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FOREST ECOSYSTEM RESEARCH AND ASSESSMENT

Department of Natural Resources
Natural Sciences Precinct

Queensland Government
Department of Natural Resources

– Airborne Laser Scanning –
A Tool for Monitoring and Assessing the Forests and Woodlands of Australia

Laser Altimetry Report 1

June 2000

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Acknowledgments

The authors would like to thank:

- QDNR (Tim Danaher in particular), Forestry Tasmania (Martin Stone and Tim Osborn in particular), BRS, AAM and QUT for financial and in-kind support
- Dave Jermyn, Celia Mackie and Dave Harris from QDNR for the field data collection
- Peter Todd from QDNR for organising the survey work and site selection
- Richard Statham, Ian Craig and Stephen Hughes from the Bundall regional office for the detailed survey work at the Springbrook sites
- Staff from Gassman & Associates for setting up base stations and establishing control points for the Springbrook data

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1 ABSTRACT

A methodology for forest inventory in south-east Queensland utilising airborne laser scanning was assessed. Trials were conducted in open dry sclerophyll forest in St Marys State Forest near Maryborough and dense wet sclerophyll and complex notophyll vine forest near Springbrook in the Gold Coast hinterland. Use of a laser scanner for the production of digital terrain models (DTM's) of the ground and derivation of canopy height and foliage density was evaluated.

DTM's were produced using cell-based modelling and triangulated irregular networks (TIN's). Very high levels of precision were achieved in areas of relatively little understorey (standard deviation of 13 cm to 20 cm). The accuracy was reduced to approximately 1 meter where very dense understorey obscured the ground and limited the intensity of laser ground hits.

Canopy density (foliage projected coverage) was derived for eight 100 meter transects, with a coefficient of correlation of 0.91 between ground and laser derived values. Seasonal variation between capture of laser and ground based data (eg. laser data capture occurred in July 1998 for all sites, but fieldwork in St Marys in May 1998 and in Springbrook in July 1999) could account for some variability.

Tree height was recorded at seven locations. For sites with low laser sampling intensity the top tree height was slightly underestimated whereas there was no difference in ground and laser measurements for the other sites.

2 INTRODUCTION

In the face of growing public scrutiny, and decreasing financial resources, forest managers are increasingly under pressure to deliver efficient and effective means of monitoring forests. Recent international policy initiatives such as the Montreal Process and Kyoto Protocol in particular have contributed to this.

The Montreal Process, signed by the Australian Government and a number of other nations in 1998, contains a commitment to the continuing monitoring of indicators of forest sustainability. Subsequent work within Australia by the Montreal Implementation Group and in conjunction with Regional Forest Agreements has transferred some of this responsibility to the States.

The Kyoto Protocol contains a requirement for Australia to achieve (and report against) defined targets in greenhouse gas emissions. Forest biomass is a major sink (through tree growth) and source (through tree clearing and other forest management) of greenhouse gas.

Queensland has the second most extensive area of forest in Australia (52 million ha) which whilst relatively low in productivity and value pose a significant challenge in terms of adequate long term assessment and monitoring. Sampling utilising remote sensing technologies, such as laser altimetry, offers cost-effective tools that will be part of a comprehensive monitoring system.

Airborne laser scanner (ALS) data provides a direct measure of forest structure. The technology in most cases is also highly flexible, being mountable in fixed or rotary wing aircraft. It can be used in a variety of modes and sensitivities to establish ground and canopy surface profiles as well as vertical sections through the stand. As such it is a useful tool for assessing forest structure and density (hence potential resource), height (hence productivity), condition (hence habitat quality). Sampling over time and providing detailed information on changes to canopy heights and foliage density could provide a cost-effective method for monitoring carbon fluxes and trends in forest condition.

Similarly to other remote sensing technologies, information derived from laser scanning systems becomes particularly useful when integrated with other datasets. For example high-resolution digital video or large-scale aerial photography can be used to obtain forest type, species and growth stage information. Combining this with structural information provided by laser scanner data could provide an effective inventory tool.

Until recently, airborne laser altimetry had been largely untested under Australian conditions. Initial trials in 1998 (Tickle et. al., 1998) using a laser profiling and digital video system produced excellent results and highlighted the potential of airborne laser instruments for broad forest inventory work. Following this the Department of Natural Resources was approached by AAM Surveys to evaluate a laser scanner imported to Australia for a short time. Further information on the analysis, problems and general findings of this and other ALS trials by AAM in Australia is available from Jonas et al. (1999) and an internal report (Fraser et al. 1999).

Given the limited funding available tests were necessarily restricted in their geographic extent but attempted to sample across a range of sites. The study was conducted across three areas with variable forest type, density and terrain. The data from one of these sites, the open woodland near Dingo (approximately 120 km west of Rockhampton) has not been analysed yet. Results for the open dry sclerophyll forest site in St Marys State Forest near Maryborough and the wet sclerophyll/complex notophyll vine forest site near Springbrook in the Gold Coast Hinterland are included in this report.

The trial was jointly sponsored by the Queensland Department of Natural Resources (QDNR), the Bureau of Rural Sciences in Canberra (BRS), Forestry Tasmania, AAM Surveys and Queensland University of Technology (QUT). The objectives were:

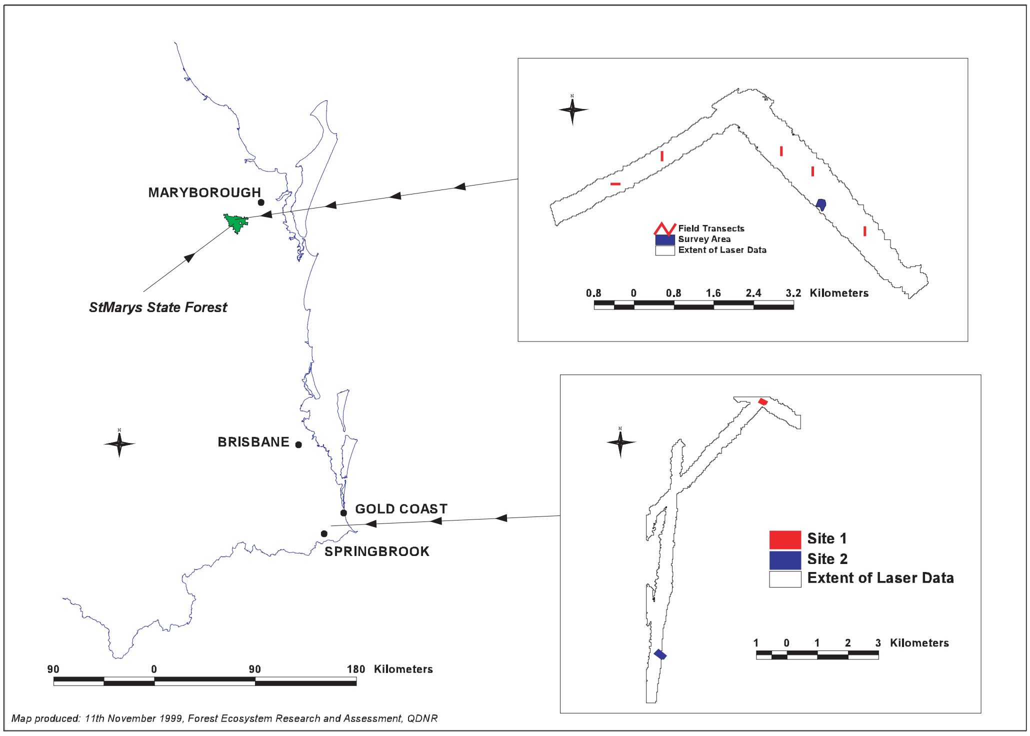
- to evaluate the usefulness of the laser scanning for creating ground DTM's, and
- to evaluate its usefulness for assessing foliage density and tree height (ie. as a sampling tool).

Another key objective is to integrate the laser data with large-scale photography or video data to develop a comprehensive monitoring system. This work has not been completed and will be part of on-going research. Other current relevant research includes a QDNR funded project which includes laser profiler and digital video data capture and field measurements over three sites four times a year for two years. The aim of this project is to assess seasonal variation, the potential for monitoring over time and defining the sample sizes required to represent the variability in a chosen forest stand.

3 LASER DATA CAPTURE AND FIELD WORK

In July 1998 airborne laser scanner data was obtained for an area of about 550 ha in St Marys State Forest near Maryborough and 650 ha in the Gold Coast hinterland near Springbrook (Figure 1). Both study areas were flown at first return to provide detailed canopy density and height information and last return to penetrate to the ground on a regular basis. Base-stations were set up and GPS correction details collected prior and during the data capture process for each of the sites. The sampling intensity was increased for the denser Springbrook site by reducing the laser swathe from 400 to 300 meters.

Figure 1 The Springbrook and St Marys Study Areas



St Marys State Forest is located about 25km southwest of Maryborough. Most of the area is open dry sclerophyll forest. The principal species include *Corymbia citriodora, Eucalyptus acmenoides, Corymbia intermedia, Eucalyptus fibrosa* subsp *fibrosa, E. siderophloia* and *Corymbia trachyphloia*. Site elevation is between 20 – 250 m and the terrain is lightly dissected. Crown cover is generally between 50%-80% (DNR 1998), except for areas that have recently been logged.

136 survey points were collected within a subset of the ALS data by AAM staff. A local base station was established using dual frequency GPS receivers. Following this a number of temporary station were set up using single frequency GPS and survey points were collected through radiations by Total Stations. Information on forest attributes was available for five sites as a result of a trial in 1998 assessing a laser profiling and digital video system (see Tickle et. al. 1998). This included individual tree heights and Foliage Projected Cover (FPC) measurements along a 100 meter transect at each of the sites.

The Springbrook area was selected as it ranges from moist to wet sclerophyll forest with areas of complex notophyll vine forest. There is a large range of species in the area. Site elevation is between 30 to 600 meters including some very steep terrain. Most of the forest covered by the laser swathe is in the 80%-100% crown cover class (DNR 1998).

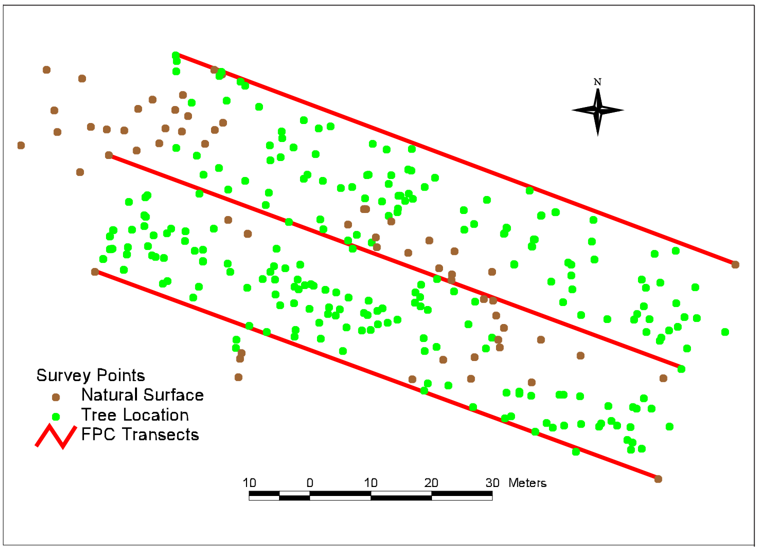
In July 1999 a three-day fieldtrip to the Springbrook area with five DNR staff, including three regional surveyors from the Bundall office, resulted in two sites being visited. Point data was collected using a real-time kinematic GPS unit to provide sub-centimeter accuracy to establish control and a Total Stations system to survey below dense canopy. The first site was located in the centre of the laser swathe and has dimensions of 40 m x 100 m. It had a dense overstorey, but relatively little understorey. 310 points were surveyed including the location of the 249 trees covered by the plot area.

The second Springbrook site was located at the edge of the swathe. It is mostly an open area of 70 m x 100 m near a house surrounded by very dense understorey 6-8 meters in height. The location of each of the 50 trees within the plot was surveyed, as well as 38 natural surface points which included 20 meters of a track leading into dense understorey that was within the scanner swathe (see Figure 7 on Page 11).

Figure 2 Fieldwork at Springbrook Site1

Foliage projected coverage was measured within the first site along three transects (Figure 3). For each tree at both Springbrook sites diameter at breast height (DBH), species, growth stage and canopy dimensions in four directions were recorded, as well as canopy height information using a handheld laser range finder. The individual tree information has not been analysed yet and will be part of future research.

Figure 3 Springbrook Site1 – Field Data Collected



FPC was measured at one meter intervals along a 100 meter tape using the method described by Specht (1970). This involves the use of a tube with internal crosshair which is attached to a rod two meters in length. A mirror placed at 45 degrees at the bottom of the tube allows an operator to record the presence or absence of green leaves or branches in the canopy vertically above. For a given length of transect, the FPC percent is equivalent to the number of green leaf occurrences divided by the total number of observations.

4 PROCESSING OF LASER DATA

Following data capture the information then went through a number of processing stages commonly applied to airborne laser scanner data. These are generally sequential in nature, with the data quality improving at each stage. They include:

1. **Data reduction** – which involves combining the position, orientation and ranging data to compute a set of 3D xyz coordinates in a spheroidal coordinate system;
2. **Datum refinement** – whereby the coordinates are transformed onto the required datum. This typically involves reducing the data to orthometric heights using a geoid model and/or transforming and testing that the data is in the project's horizontal and vertical coordinate system, usually using a series of ground-truth points.
3. **Accuracy refinement** – a properly defined ALS project offers survey redundancies; these may involve cross-strips, swathe overlaps and/or ground-truth points. This redundancy can be used to improve the data accuracy, particularly at the swathe edges.
4. **Classification refinement** – the data reduction process classifies the data into "ground" and "non-ground" laser strikes using a recursive morphological filter based on changes in slope defined by points categorised as "ground". Further refinement is possible by utilising different classification algorithms and all available data sources to optimise the surface definition required by the project. This step is particularly important in vegetated areas to remove "ground" laser strikes from undergrowth and forest litter, or to identify tree crowns from "non-ground" strikes.

The initial data reduction phase was completed in Holland by Geodan Geodesie B.V. with subsequent processing done by AAM Surveys in Australia. Recent technology transfer now enables all processing to be undertaken in Australia. Steps 1 and 2 can be done overnight, with the following steps dependant upon the level of refinement required.

5 ANALYSIS AND RESULTS

5.1 DIGITAL TERRAIN MODELS OF THE GROUND

Both, cell-based modeling and triangulated irregular networks (TIN) were used to produce digital terrain models (DTM's) of the ground using the laser scanner datasets (for further detail on topographic modelling using ALS data in Australia see Byrne et al. 1999). The accuracy of these surfaces was assessed using survey points collected in the field. Table 1 shows the number of survey points, the area they were collected in and the sampling intensity of laser ground hits.

Table 1 Laser Sampling Intensity for the Survey Areas in St Marys and Springbrook

Site	Sampling Intensity of Laser Ground Hits (m^2 per hit)	Survey Area (ha)	Number of Survey Points
St Marys Survey Area	11.5	2.25	136
Springbrook Site 1	1.15	0.4	310
Springbrook Site 2	2.4	0.7	88

Tables 2 to 5 show the results of the cell-based modelling for a number of cell sizes for each of the survey sites. The TOPOGRID function in ArcInfo was used to generate the DTM's.

Table 2 Accuracy of DTMs at Various Cell-Sizes for the St Marys Survey Area

Cell Size (m)	Standard Deviation (m)	Mean (m)
0.5	0.15	-0.44
1	0.14	-0.44
2	0.14	-0.44
3	0.14	-0.44
5	0.13	-0.46

The size of the mean suggests that there is either a datum difference between the field survey and the ALS survey (see "Step 2 – Datum Refinement") or a systematic error in the laser capture process. It was an error that was also found at both Springbrook sites and can be corrected if required. Of more importance is the standard deviation of around 14 cm which indicates relative positional accuracy. Varying the cell size makes little difference for the St Marys survey area. The most likely explanation for this is the gentle terrain (ie. there is little change in terrain in an area of 5 m x 5 m or 25 m^2). It also implies that the sampling intensity (one hit per 11.5 m^2) for laser ground points could have been reduced to produce a similar DTM accuracy.

Similar results were achieved using a TIN. Deriving a height from the ALS model at each of the 136 ground test points quantified the accuracy at a standard deviation of 0.13 m.

Table 3 Accuracy of DTMs at Various Cell-Sizes for the Springbrook Site 1

Cell Size (m)	Standard Deviation	Mean
0.5	0.214146	-1.10204
1	0.203715	-0.99951
2	0.310847	-1.26293
3	0.438247	-1.25584
5	0.708934	-1.36383

The above results indicate that a one meter pixel size provides the most accurate DTM. The ground sampling intensity for this particular plot is one hit per 1.15 m^2. Note that the intensity for the entire Springbrook laser area is less than that. This site has a higher intensity, as it is located close to the centre of the laser scan swathe.

The TIN model provided the best result with a standard deviation of 0.19 m.

Figure 4 Standard Deviation of DTMs for Springbrook Site 1

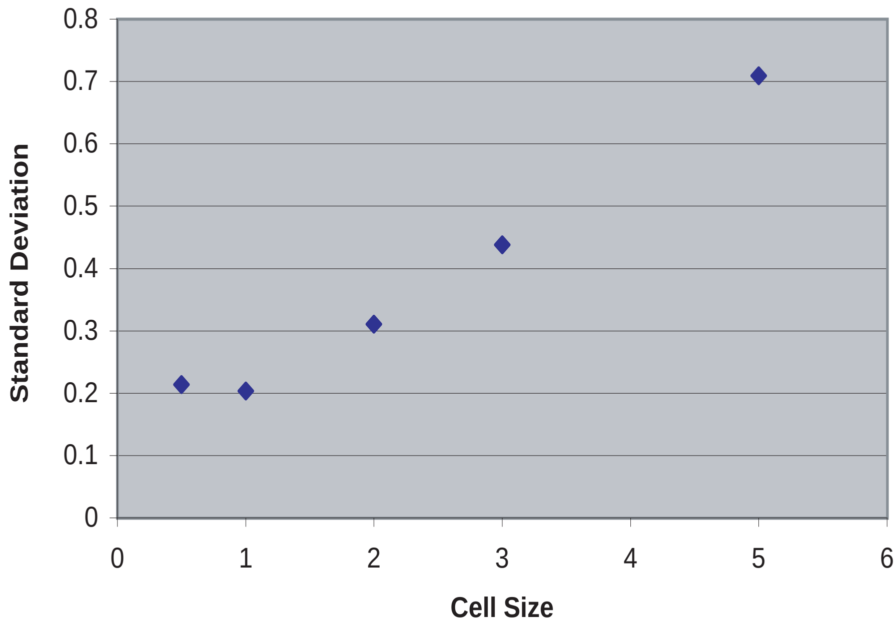


Figure 5 Differences in ALS-Derived DTM (1 m Resolution and Survey Points for Springbrook Site 1

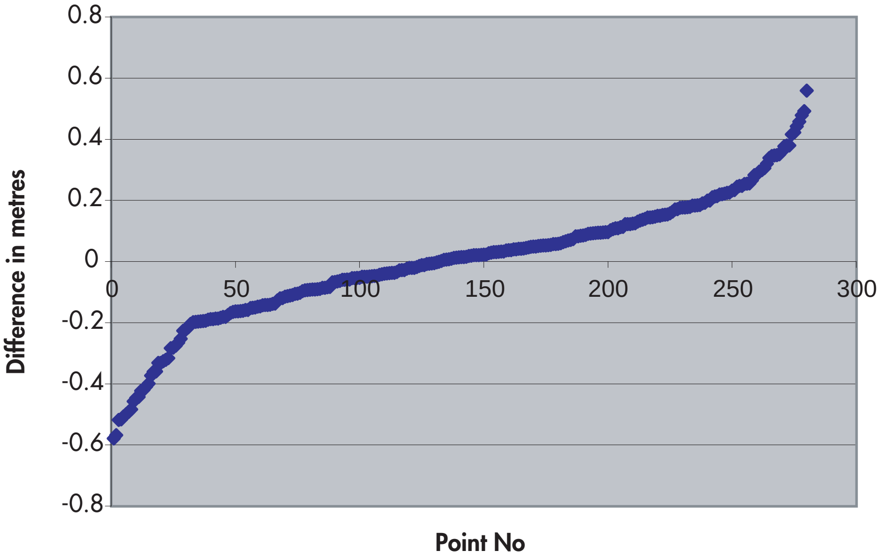


Figure 5 shows that the majority of survey points are within 20 cm of the corresponding DTM with some extreme errors of 60 cm.

Figure 6 TIN for an Area including Springbrook Site 1 and Corresponding Photos

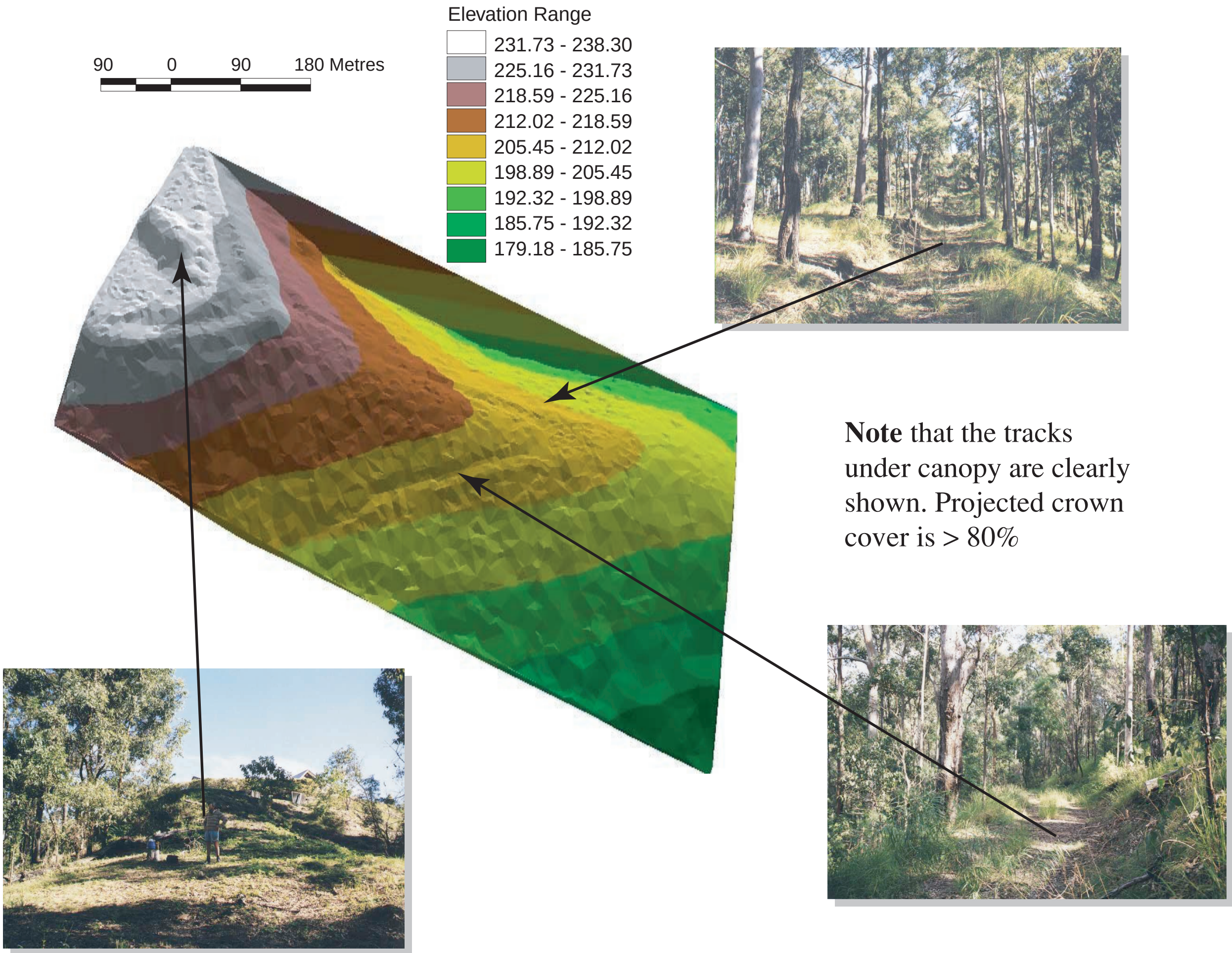


Table 4 Accuracy of DTMs at Various Cell-Sizes for the Open Area at Springbrook Site 2

Cell Size (m)	Standard Deviation	Mean
0.5	0.226398	-1.38093
1	0.208285	-1.39297
2	0.247749	-1.3581
5	0.56535	-1.0864

As mentioned previously the second site in the Springbrook area is mostly open with a track leading into surrounding dense understorey. Unfortunately only about 20 meters of this track was covered by the laser scanner swathe. Based on three survey points along the track and analysis of the standard deviation of the laser ground hits a DTM accuracy of about one meter appears achievable under these conditions. It should be noted that the site is at the edge of the swathe and better results are likely to be achieved towards the centre where penetration to the ground is more likely.

Generating an accurate ground DTM through traditional methods would be a time-consuming task, as it is very difficult to collect survey points in areas of dense understorey (see Figure 7).

The TIN approach applied by AAM staff using Geopak software resulted in a standard deviation of 0.17 m for the open area at Springbrook Site 2 and was again more accurate than cell-based modeling.

Figure 7 Springbrook Site 2 Photos

5.2 FOLIAGE PROJECTED COVERAGE (FPC)

An estimate of foliage projected coverage for a particular area was derived from the laser data through the following steps:

1. A ground DTM using all laser points classed as ground was produced
2. A count of first return ground hits was produced
3. The distance between first return above-ground hits and the DTM was derived and points higher than 2 meters above the ground DTM were selected to provide a count of 'vegetation hits'.
4. Calculating FPC using the following ratio:

FPC = count of first return vegetation hits /
(count of first return ground hits + count of first return vegetation hits)

For small areas representing the field sites, the above steps were completed in a GIS environment using point coverages for the laser hits and a raster layer (or TIN) for the DTM. This approach, however, was slow and required considerable disk space when deriving FPC values for the entire study area or larger subsets. To overcome this limitation a C-program was written which uses (i) the text files supplied by AAM with laser pulse information for first return vegetation and ground hits as input and (ii) another text file representing the ground DTM generated previously. The FPC is then calculated for a specified cell size and any selected area using the above ratio.

St Marys Field Sites

Each FPC transect was positioned along the centre of a 50 m x 100 m permanent plot. The location of each 100 meter transect and permanent plot is known within +/-10 meters. FPC values based on ALS data were derived for an area equivalent to the permanent plot area. FPC was also derived for both a 5 meter and 12.5 meter buffer around the line representing the field transects.

Table 5 Laser and Field FPC Estimates for the St Marys Field Sites

Plot No	Laser FPC for permanent plot area	Laser FPC for 12.5 m buffer around Transect	Laser FPC for 5 m buffer around Transect	Field FPC along Transect
1	43	51	49	59
2	38	39	41	46
3	44	44	50	49
4	34	34	42	52
5	21	23	25	36

In each case the laser FPC underestimates the field FPC. The differences in FPC estimates for the entire plot area (equivalent to a 25 meter buffer around the centre transect), the 5 and 12.5 meter buffers gives an indication of the on-ground variation and the size of samples required to represent a particular forest stand.

Springbrook Site 1

The location of each of the three field FPC transects at this site is known within a few meters (Figure 3). The FPC ratio was calculated by buffering a line representing a field transect by varying distances and selecting all vegetation and ground hits (first return only) within the buffer area to derive the FPC ratio. Note that 'vegetation hits' are the laser returns that are classed as non-ground and are two meters or more above the generated ground DTM.

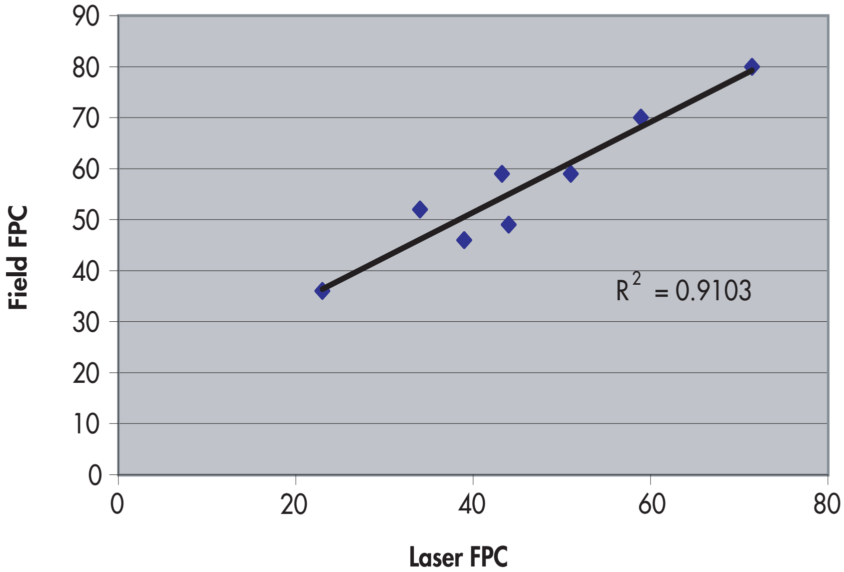
Table 6 Laser and Field FPC Estimates for Springbrook Site 1

Transect	Laser FPC 1 m Buffer	Laser FPC 2 m Buffer	Laser FPC 3 m Buffer	Laser FPC 4 m Buffer	Field FPC
North	62	63	59	57	70
Middle	46	43	43	43	59
South	62	78	71	70	80

Table 6 shows the FPC value for a range of buffer sizes applied to lines representing the field transects. Based on these three transects the laser FPC consistently underestimates the ground FPC.

Note that foliage projected cover was not collected on the ground at the second site in Springbrook, as the area around the house is very open and setting up a transect in the surrounding dense understorey would have been extremely difficult.

Figure 8 Correlation of Field and Laser FPC for the St Marys and Springbrook Sites



The coefficient of correlation of 0.91 may have been improved if field data collection had occurred at the same time as the laser flight. For the St Marys sites the field trip took place in May 1998 and for Springbrook in June 1999. ALS data was obtained in July 1998. On-going improvements in processing techniques of ALS data may also reflect in results achievable.

5.3 TREE HEIGHT ANALYSIS

The aim of this step is to test the various ALS sampling intensities and the effect on the accuracy in estimating tree height. The long-term aim is to delineate individual tree crowns or clusters of trees and assign height attributes. In this study the tallest tree as measured on the ground for each field site was compared to the tallest tree as measured by the laser. Each laser pulse is identified by x, y and z coordinates where the z value is height above sea level. To derive the height above ground the corresponding z value in the generated ground DTM is subtracted from each vegetation pulse height value. Selecting the maximum value for a specified area then identifies the tallest tree based on ALS data.

At the St Marys site all trees with the canopy overlapping or touching the transects were measured in the field. Crown diameters for the upper canopy trees varied between 5 to 15 meters. To select an equivalent subset from the laser scanner data the lines representing the field transects were buffered by 15 meters and the highest vegetation laser hit selected to identify the tallest tree. For the two sites near Springbrook each tree within the plot area was measured and the accurate location obtained from the tree maps produced. Subsets to represent Springbrook Site 1 & 2 were selected from the laser data and the highest laser vegetation hit was identified. Table 7 shows the comparison of the tallest tree measured in the field and the highest laser hit for the area and the sampling intensity of laser vegetation hits.

Table 7 Tallest Tree for Each Site Based on Laser and Field Data

Site	Top Height - Field	Top Height - Laser	Sampling Intensity for Vegetation Hits (m^2 per hit)
Springbrook 1	28.90	28.4	1
Springbrook 2	35.00	35.2	1
St Marys 1	27.80	25.2	5.8
St Marys 2	25.30	23.2	7.6
St Marys 3	34.80	33.3	8.3
St Marys 4	34.90	30.7	7.6
St Marys 5	24.50	23.7	5.4

It should be noted that the height is generally underestimated when using less intense laser sampling. For each site the tallest tree was in the same location on the ground as in the laser data. Although this analysis is simplistic it shows that the height for the upper canopy species can be obtained accurately.

Orthophotos have been produced for subsets of the study areas using ALS data, ground control points and 1:5,000 color photography. This allows for some species discrimination of individual trees, in particular in areas where sufficient control points have been collected, but in general needs more refinement.

6 CONCLUSION

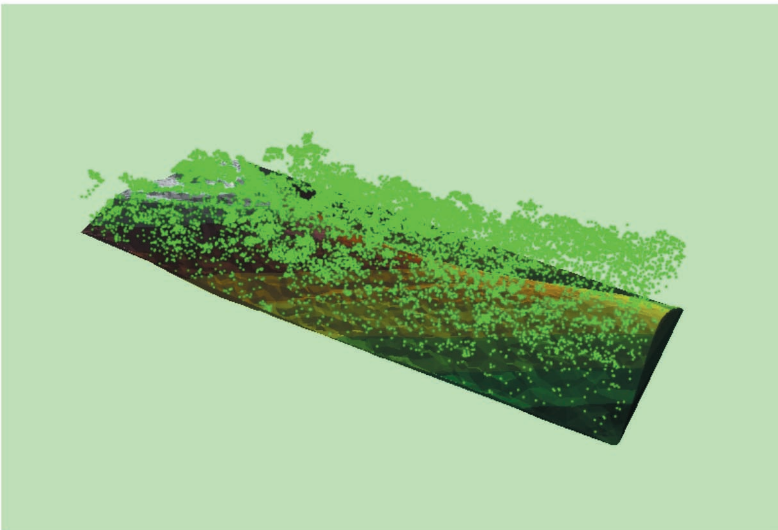
The results demonstrate the potential of laser scanning as a useful tool for determining vegetation structure and condition, as well as production of high-resolution digital terrain models of the ground.

The standard deviation of the digital terrain models varied from 0.13 m to 0.19 m (using TIN) for sites with mid-dense to dense canopy cover. However, the accuracy of ground DTM's was reduced in an area where very dense understorey resulted in a lower frequency of ground hits. Errors of up to 1 meter are possible. It is likely that this could be addressed by changing the settings on the scanner or by reducing the speed and/or flying height of the aircraft.

The results for assessment of foliage projected cover (r^2 of 0.91) were encouraging. Better coordination of laser data capture and fieldwork may yield further improvements.

Results for measurement of tree height were also encouraging, although the analysis is simplistic and could certainly be improved. Tree-top DTM's were generated based on the vegetation hits, but require considerable analysis before detailed information can be extracted. There is a lot of potential to identify individual trees or cluster of trees with further processing.

Figure 9 Ground DTM and Vegetation Hits for an Area including Springbrook Site 1



Future development of the laser scanning technology for forest assessment and monitoring should be directed toward:

- the application of tree (or tree cluster) identification algorithms to delineate and attribute individual trees (or clusters).
- integration with large-scale photography or possibly high-resolution video. This would require some manual interpretation.

- integration with multispectral or hyperspectral data to produce a more automated system for forest inventory.
- development of algorithms for each broad forest type which convert the temporal changes in foliage density and tree heights into carbon increments.

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