sample of each strata to establish estimates of volume, growth stage, stocking and forest products. Although the variance characteristics of the plot information is usually well quantified, the same cannot be said for the classes mapped from API, with correlations between ground plots often less than 40 percent. The consequences of such a miss-match in attribute accuracy mean that calculations of standing volumes and sustainable yields may be rendered invalid due to unquantified errors in the area of each API stratum

The cause of the problem is twofold: the high cost of establishing enough plots to effectively measure the spatial heterogeneity of our forests; and the subjective elements of API which results in significant levels of variance within and between mapped strata.

The application of large-scale (less than 1:5,000) aerial photography has long been recognised as a valuable tool for bridging the gap between ground measurements and API. This technology has demonstrated the capacity to create measured “photo-plots” (i.e. individual tree measurements) as part of a multi-stage sampling process to more effectively link ground measurements to API. Although the use of large-scale analogue photography has been operational in countries such as Canada for many years (Spencer and Hall, 1988, Pitt, 1997, Nielson, 1997, Spencer, 1997), there has been very little application in Australia, apart from an inventory of 2 million hectares of forest in Western Australia (Spencer, 1992). The reasons for the lack of adoption are possibly due to a combination of poor understanding of the methods and a perception of high cost of data capture, film processing, the labour-intensive costs of parallax-based measurement of stand variables, the need for specialised camera equipment, and photo-measurement. This is in spite of the Western Australian study that demonstrated that ground quality data could be collected at 1/10th of the cost of traditional ground surveys.

Another remote sensing technique previously untested in Australia's forests is that of laser altimetry, which has the capacity to measure ground elevations, tree height, and a range of other canopy characteristics useful for estimating stand variables such as canopy density and depth.

During the last 15 years a number of experiments have been conducted to determine vegetation characteristics using airborne laser altimetry devices (e.g. Nelson *etal*, 1984 and 1988; Nilsson, 1994, Jacobs, 1993, Ritchie, 1996 and most recently Naesset, 1997). Laser altimetry transmits a laser pulse which determines the distance to a target according to the time taken for the pulse to travel back to the sensor. Initial interest in laser altimetry centered on terrain mapping by exploiting the laser's ability to penetrate spaces between vegetation in order to derive ground elevations. In 1984 Nelson *etal* found the noise created by vegetation which made terrain mapping difficult in some areas showed a great deal of potential for determining tree canopy height and changes in canopy density.

Although the earlier experiments showed a great deal of promise in describing tree height and canopy characteristics, they were hindered not by the accuracy of the laser measurements, but by the problems in determining the location of the aircraft (Nilsson, 1994) in the days prior to Differential Global Positioning Systems (DGPS). Laser altimetry systems have also been hindered by the fact that it is very difficult to interpret raw coordinate data without image information in the same coordinate system.

Recently a system has been developed in Australia by Southwest Pacific Helicopters that has overcome many of these problems with the integration of a helicopter-based laser rangefinding device, Charge Couple Device (CCD) color video camera and DGPS facility which records the x, y and z location of the helicopter onto every frame of the video. Given the potential utility of large scale photography and laser altimetry, the Bureau of Resource Sciences and Queensland Department of Natural Resources have recently undertaken the first trial in Australia of the system described above. This promises to overcome many of the financial and labour burdens of large scale photography, and potentially replace or supplement a large amount of inventory currently being undertaken from ground sampling.

This paper demonstrates the capacity of these technologies to provide quantitative data on stand height, growth stage, crown size, canopy density and stocking at a fraction of the cost of traditional inventory techniques currently used in Australia.

Study Area

The trial was undertaken in St Marys State Forest approximately 50km south west of Maryborough in southeast Queensland. The site was selected because it has been the focus of several long-term silvicultural and ecological studies which could provide data for this project. There are also plans to undertake further remote sensing studies which may take advantage of the data collected from this study.

The study area consists of approximately 20,000 hectares of native forest. Most of the area is mixed dry eucalypt forest dominated by *Corymbia citrodora* (spotted gum), *Eucalyptus fibrosa* (broadleaf red ironbark), *E. siderophloia* (grey ironbark), *E. acmenoides* (white mahogany) *and E. intermedia* (red bloodwood).

The majority of the area has been selectively logged at least once, with most forest stands consisting of a range of age classes and size classes. The area is also grazed to varying degrees and has been regularly burned. The topography is gently undulating with local relief usually less than 50 metres. This range of management and disturbance regimes has resulted in an extremely heterogeneous forest which provides a challenging testing ground for remote sensing applications.

Within the larger study area, permanent Detailed Yield Plots (DYPs) have been established by the Queensland Forest Service in order to monitor growth and yield of the forests under a range of silvicultural regimes. Eight of these plots measuring 50 metres by 100 metres (0.5ha) were chosen for the study which provided a range of conditions and forest types within easy road access.

Materials and Methods

Instrumentation

Southwest Pacific Helicopters of Kingscliff NSW developed the system described below. Due to the commercial nature of the technology, only a general description of the instrumentation is provided. The airborne platform consists of a laser rangefinding device and colour Charge Couple Device (CCD) video camera mounted on a McDonnell Douglas helicopter equipped with a real-time Differential Global Positioning System (DGPS).

The laser device used in this study was a pulsed infrared laser transmitting and receiving 248 signals per second. The beam divergence of the laser is 3 milliradians which produces a roughly circular “footprint” on the ground of 0.003 times the flying height above the ground. In this study the helicopter was flown at between 30m and 50m above the tree canopy at a speed of 8-14 metres per second (30-50km/h). This resulted in a laser “footprint” of 10-15cm at canopy height, and a sampling interval on the ground of 3-5cm (each sample overlaps the previous sample).

The timing mechanism of the laser receiver allows the recording of a return laser pulse to within 1 nanosecond ($1x10^{9}$ seconds). Ritchie (1993) found that similar recording precision allowed vertical recording accuracy of within 5cm for a single measurement. Digital data from the laser are recorded onto a portable computer and include information on DGPS readings, aircraft headings, altitude, range to target, and aircraft gyroscope and accelerator information. The gyroscope and accelerator are used to correct the DGPS readings to the location of the target, rather than the DGPS antenna. The DGPS is updated every 1/25th of a second, and simple linear interpolation is used to attach the DGPS reading to each laser return signal.

A Charge Couple Device (CCD), color SVHS video camera bore-sighted to the laser was used to image the flightpath of the helicopter. Each video frame captured every 1/30th of a second contains information on time, date, DGPS reading, heading, altitude and ground speed. Given a flying height of 30-50m above the tree canopy, a nominal photo scale of 1:600-1:1000 was attained which enabled individual trees and features on the ground such as logs to be identified.

Software was written by Geoarc Australia to syncronise the video and laser information and allow their simultaneous display using WINDOWS digital AVI files and customised graphing software. The end result is a system that allows the precise location of laser data relative to features on the video image.

Both laser and video data were attained over the 8 DYPs including several hundred metres either end of the plots. Tarps were placed in the centre of each plot incase problems were encounted with the DGPS navigation. The tarps also assisted the pilot to ensure that the flightpath coincided as close as possible to the centre of the plots. Each plot also had map coordinates derived from a portable DGPS. An example of one of the laser profiles is shown in Figure 1.

Following the collection of data from the helicopter on March 16, 1998, 1 day was required to post-process the laser data and framegrab video data from the analogue SVHS tape onto digital video files, which were written to CD. Fieldwork was undertaken 2 days after the flight.

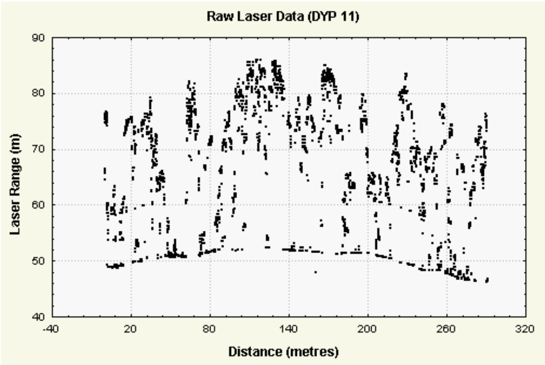


Figure 1

Ground Data Collection

In order to ensure that transects placed on the ground coincided as close as possible with the laser data, a laptop computer loaded with the digital video was taken into the field to enable features that passed through the principle point of the video to be located on the ground. Once specific canopies or features such as logs or sticks were identified on the ground that intersected a crosshair on the computer screen a tape was laid on the ground. In areas where the forest canopy was too dense to locate features on the ground, or where shadows confounded identifying the location of the laser strikes, the helicopter compass bearing information recorded on the video display was used in conjunction with a hand-held compass to lay out the transect tape.

Seven transects of 200m and one of 100m were established which extended through the 100m long DYPs. Field estimates of species, growth stage, top height, height to branching, diameter at breast height (DBH), crown width, crown gap and distance along transect were recorded within each DYP. Any tree whose canopy came within 2 metres of the tape was recorded. Field estimates of species and growth stage (Jacobs, 1955) (regrowth, pole, early-mature, mature, late-mature, over-mature) were recorded by a trained ecologist with experience in the region. Estimates of tree topheight and height to branching were done using a Criterion Laser Rangefinding device mounted on a tripod. Two operators were used on one of the transects to measure the heights of the same trees in order to calculate the precision of ground-based height measurements. The permanent tag number on each tree was also recorded to allow comparisons of these data with the Forest Service.

Estimates of crown cover derived from crown width and gap measurements were done following the procedures of McDonald *etal* (1990). Many of the transects had dense areas of regrowth that did not allow nor warrant the measurement of every tree. In such cases an average height estimate was made and the length of transect dominated by the regrowth was recorded. Crown width and gaps were assumed to be 1m and 0m respectively to allow systematic recording. In all, 134 trees were recorded within the 8 transects, in addition to the linear estimates of regrowth.

For the entire length of the seven 200m transects and the single 100m transect, estimates of Projective Foliage Cover (PFC) of overstorey trees was measured at 1m intervals using a tube and crosshair method after Specht (1970). This method uses a tube with a crosshair attached to a rod 2m above the ground. A mirror placed at 45 degrees at the bottom of the tube allows an operator to record the presence or absence of green leaves (GL) or branches in the canopy vertically above. For a given length of transect, the PFC percent is equivalent to the number of GL occurrences divided by the total number of observations. In theory this measurement should be proportional to that responded to by the laser from above the canopy.

Laser and Video Data
Between 4000 and 7000 laser strikes were recorded for each transect depending on the speed of the helicopter. Unfortunately, due to operator error, laser data for one of the eight transects was not saved onto the helicopter's computer, leaving 1.35km of laser data for analysis over 7 transects.

Since the raw laser data are purely the range from the helicopter to an unknown target, they must be classified as ground or vegetation responses before some forest variables can be estimated. Although Geoarc Australia have written algorithms to do this, for this study the laser strikes were classified using a supervised approach. The data were imported into a Geographic Information System (GIS) and the ground was defined using a line of "best-fit" between the laser strikes. In order to replicate a minimum height above ground of 2m used for PFC estimates, the GIS was used to select all laser strikes within a parallel line 2m above those classified as ground strikes. The laser data were also converted to the same coordinate system as the transect tape to allow coincident graphing of laser and ground data.

Due to the heterogeneous nature of eucalypt crowns, and the likely error in registering the ground and laser data, it is probable that summarising either laser data or ground PFC data over short distances would create considerable noise in any comparisons. To avoid this problem both ground and laser data where summarised for each transect.

To derive a total estimate of crown cover from the laser for each transect, the data were graphed as a line with all points less than 2m above the ground highlighted (shrubs, small regrowth). Using the vertical lines on the graph (above 2m) to delineate the edges of crowns, the total length of "crown" and total length of "gap" were simply measured off the active graphing display.

Due to the very narrow laser beam, it was highly likely that a large number of the "candidate" trees measured on the ground would not have returned a laser response. To overcome this the laser data were graphed with a mark on the x-axis to locate the distance along the transect of each tree measured. Using this method is was quite obvious where the laser had not struck a tree that was measured on the ground. Once these trees were removed from the ground data it was possible to make comparisons between ground and laser data for each tree. The maximum height of the laser strike was calculated at the distance along the transect coinciding with each ground-measured tree.

Originally it was planned to undertake estimates of total stocking and growth stage by stereoscopic assessment of hardcopy videography. Due to technical difficulties (now overcome) converting the SVHS alogue video to digital files it was not possible the produce still images of high enough quality for visual interpretation. Therefore all interpretation was done using a broadcast quality video player and screen which allowed the video to be paused without significantly degrading the image quality. The DGPS readings displayed in each video frame were used to locate either end of the transect and the ground speed also displayed on the video was used to validate the distance traveled along the transect. A crosshair was then marked on the screen and any tree crown which came within 2m of the crosshair was interpreted according to its species and growth stage as with the ground measurements. Total stocking was simply the sum of trees recorded along the transect (as per the ground data) and each growth stage was summarised in proportion to the total stocking.

Results and Discussion
Analyses were undertaken to compare estimates of the following variables collected from traditional ground transects and the same variables estimated from the airborne system:
tree height; Projective Foliage Cover (PFC); total Crown Cover (CC); total stocking; growth stage proportions, and species abundance
First the heights of 80 trees measured on the ground were regressed against the estimated height from the laser (Figure 2). The coefficient of determination (r^2) was calculated to be 0.97 with all points tightly clustered around the 1:1 line. Several previous studies (Aldred and

Bonner,1985, Nelson *et al*, 1987 and Naesset, 1997) had found that laser data significantly underestimated the mean dominant height of some forests by up to 4 metres. These large differences were due however, not to the nature of the laser, but rather in the methods used to summarise the data. In the above studies the mean dominant height of forest stands was calculated by summarising the entire "non-ground" laser response. The underestimate of tree heights was in fact due to the laser sampling the edges of canopies more often than it samples the tops of the tree crowns. In this study only the highest point in each measured crown was included in the summary which resulted in height measurements at least equal to if not more accurate than ground measurements.

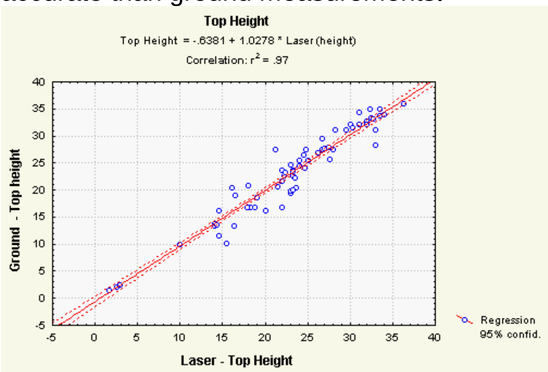
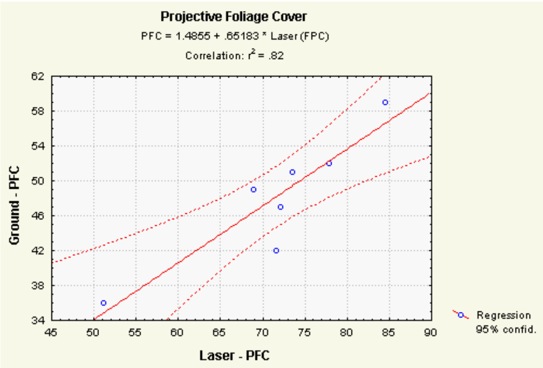


Figure 2

The broad and interlocking nature of dense eucalypt forest crowns can lead to a great deal of subjectivity in locating and measuring the actual top of the crown, even with sophisticated rangefinding equipment. To test the precision of ground measurements two operators measured the same trees in one of the DYP's. On average both operators measurements were within 7 percent, however, 2 of the 9 trees sampled differed by 17 and 19 percent. Differences of 5m in operator interpretation of tree tops suggest that the airborne laser method is in fact a more accurate and precise method of measuring trees. It is also likely that the difference would become even more evident in tall dense forests and plantations.

Both the laser data and ground data were pooled to provide a summary for each transect, effectively providing 7 samples for analysis. The proportion of laser pulses striking vegetation 2m above the ground was regressed against the ground transects. The coefficient of determination (r^2) was calculated to be 0.82 (Figure. 3.). Although the laser data generally overestimated PFC, all but 1 transect was tightly clustered around a 1:1 line, suggesting that ground measurements can easily be predicted. In order to identify the reasons for the significant (10% more than other transects) overestimate of DYP 8, the transect was subdivided into two, 100m transects and again summarised. Using the videography, the location of the overestimate was found to be a relatively dense patch of regrowth that dominated the second half of the transect.

There are two potential reasons for the overestimate. First, the regrowth was approximately 15m tall (estimated from the laser), about half the height of adjacent mature trees being used as the basis for the helicopter height above the trees of approximately 30m. The effective laser footprint would therefore have been approximately 10cm wide on the taller trees and 15cm wide by the time it struck the more dense regrowth which may not have allowed the laser to penetrate to the ground. Second, the PFC ground observations may have been made through a less dense portion of the regrowth. Given that several other transects had significant proportions of regrowth that were not affected to the same degree, the second reason seemed the most likely. The second half of DYP 8 was omitted from a second regression which gave a coefficient of determination (r^2) value of 0.934 (Figure 4.), again with transects clustered around a 1:1 line. Further analyses need to be carried out to ascertain the impact of laser footprint size on estimates of PFC, however, given variable nature of these forests, the estimates of PFC from laser data are well within the measurement tolerances associated with ground measurements.



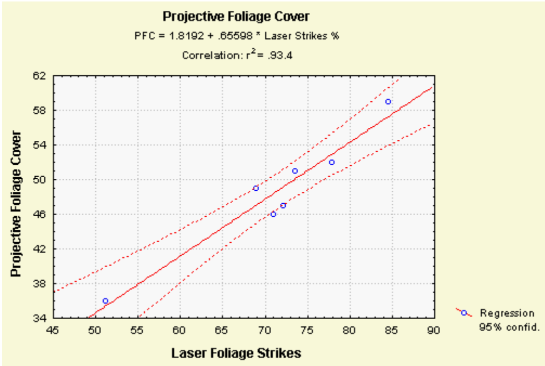


Figure 3 **Figure 4.**

The density of forest canopy was estimated using the two measures most commonly used in Australia, percent Canopy Cover (McDonald *etal*, 1990) and Projective Foliage Cover (Specht, 1970). The first measure looks at the total proportion of the ground that is covered by tree canopies assuming the canopies are opaque. It is usually measured from the ground by estimating the average crown widths and gaps along a defined transect. In forestry applications CC is most often estimated against a “standard” using aerial photography as a surrogate for stocking. PFC (previously described) is most often used in ecological studies and is a more appropriate measure of photosynthetic potential relating to remote sensing studies (than CC). However, it is very rarely used due to the increased measurement time. Both measures have their problems: CC can be highly prone to operator error and although PFC is less prone to operator error, the heterogeneous nature of forests often requires a large number or lengths of transect before the variance in the data is stabilised.

Crown cover (CC) data estimated using the laser was regressed against the ground measured variable. The coefficient of determination (r^2) value was calculated to be 0.903 (Figure 5.), with all transects clustered around a 1:1 line. The estimates of CC from the laser were all within 5-10 percent of ground measurements. These results are also supported by Ritchie (1996) who found laser measurements to be the equal of ground measurements of canopy cover. Crown cover could also be calculated by digitising the boundaries of tree crowns from stereo interpretation of video images. This will be investigated in further studies.

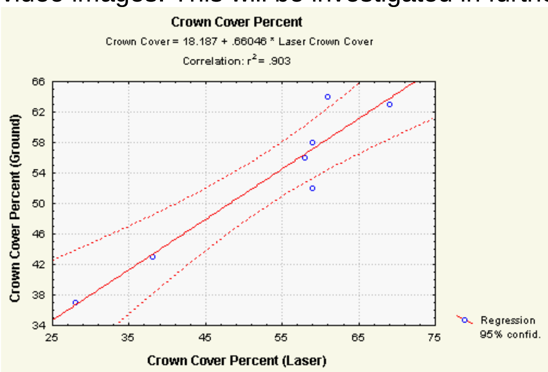


Figure 5.

Estimation of total stocking and growth stage proportions are vital to the prediction of current standing volumes and the initialisation of growth models to predict future forest growth. Growth stage is also highly relevant to habitat studies which require information about future recruitment of “oldgrowth” forest. Due to the highly disturbed nature of the forests in the study area, there were too few over-mature trees to consider them in the analyses. Also due to the relatively subjective nature of separating a “pole” from an “early mature”, or an “early mature” from a “mature” tree the data were aggregated into 3 relative age classes: regrowth, mature, senescent, and only the first two classes were analysed.

Regrowth and mature trees were summarised according to their proportions of total stocking and regressions were analysed between the ground and video data. The coefficients of determination (r^2) for both age classes were found to be 0.85 (Figure 6 and 7). Proportions of each age class were again close to the 1:1 line (slopes of 0.86 and 0.89 respectively) and could easily be used to predict age class proportions on the ground. Total stocking estimated from the video and ground data were also regressed. The coefficient of determination (r^2) was 0.895 (Figure 8.), again with a slope of close to 1:1. One transect was identified to be outside the 95% confidence limits. The video stocking overestimated the ground stocking by 20%, although both regrowth and mature proportions were almost identical. The most likely cause of this was a small difference in the lengths of the video and ground transects.. The original intention of this study was to use stereo interpretation of high quality imagery, rather than simple on screen interpretation. Given the fact that growth staging of trees is generally highly reliant on the shape of the crown, it is probable that such estimates would improve with stereo interpretation. It is also likely that as the density of forest increases, the capacity to see regrowth or suppressed trees below the canopy will decrease which will require correction factors to be developed from ground data.

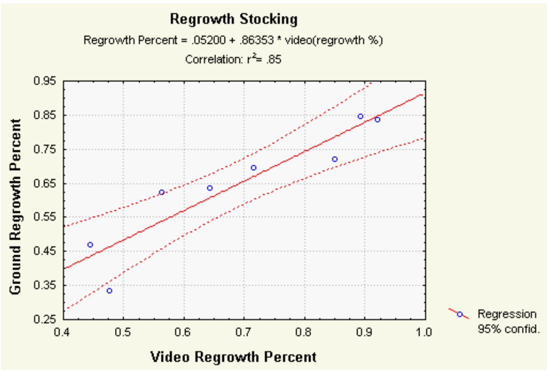


Figure 6.

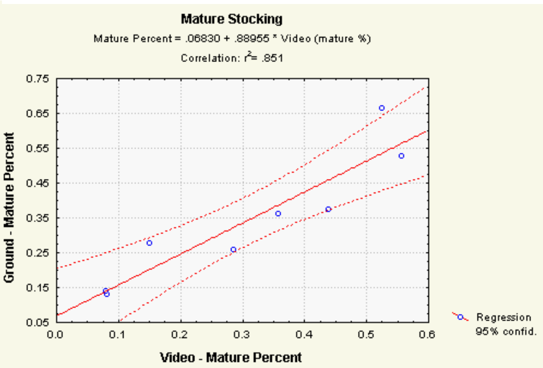


Figure 7.

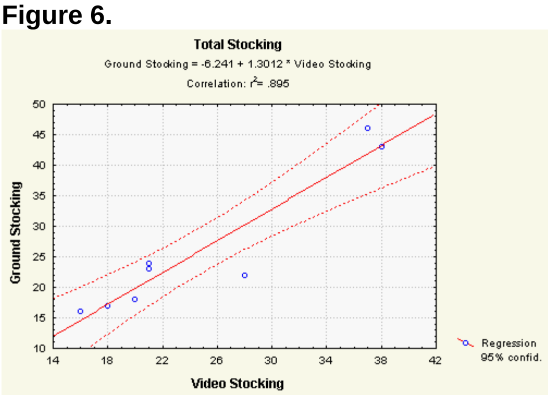


Figure 8.

Due to the relatively small sample, species data were grouped into categories of Ironbarks, Stringybarks, or Gums. In order to take account of any differences in the numbers of trees recorded, the expected numbers of trees in each class were calculated by multiplying the number of trees observed in the video interpretation by the ratio of the ground data in a given class to the total number of trees observed on the ground. The differences in proportions of each class were then tested using a Chi-squared analysis. A p-value of 0.11. suggested that there is no difference in species group proportions between the video and ground assessments. It appears that it is harder to confidently identify a tree type using video interpretation, but in general, the proportions of species groups identified is the same using video as ground assessment. The strength of this relationship will always depend of the ability, and local knowledge of the interpreter.

Recent Developments

Since this study, Southwest Pacific Helicopters and Geoarc Australia, have re-developed and improved the majority of the instrumentation. The laser rangefinding device has been upgraded to transmit 1000 pulses per second (instead of 248), and the footprint of the laser has been decreased from 3 milliradians to 1 milliradian. The laser has also been programmed to receive first and last returns. The 880 line CCD, SVHS video has been maintained, however, the analogue video data capture has been replaced with an end-to-end digital data capture system which enables imagery to be captured without any loss in resolution. This will enable stereo interpretation and measurement from near-photo quality imagery.

Conclusions

The integration of differential global positions systems, state of the art digital video (or digital camera) systems, laser rangefinding devices and flexible airborne platforms such as helicopters, provide the capacity to capture ground quality (or potentially better) information at a fraction of the cost of traditional inventory. Such a system will allow data to be collected in previously inaccessible areas and will provide a permanent record of locations that can be utilised in projects outside original inventory objectives.

The monitoring of forest ecosystem processes using ground sampling is often confounded by poor precision of locational information which reduces the capacity to calibrate airborne or satellite remote sensing data. These technologies bridge the gap and provide locational accuracy often unattainable in densely forested areas.

Australia's commitment to sustainable forest management and greenhouse gas initiatives will require a complete re-think of the methods used to monitor Australia's 156 million hectares of forest and woodland, particularly in relation to forest condition and carbon sinks and sources. Given the significant technical and financial limitations of wall-to-wall mapping and monitoring, more efficient methods of sampling need to be developed. A system such as the one described in this study (used in combination with focused ground survey) could provide the means for establishing baseline strategic inventories, and monitoring changes in condition and biomass within a multi-stage sampling and mapping framework.

Acknowledgments

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