FOREST ECOSYSTEM RESEARCH AND ASSESSMENT

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Using Airborne Laser Altimetry to Assess and Monitor Biodiversity

(Queensland Department of Natural Resources, Environment Australia, CRC for Carbon Accounting)

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Abstract

To demonstrate the potential of laser altimetry as a biodiversity assessment and monitoring tool, multiple passes have been conducted over three study sites at regular intervals over a two year period. The study sites were chosen to represent a range of forest conditions and stages; the first, a control site was established to monitor a mature forest maintained free from external disturbances such as logging, the second site acted as a treatment with standard selective timber harvesting monitored before and after logging, and the third, a new plantation site, provided the opportunity to monitor regrowth. Twenty-two sites in south-western Queensland were also chosen for a single helicopter pass, allowing for the demonstration of laser altimetry as an assessment tool over a variety of landscapes and forest types.

Laser data was captured at flying heights of 30 metres, 60 metres and 100 metres above the upper canopy level at each of the two year monitoring sites, to determine the effect of laser ‘footprint’ size on resulting foliage projected coverage (FPC) and tree height measurements. Field measurements of FPC and tree height were recorded at the same time as the laser data capture and were found to be highly correlated with laser data estimates (correlation coefficients of 0.92, 0.94, and 0.96 were obtained for FPC analysis and 0.91, 0.93, and 0.91 for tree height analysis).

The monitoring of changes in FPC and tree height with time was also highly successful. For example, a drop in FPC was clearly observed after the logging event at the harvest site, and was followed by a gradual increase in FPC with time as regrowth occurred. The growth increase at the plantation site was also clearly observed through both FPC and tree height data.

The interpretation of high-resolution digital video, captured at the same time as the laser data, provided information on forest type, species type and growth stage of trees. The number of dominant species matches obtained through a comparison of field and video data was 15 out of a possible 22 western sites, and it is expected that this result would further improve with a small degree of field calibration by the video interpreter.

Introduction

There is widespread community concern that the condition of vegetation, in terms of its age/size-class, structural complexity and species composition, is deteriorating as a result of unsustainable resource use practices (State of the Environment Australia 1996). Vegetation condition is an important indicator of overall ecosystem health and such a decline has serious implications for productivity and biodiversity conservation. Governments are already making substantial investment in the assessment and monitoring of vegetation.

In Queensland for example, the Statewide Landcover and Trees Study (SLATS) delineates the boundaries of woody vegetation at a scale of approximately 1:100,000 for a number of years (1988, 91, 95, 97 and 99). This provides some information about young regrowth forest. In the future Landsat MSS data will be used to map the extent of woody vegetation dating back to 1972. This will provide further detail on the age and growth stage of woody vegetation. The Queensland Herbarium, Environmental Protection Agency, maps remnant vegetation at broad scales, useful for assessing biodiversity at a regional scale. The only proven and relatively non-subjective method to monitor changes in biodiversity condition in relatively short time frames (e.g. less than a decade) is ground survey. The extent and frequency of field measurements are in most cases very limited by budget and time constraints.

Airborne laser altimetry, which provides a profile of the canopy and understorey vegetation structure, offers promise as an effective, efficient and reliable supplement to ground-based survey, and as a complement to coarser satellite-based sensors such as Landsat. Laser systems in combination with digital video also provide a substitute for large-scale photography as a sampling tool. Although airborne laser altimetry has been in use in North America and Europe for some time, is it only recent technological advances that have greatly enhanced its potential utility for vegetation inventory. This technology has been available in Australia since 1998 and the initial investigations conducted in Queensland (Tickle et al. 1998, Witte et al. 2000) have produced outstanding results.

Similarly to other remote sensing technologies, information derived from laser scanning systems becomes particularly useful when integrated with other datasets. For example, airborne laser altimeter data provides measurements of canopy structure, properties, and patterns across large areas (Ritchie et al. 1993), but when combined with high-resolution video may also provide detailed information on species identification, growth stage, canopy patterns and crown diameters (Jacobs et al. 1993).

As described by Koch (1999), laser altimetry data offer valuable and promising input into biodiversity studies as they provide detailed and accurate information on height and vertical structures. Further, the ability to produce automated quantitative measurements of terrain height, vegetation height and vegetation density will lead to an improved quality of biodiversity studies (Koch 1999).

Australian development work has to date been restricted to investigating the relationships between laser data and vegetation attributes in a single-pass. The aim of this project was to demonstrate the potential of laser altimetry as a monitoring tool, and as such, multiple passes have been conducted over the same areas to evaluate the accuracy and reliability of the technology under constant conditions, its sensitivity to baseline seasonal change and its reliability for consistently assessing known change (e.g. from timber harvesting or growth).

This project was sponsored by the Queensland Department of Natural Resources (QDNR) as a two year research project into the application of laser altimetry for forest inventory and vegetation monitoring. Further funding was provided by Environment Australia to assess and report on the use of laser altimetry as a tool for monitoring biodiversity. The CRC for Carbon Accounting have also contributed supportive funding and a separate report relating foliage density and tree height to biomass is to be produced in the near future.

Laser Data Capture and Field Work

Monitoring Sites

To demonstrate the potential of laser altimetry as a monitoring tool, multiple passes have been conducted over the same areas at regular intervals over a two year period (data captured during February, May, July, November 1999 and March, May 2000). Three sites were chosen for this study. The first acted as a control, a mature forest maintained free from external disturbances such as logging to allow the monitoring of background seasonal change and variation in laser response. The second acted as a treatment, with standard selective timber harvesting monitored before and after logging, and the third, a new plantation site, provided the opportunity to monitor regrowth (see Figure 1 and description below for location/site information). Laser and field data was collected over two transects within each site for each of the six separate dates. Transect lengths of 100 metres (m) at the control site, 200 m at the harvest site, and one of 183 m and another of 165 m at the regrowth site were established.

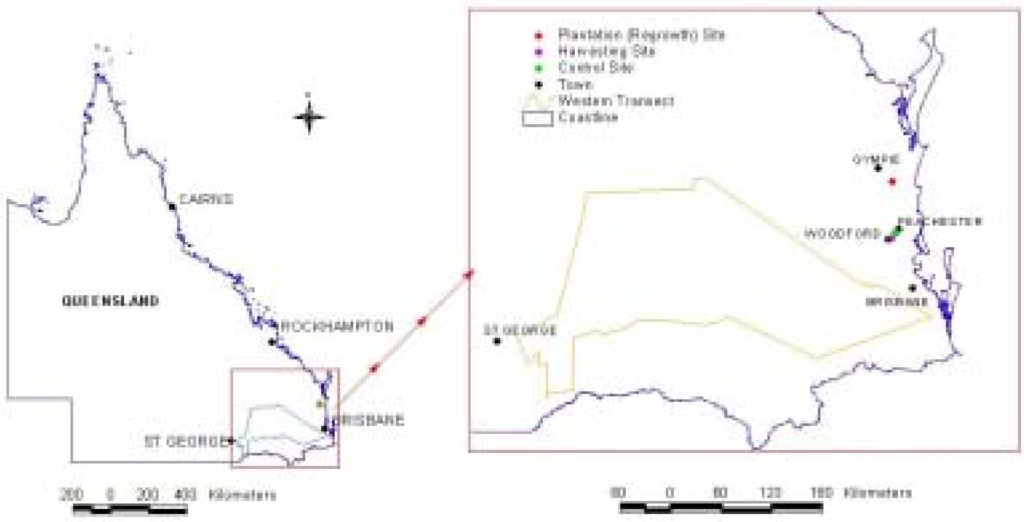


Figure 1. Field Site Locations

The control site was established approximately five kilometres from Peachester. Principal species at this site include blackbutt (*Eucalyptus pilularis*), tallowwood (*Eucalyptus microcorys*) and red mahogany (*Eucalyptus pellita*). The harvest site, located approximately three kilometres from Woodford, included principle species of white mahogany (*Eucalyptus acmenoides*), red bloodwood (*Corymbia intermedia*), synima (*Synima cordierorum*) and blackbutt (*Eucalyptus pilularis*). The regrowth site, a plantation of Gympie messmate (*Eucalyptus cloeziana*), was established in 1998, and is located approximately two kilometres from Pomona.

Laser data was captured at flying heights of 100 m, 60 m and 30 m above the upper canopy level at each site, to determine the effect of laser 'footprint' size on resulting foliage projected cover (FPC) and tree height measurements. Further, the 60 m flight was performed three times in order to test the ability to replicate laser results when flown on the same day during the same conditions. Transects for each of the two year monitoring sites were permanently marked with a steel peg and a clearly visible object (i.e. blue tarpaulins) to ensure the best possible repetition of the transects by the helicopter pilot (see Appendix 1 photo). Field measurements of FPC (for all site transects) and tree height measurements (at the regrowth site) were recorded at the same time as the laser runs were flown to enable comparisons and correlations between laser and field data.

FPC field measurements were recorded at the control, logging and harvest sites at one metre intervals using a tube and crosshair method developed by Specht (1970). This method uses a tube with a crosshair attached to a rod two metres above the ground. A mirror placed at 45 degrees at the bottom of the tube allows an operator to record the presence of either green leaf (GL), dead leaf (DL), branch (BR) or 'sky' in the canopy vertically above (see Appendix 1 photo). For a given length of transect, the FPC percent is equivalent to the number of GL occurrences divided by the total number of observations. The majority of FPC measurements throughout this report have therefore been based upon GL recordings, however comparisons to GL, DL and BR recordings have at times been made.

A different technique was required to be used for the regrowth (plantation) site due to the small height of the trees. A 'stick' method was therefore employed whereby a height staff was placed along the transect at one metre intervals and the highest GL touching the stick was recorded. The number of GL occurrences divided by the total number of observations could therefore be calculated as for the previous method. Tree heights were also recorded in the field for each tree along the two transects through the use of a height staff.

Western Transect
A series of sites in south-western Queensland (Figure 1) were also chosen for a single helicopter pass, allowing for the demonstration of laser altimetry as an assessment tool over a variety of landscapes and forest types. Data was captured for over 1000 km with field FPC measurements being collected at 22 sites across a broad range of forest types.

Laser data was supplied by South West Pacific Helicopters. First return data was supplied with ground and vegetation hits combined, and as such extensive work was carried out to delineate the ground from the vegetation. A number of increasingly sophisticated programs were developed, tested and implemented to perform this delineation, after which tree height and FPC could be determined. High-resolution digital video was also collected simultaneously with the laser data.

Biodiversity Condition Indicators

The most apparent application of laser altimetry to biodiversity condition assessment is through forest structure information. Structural diversity is defined in respect to biodiversity as an analysis of the spatial heterogeneity of age, height and density of forest stands across a landscape (Waring and Running, 1998). Forest structural attributes are recognized as important measurements in the monitoring of species, population and community dynamics (Hunsaker et al. 1998). Airborne laser altimetry data provides a direct measure of forest structure, with the ability to establish ground and canopy surface profiles, measurements of forest density, crown size and stand height. The use of high resolution digital video, captured at the same time as the laser data, provides a basis for assessing forest type, species type and growth stage of trees. Interpretation of digital video data may also aid in delineating forest disturbance extent, type, intensity and recovery.

Foliage Density: Foliage projected cover may be derived from the laser data using an equation which utilises both ground and vegetation hits. This information may also be used to monitor vegetation regrowth, and to assess forest condition and recovery after disturbance.

Tree/Canopy Height: Heights for each laser ‘hit’ can be derived to provide a profile of the canopy and understorey vegetation. Such information may be used to determine overall stand height and provide information on vegetation regrowth.

Species Type: The type and variety of species found in a forest stand can be determined from high-resolution digital video, and would provide a general level of understanding of species diversity at a site.

Growth Stage: Similarly the growth stage can be derived by manual interpretation of the video. Growth stage (condensed into groups of senescing, mature, regeneration) of species may provide information on forest age and condition. This information would be useful in verifying and monitoring vegetation regrowth in conjunction with the laser data.

Assessing Biodiversity Variables

Foliage Density

Two year Monitoring Sites

FPC measurements were performed in the field at all sites and could therefore be compared to the laser derived FPC measurements at the approximate 30 m, 60 m and 100 m flying heights. Figure 2 shows the correlation of field and laser FPC for data collected across all dates at each of the three flying heights.

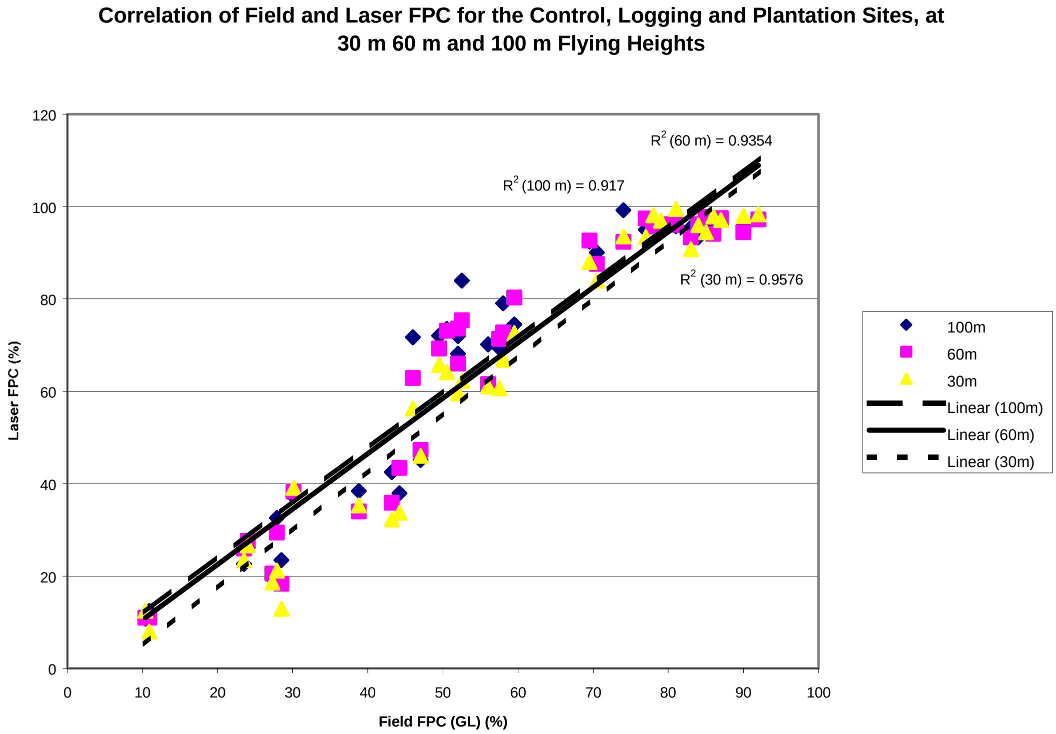


Figure 2. Correlation of field and laser FPC for all sites and at all flying heights

Field and laser FPC measurements were highly correlated at all three flying heights, with the 30 m flight showing the strongest correlation with an R^2 of 0.958. Strong correlations were also obtained for the 60 m and 100 m flying heights with an R^2 of 0.935 and 0.917 respectively. The difference in FPC's between the three sites (regrowth, logging and control) can be clearly viewed on the graph with three separate clusters of data apparent.

Western Transects

Field FPC was recorded for 22 sites within the western transects and information regarding species type and approximate percentage of dominance was also recorded at this time. Various sites were then grouped together for FPC regression analysis based upon dominant species recorded at each site. The field data for the three resulting species groups, Cypress, Eucalypt and Acacia, could then be correlated with the laser FPC results over the same sites (Figures 3, 4 and 5).

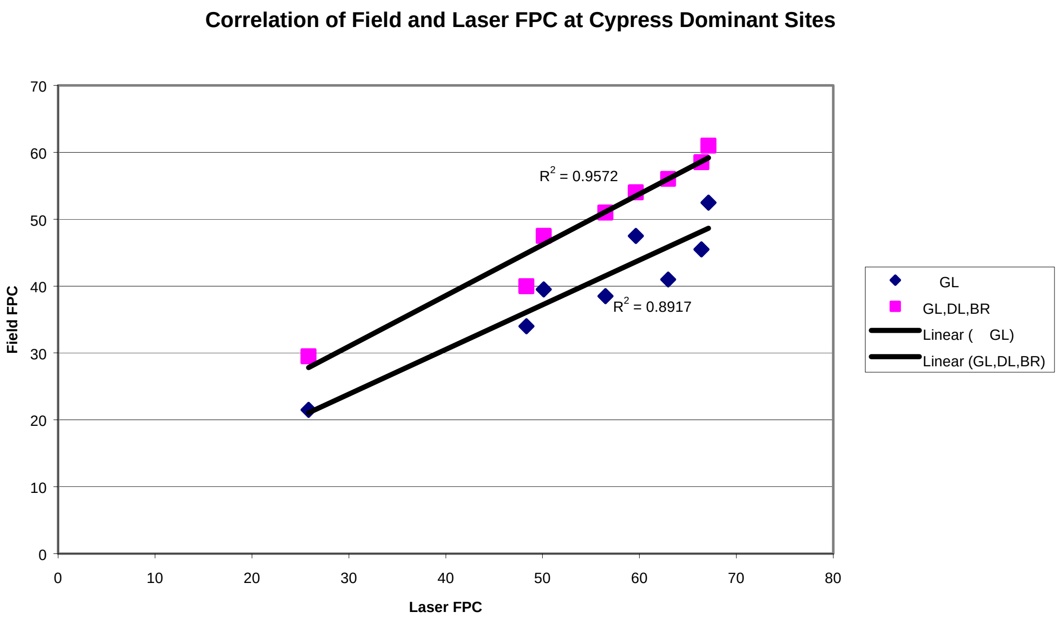


Figure 3. Correlation of field and laser FPC at Cypress dominant sites

The regression results for both GL (0.8917) and GL, DL, BR (0.9572) are displayed in Figure 12. The higher R^2 recorded for the GL, DL, BR regression was unique to this data set and may be explained in relation to the structure of Cypress species. The needle-like leaves of Cypress trees present a much smaller surface area than a leaf typical of a Eucalypt or Acacia species, and as such, the number of field FPC hits of green leaf would reduce and the number of hits recorded as branch would increase. It is therefore recommended that this factor be taken into account when assessing the FPC of Cypress (or other vegetation with needle-like leaves).

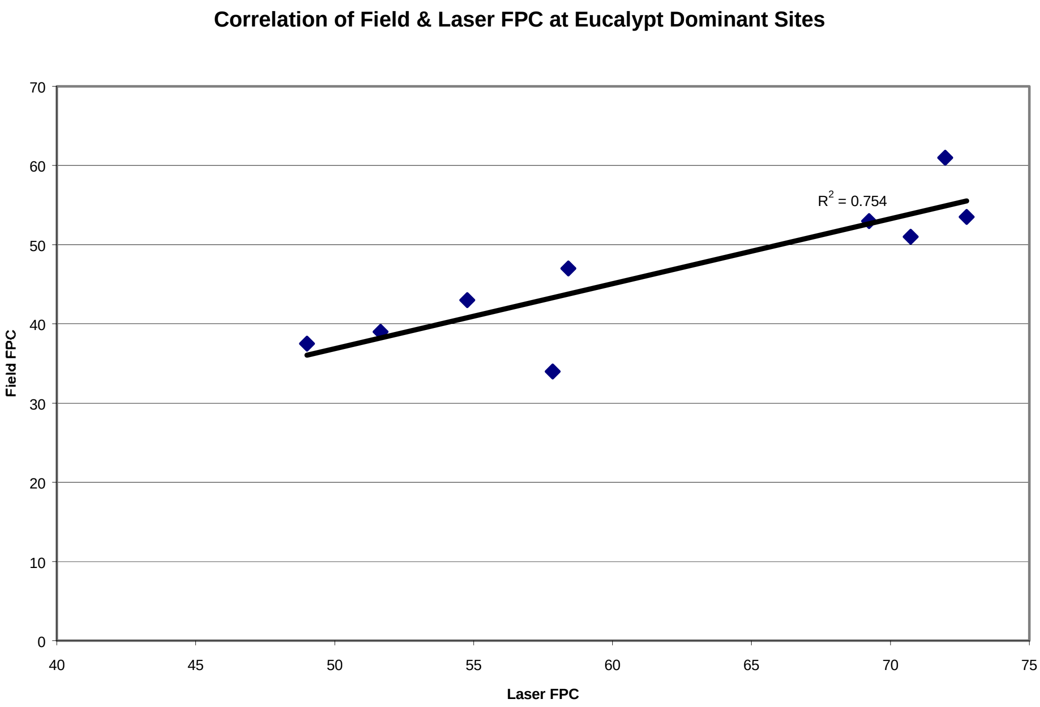


Figure 4. Correlation of field and laser FPC at Eucalypt dominant sites

An R^2 of 0.754 was recorded for Eucalypt dominant sites. It should be noted that the field FPC measurements for the Eucalypt dominant sites were taken from an additional fieldtrip carried out in December 2000, one year after the laser data was flown. This fieldtrip was necessary as a means of clarifying the data collected at two of the sites where anomalies to the correlation existed. Further explained, two of the sites presented a 1:1 relationship between laser and field FPC estimates, while all other data had shown an approximate 4:3 relationship (with the laser FPC being greater than the field FPC). All of the Eucalypt dominant sites were remeasured at this time to ensure that any general changes e.g. resulting from differing climatic conditions between the two years could be acknowledged. It was found though, that the majority of sites had only minimal changes in FPC (1 – 5%), while the two main sites in question were recorded with much lower FPC values during this additional fieldtrip (more in accordance with the 4:3 relationship). The reason for the initial 1:1 relationship was not discovered. Errors in global positioning system (GPS) or field data collection are possible explanations.

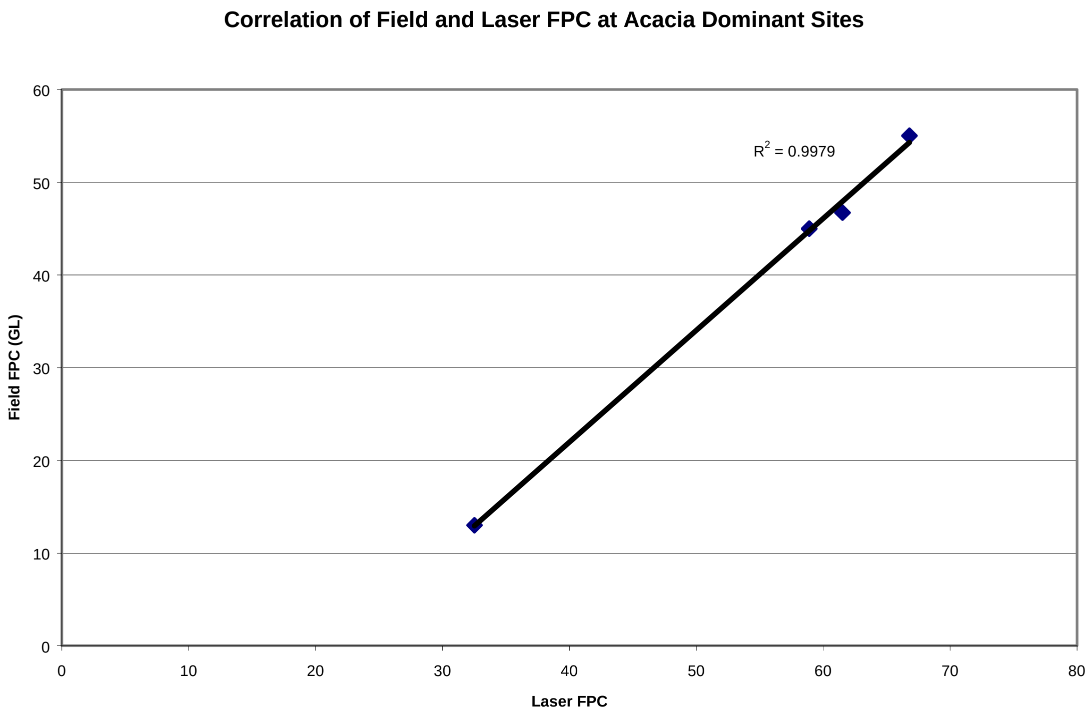


Figure 5. Correlation of field and laser FPC at Acacia dominant sites

The results for Acacia (0.9979) dominant sites indicates a high correlation between field and laser FPC. It should be noted though that only a very small number of samples have been collected for this vegetation type (only four samples in the regression), and as such some caution should be used in its interpretation

Tree/Canopy Height

Measurements of tree height were performed in the field at the regrowth (plantation) two year monitoring site for each of the six dates. Correlation of the mean height measured in the field to the mean height obtained through laser measurements at 30 m, 60 m and 100 m flying heights are shown in the graphs below (Figures 6, 7 and 8 respectively). Each graph is a comparison for both transects over all six dates.

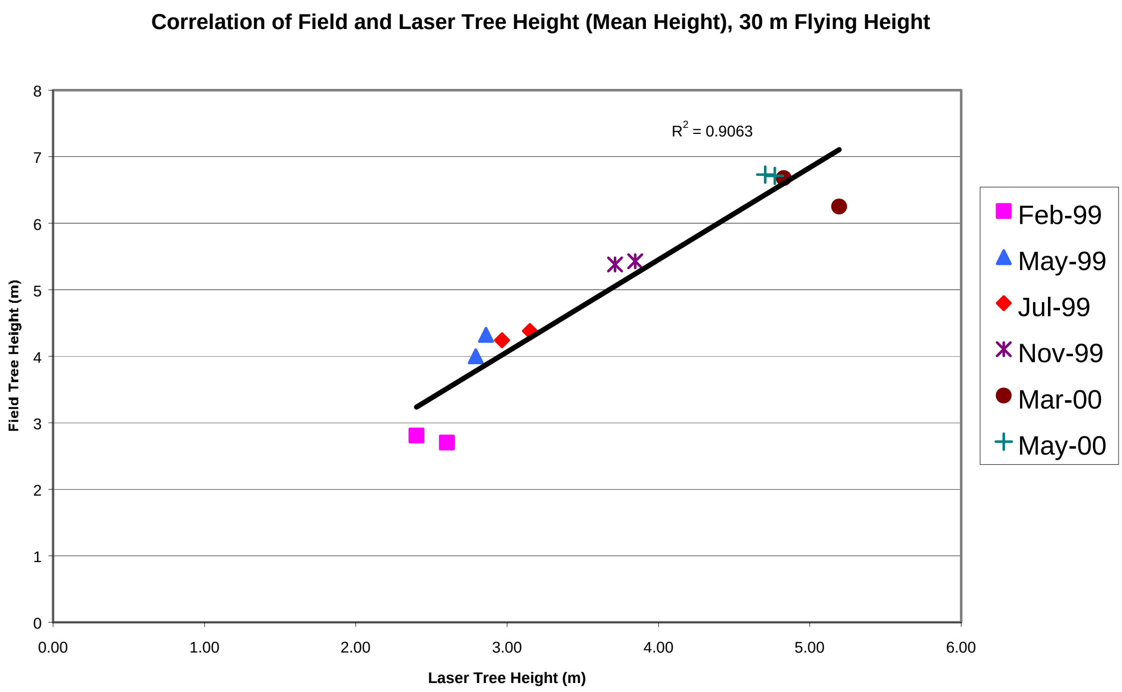


Figure 6. Correlation of field and laser tallest tree heights at the regrowth site with a 30m flying height

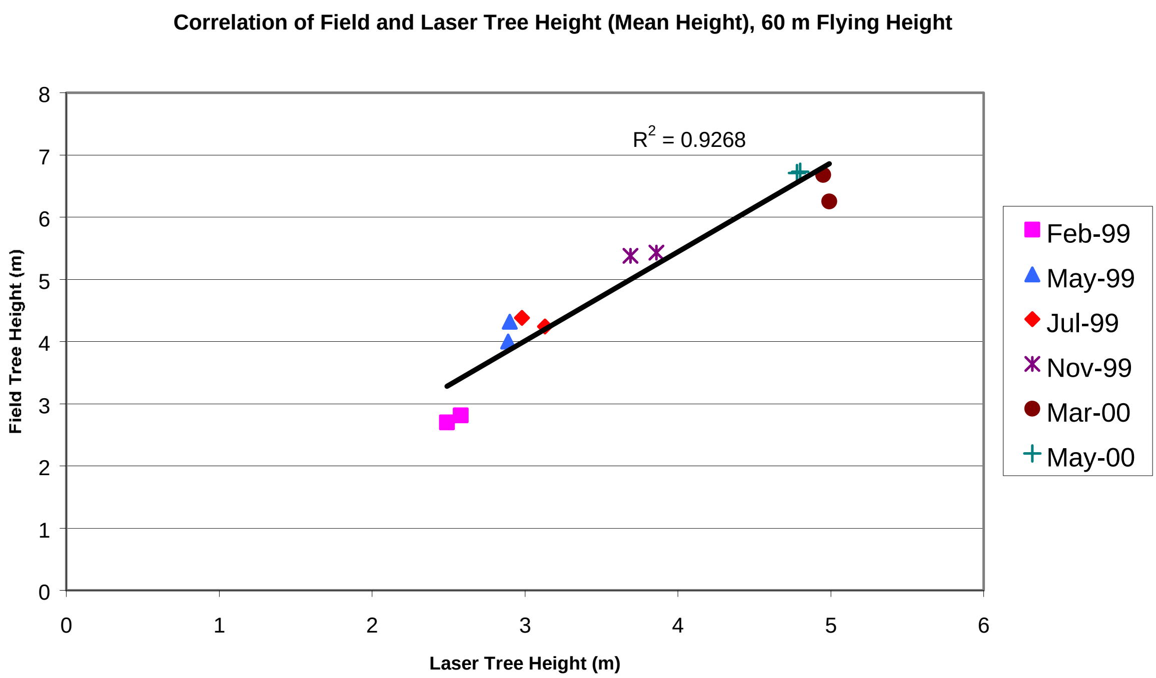


Figure 7. Correlation of field and laser tallest tree heights at the regrowth site with a 60m flying height

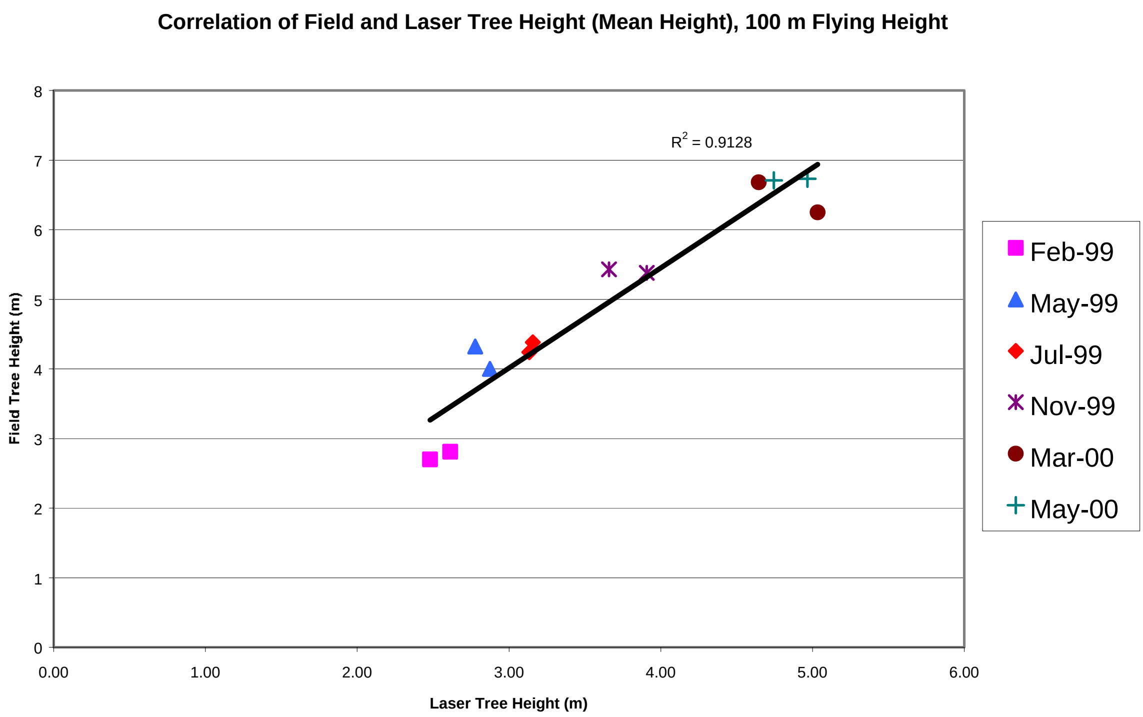


Figure 8. Correlation of field and laser tallest tree heights at the regrowth site with a 100m flying height

The highest R^2 (0.9268) was therefore obtained at the 60 m flying height, however very high values were also obtained for the 30 m (0.9063) and 100 m (0.9128) flying heights. It should be highlighted also, that these tree heights cover a very small range of values, thereby increasing the relative standard of the regression results.

Ground based data on tree heights was collected for the control and harvest sites during the first fieldtrip (February 1999) only. A comparison of the maximum height laser and field results may be viewed in Table 1.

Site	Control		Logging	
	Transect 1	Transect 2	Transect 1	Transect 2
Laser Measurement	45.7	47.4	37.3	35.4
Field Measurement	44.0	46.2	35.7	33.9

Table 1. Comparison of laser and field maximum tree height measurements recorded in February 1999.

While ground based tree height data was not recorded for the other dates, it may be assumed through the results of the regrowth site, the above comparison (Table 1) and through the results of past studies using the same technology and techniques (e.g. Tickle et al. 1998; Witte et al. 2000) that the laser height measurements for these sites are very accurate.

Species

Digital video interpretation of dominant species type at each of the 22 sites along the western transect was performed and compared to field data. Although a consistent error in the video interpretation originally occurred, whereby white cypress pine (*Callitris glaucophylla*) was identified as silver-leaved ironbark (*Eucalyptus melanophloia*), upon re-calibration of the data, 15 out of 22 sites were matching at the species level and 21 out of 22 sites at the genus level.

Species Type: Comparison of Field Results to National Vegetation Information System Data

The Queensland Herbariums National Vegetation Information System (NVIS) data has been compared to the 22 western field sites in relation to species type present at each site. It should be noted that this is a simple comparison using only a small subset of sites scattered throughout the Southern Brigalow Belt bioregion. Further, the ability of the NVIS data to capture the diversity of these sites should be considered in light of the very different scales of mapping between the NVIS vegetation data (1:250,000) and the use of laser altimetry/video data and fieldwork as detailed survey tools with a spatial accuracy of better than 10 metres. The results of the intersection of the NVIS data with the field results and digital video results are summarised below. The number of species matches obtained through a comparison of field and video data is also outlined.

Number of sites where field determined species matches with the intersection of NVIS determined species:

Species Presence Level	**Number of Matches (out of a possible 22 Sites)**
Dominant	12
Sub-Dominant	11

Number of sites where digital video determined species matches with the intersection of NVIS determined species:

Species Presence Level	**Number of Matches (out of a possible 22 Sites)**
Dominant	11
Sub-Dominant	8

Number of sites where field determined species matches with the intersection of digital video determined species:

Species Presence Level	**Number of Matches (out of a possible 22 Sites)**
Dominant	15
Sub-Dominant	10

Five of the 22 sites were classed as either cleared or disturbed by the NVIS data, indicative of the differing scales of the two datasets.

Although species matches have occurred for some of the sites, it is unlikely that the NVIS vegetation data would be suitable as a reporting unit for measuring condition over time in conjunction with airborne laser altimeter data. The different scales of the datasets are indicative of the different potential applications of each, whereby the

NVIS data may contribute to biodiversity studies at a regional scale, while laser altimetry may be primarily used to assess and monitor condition at a more local scale. Further, the NVIS data is a mapping tool used to provide an overview of all vegetation across the state, while laser altimetry is a sampling tool, more aimed at depicting change in the structural condition of forests at finer scales.

Growth Stage

The growth stage of Eucalypt species at the 22 western sites was performed through interpretation of the digital video. The air photo interpretation officer performing the growth staging and species identification has extensive experience in growth staging Eucalypts. Although this measurement was not taken in the field for comparison, it is expected that the growth stages recorded are very accurate as the helicopter flew approximately 100 m above the ground, a height at which the video provides a detailed view of canopy structure (example in Figure 9).

Figure 9. Example of video frame used to assess growth stage

Estimating FPC and Tree Height for All Sites

The range of site FPC values and their relative placement compared to the other sites may be viewed in Figure 10. Clearly, the control site of the two year monitoring sites was recorded as having the highest FPC values, while the regrowth (plantation) site results are all clumped in the lower regions of the FPC scale, and the harvest site results are situated in the mid portion of the scale. As previously described, the relative FPC values for these three sites are quite logical in relation to the known growth stage, age and disturbance regimes of the forest stands.

The Cypress, Eucalypt and Acacia sites are all predominantly situated in the mid portion of the scale, similar in position to the harvest site. These results indicate that the forest stands measured in the western transects are of an open-forest structure, indicative of the differing conditions (rainfall, humidity, temperature, topography, soil type, etc) and consequent change in vegetation species and structure between the coastal sites and the western transects. Tallest tree and mean height measurements recorded by the laser (Table 2) also show that the western forest stands are of a lower height than the established coastal sites. Again, the lower recorded heights are a function of the different species and structural and functional adaptations to the inland conditions.

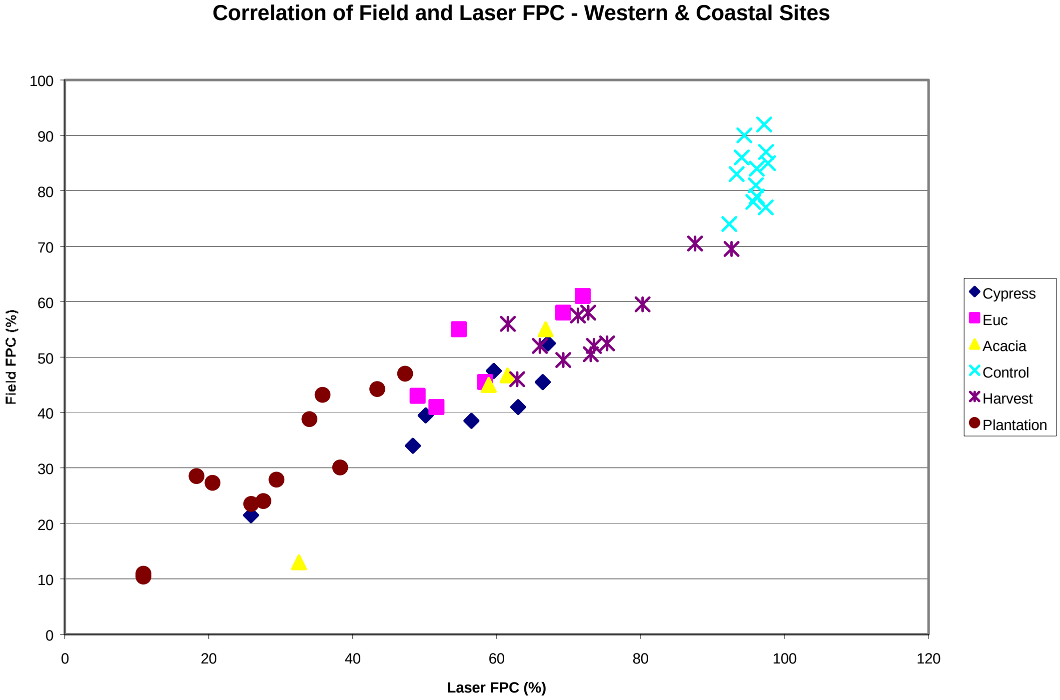


Figure 10. Relative positioning of sites across the FPC scale for both the western and coastal areas

Site	Tallest Tree (m) (Max)	Mean Height (m) (Max)
Control	47.4	36.7
Harvest	37.3	27.4
Plantation	9.5	5.0
Cypress (Western Transect)	17.3	9.8
Eucalypt (Western Transect)	25.5	17.4

Table 2. Maximum tallest tree and mean height measurements recorded across all monitoring dates and transects within a site for the two year monitoring and western transect sites.

The following analysis of variance was used to test variation in FPC with species type within the western transects. The data was grouped according to species type (Acacia, Cypress and Eucalypt), and separate linear regressions were fitted to each group. A test for equality of slopes was performed following the procedure in Sokal and Rohlf (1995). Results are in Table 3.

Source of Variation	*df*	SS	MS	F	p
Among slopes	2	168.041	84.02	6.379	0.00577 **
Within	25	329.309	13.17		

Table 3. Analysis of variance analysis for equality of slopes between regression lines.

From the analysis of variance, it can be concluded that the slopes of the three regression lines are not the same, and consequently the relationship between laser FPC and ground based estimates differ according to vegetation type. Based upon this data, it is therefore not possible to simply add a constant value to the slope as a means of adjusting for different species, as the slope itself varies with and between species type.

Monitoring biodiversity variables

Analysis for two year monitoring sites.

Foliage Density

The effectiveness of monitoring foliage density at each of the two year monitoring sites was extremely high. Monitoring of the changes in FPC over the two year time period enabled a pattern of forest condition and forest use to emerge. This is explained for each of the sites below. It is observed in each of the graphs throughout the following sections that ground FPC estimates are lower than laser FPC estimates. This has occurred as a result of the general 4:3 relationship of laser to field FPC data, whereby laser estimates are consistently higher than field measurements. While the data has remained in this format throughout this report, laser estimates could be calibrated to enable a 1:1 relationship as part of future work.

Control Site

The consistently high FPC results obtained for this site (92.3% – 99.2% for laser measurement; 74% - 92% for field measurement) are in keeping with the sites status as a mature closed wet sclerophyll forest, with no logging disturbance (Figures 11 and 12). The slight shifts in FPC values for both transects may represent a response to seasonal variation, however this is difficult to determine as the changes in FPC may also be due to flight variation.

It may be observed in Figures 11 and 12 that an increase or decrease in field FPC is not always met with a corresponding increase or decrease in laser FPC e.g. an increase is observed between March and May for field FPC, while a decrease is observed for the 100 m and 60 m flying heights for laser FPC in Figure 11. It is believed that such anomalies may be occurring as a result of ‘saturation’ levels. Further explained, if the laser is recording FPC at very high levels (as is the case with the control site where FPC values were between 92.31 and 99.51 for transect 1; and between 90.75 and 98.33 for transect 2) then slight variations in FPC may no longer be detectable by the laser. In other words, a saturation level may be reached in very closed canopy environments e.g. rainforests, whereby the laser would not be very sensitive to slight seasonal changes.

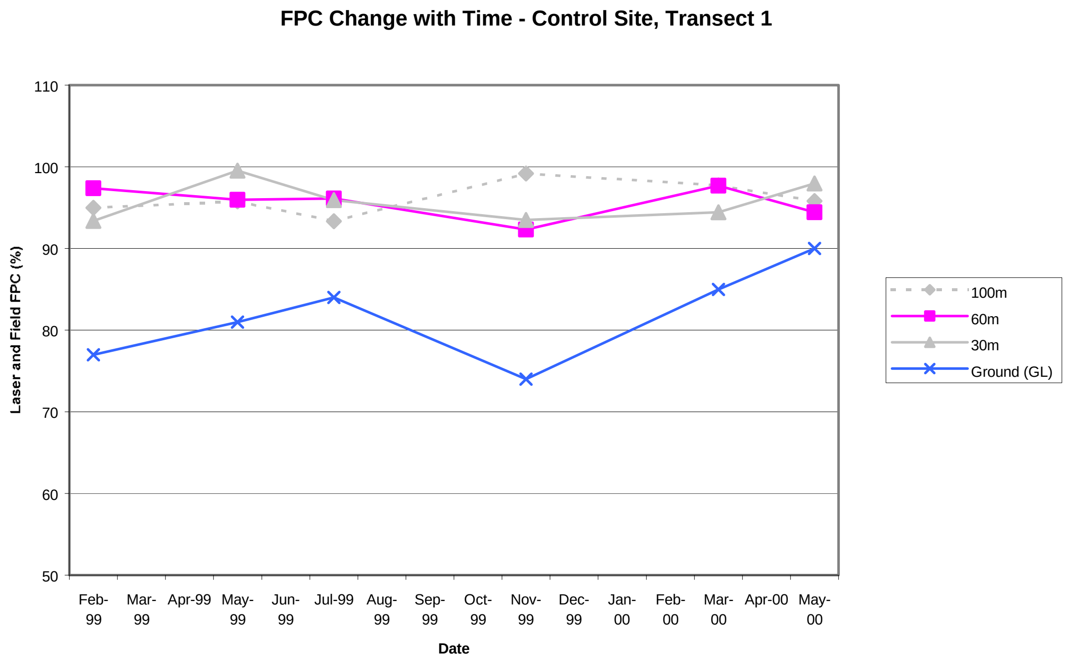


Figure 11. Change in FPC with time at the control site for Transect 1

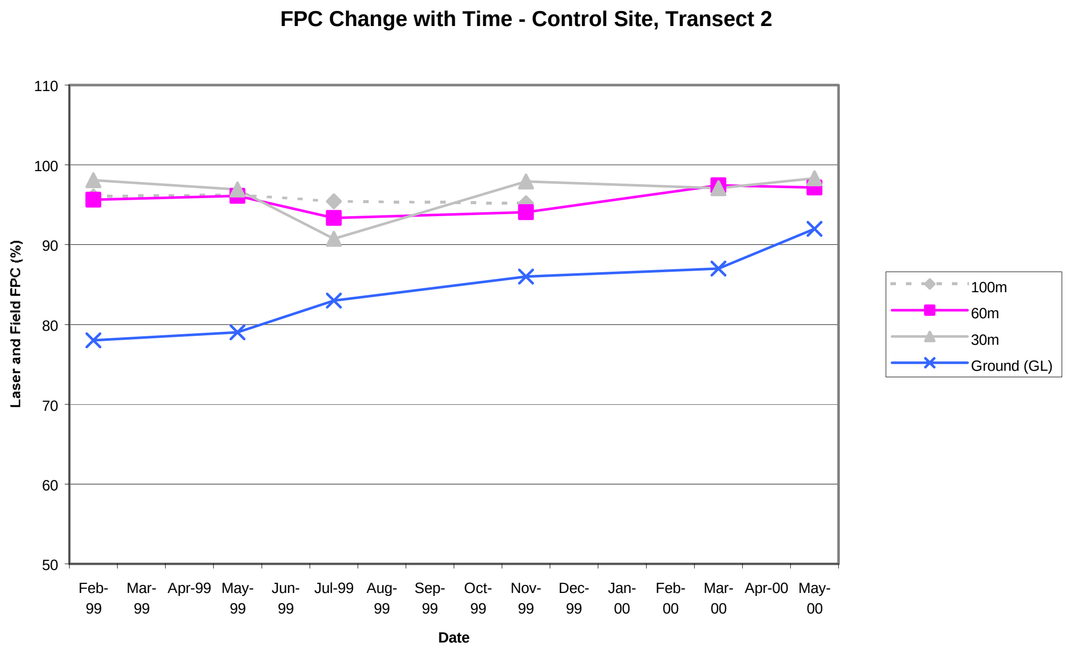


Figure 12. Change in FPC with time at the control site for Transect 2

Harvesting Site

The initially high FPC measurements obtained in February 1999, followed by a definite decrease in FPC by May 1999 for both transects has occurred as a result of a selective harvest in March 1999. An example of the change in laser profile may be viewed in Figure 13 whereby breaks and gaps have become evident since the logging event for transect 1 at a 100m flying height.

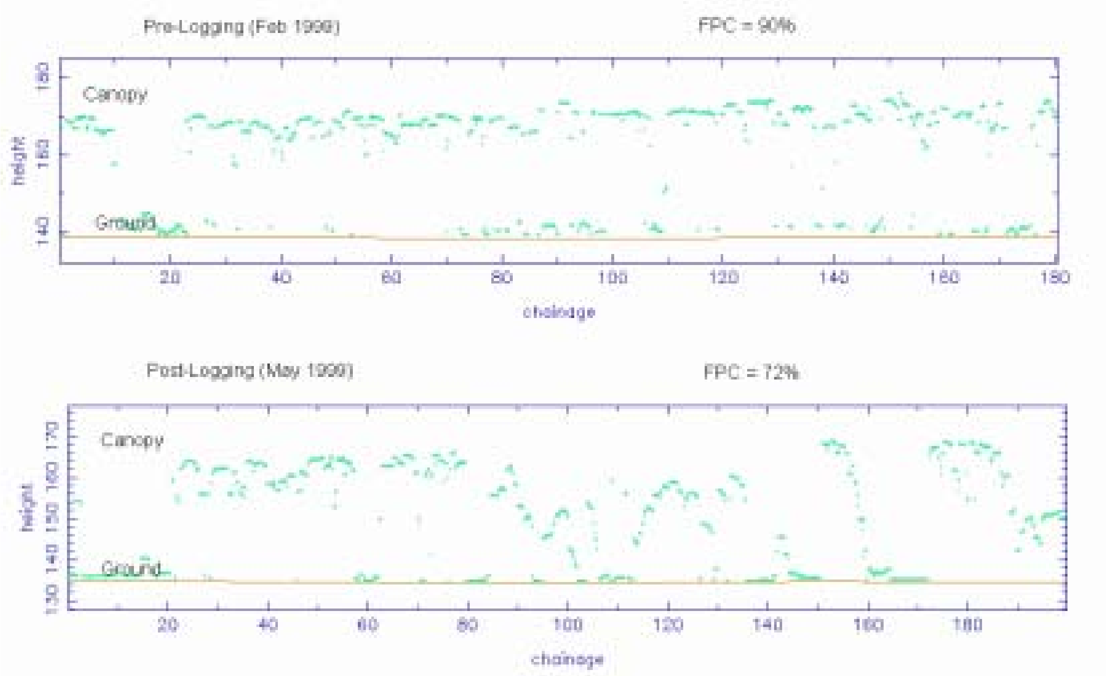


Figure 13. Laser profile for pre-logging and post-logging dates for Transect 1, 100 m flying height

The sharp decrease in FPC for both transects (Figures 14 and 15) therefore shows the result of this disturbance, and the following measurements through to May 2000 show that a gradual increase in FPC with time is occurring.

It should be noted that the FPC increase with time since the harvest has become more evident since March 2000 (the last two measurements) and prior to this increase, a period of relative stability in FPC measurements was experienced. It is also interesting to note that between the period of May 1999 and July 1999 for transect 1 (Figure 14) that a further decline in FPC was recorded over all flying heights and field measurements. Although this further decline is small, its consistency across all measurements may indicate that a lag effect was experienced. This lag effect may have been caused through the effects of secondary disturbance as a result of the harvest event e.g. soil disturbance, change in light conditions, etc.

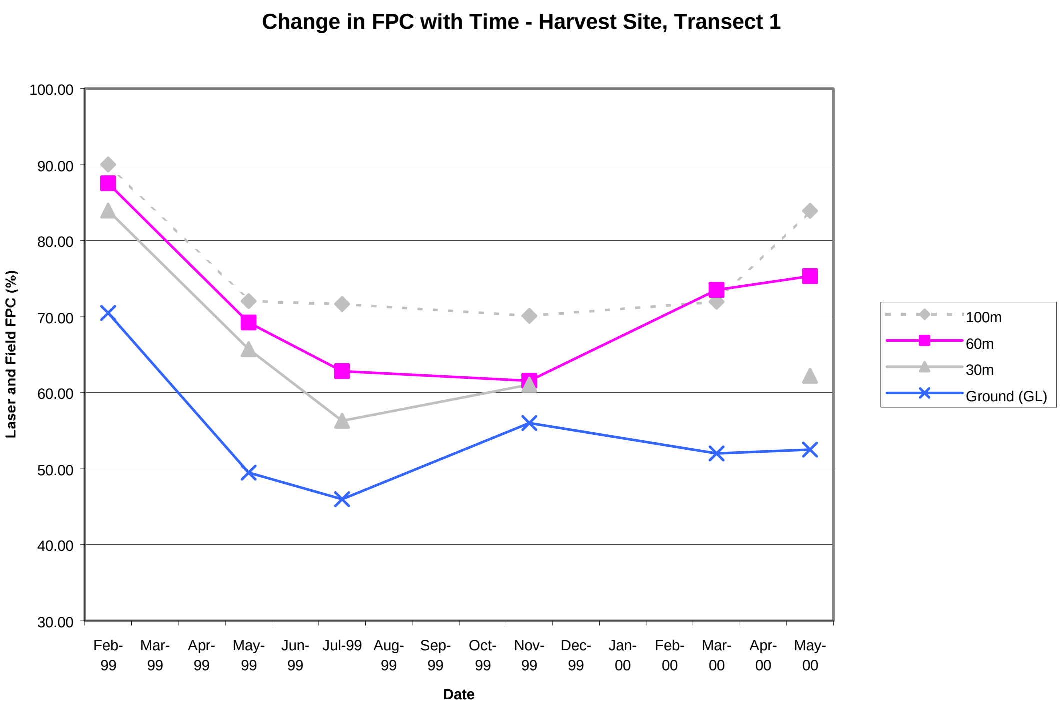


Figure 14. Change in FPC with time at the harvest site for Transect 1

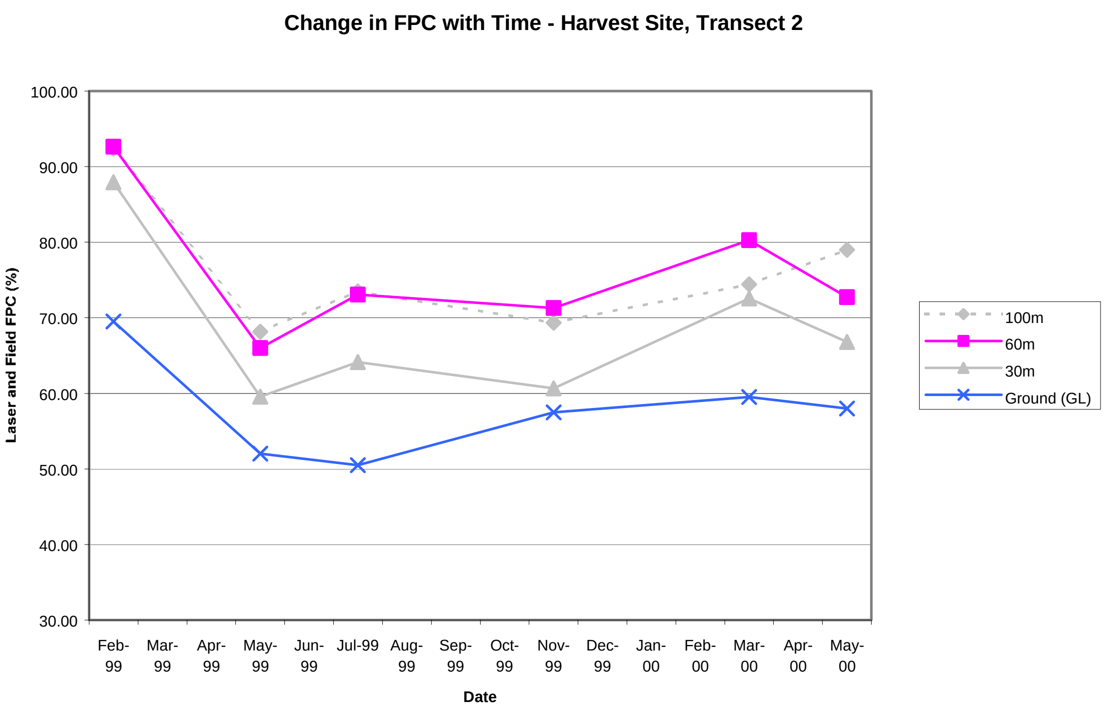


Figure 15. Change in FPC with time at the harvest site for Transect 2

Regrowth (Plantation) Site

The growth of the Gympie Messmate trees within the plantation site can be clearly viewed in Figures 16 and 17, with an increase in FPC over time at both transects. The change in laser profiles from the initial measurements in February 1999 to the final measurements in May 2000 may be viewed in Appendix 2. A decrease in FPC appears to have occurred between the measurements taken in March 2000 and May 2000, particularly at transect 1 (Figure 16).

A further set of field measurements were recorded in October 2000 to attempt to explain the March - May decrease in FPC. It was observed during this field trip that foliage damage had occurred throughout the plantation, with significant levels of dieback presumed to have occurred as a result of a beetle attack on the Eucalypts. The decrease in FPC between March and May may therefore be the result of foliage decrease through dieback. Another factor that could have contributed to the lower May 2000 FPC estimates was the strong wind conditions at the time of data capture. These strong winds may have resulted in the leaves/canopy being positioned differently and are likely to have increased helicopter movement.

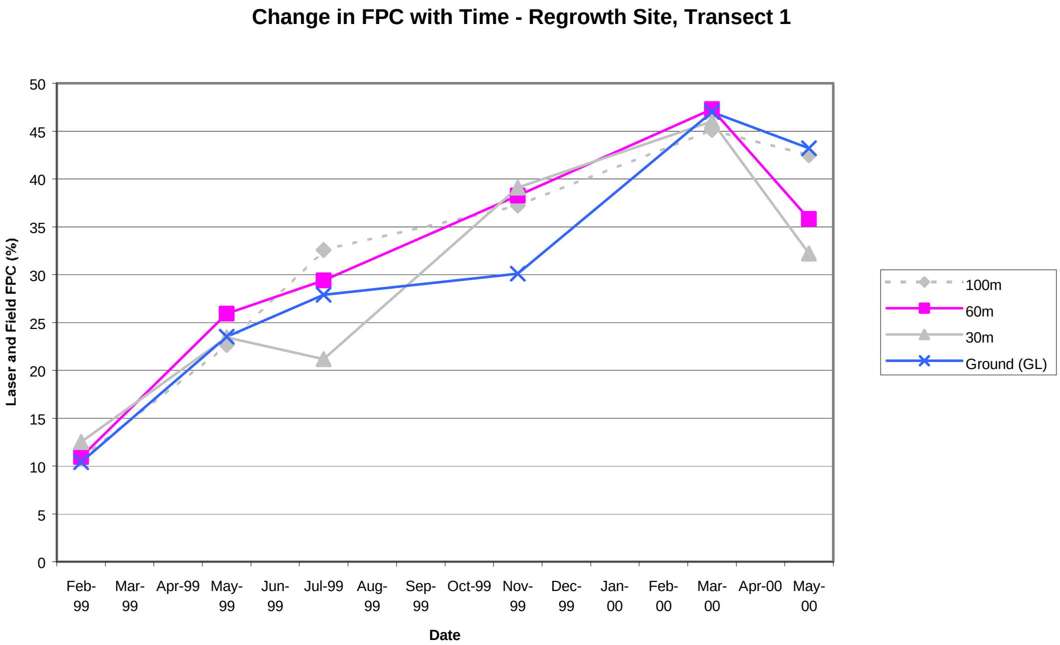


Figure 16. Change in FPC with time at the regrowth site, Transect 1

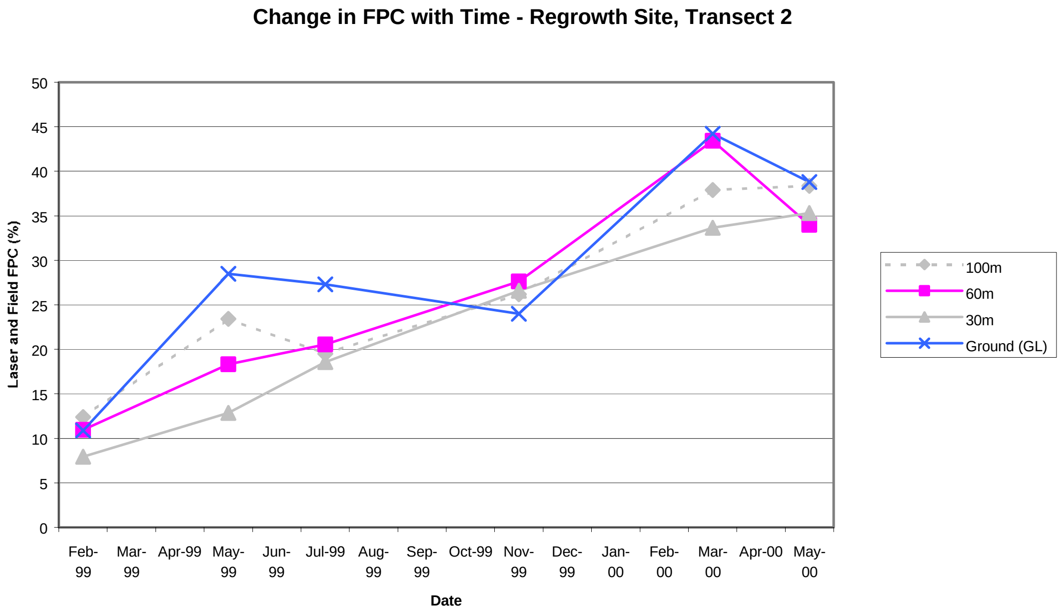


Figure 17. Change in FPC with time at the regrowth site, Transect 2

As outlined in the introduction/background information section of this report, the 'stick' method was utilised to measure field FPC at the regrowth site as the trees were too small to allow for use of the tube method. It is expected that the stick method produces an overestimate of FPC compared with the tube method, and as such, this is the only site where ground measurements are at times recorded higher than or equal to laser measurements. A comparison of the two FPC field techniques was able to be performed for the last two months (February and May 2000) and the additional October 2000 fieldtrip as the trees were then tall enough for the tube method. The differing results of the two methods are outlined in Table 4 below.

FPC Collection Method	**Field Date and FPC Estimate**					
	Feb 2000		*May 2000*		*October 2000*	
	Transect 1	Transect 2	Transect 1	Transect 2	Transect 1	Transect 2
FPC Tube	39.3	32.1	20.8	31.5	26.2	22.4
FPC Stick	47	44.2	43.2	38.8	27.3	26.1

Table 4. Comparison of field FPC results measured at the regrowth site using FPC tube and stick.

As observed in Table 4, FPC estimates obtained with the use of the stick are consistently higher than those estimated with the use of the tube. The higher FPC results obtained at the regrowth site when compared with the laser data can therefore be attributed to this method of field assessment.

Tree/Canopy Height

The effectiveness of measuring and monitoring tree/canopy height at each of the two year monitoring sites was very high. As expected, the control site was recorded as having the tallest canopy, representative of its status as a mature, closed forest. Tallest tree heights and mean tree heights recorded by the laser at each data capture date for each of the three sites may be viewed in Tables 5 and 6 below.

	Control		Harvest		Regrowth	
Date	Transect 1	Transect 2	Transect 1	Transect 2	Transect 1	Transect 2
02/99	45.7	47.4	37.3	35.4	3.8	3.5
05/99	43.8	43.5	34.4	35.6	4.9	4.2
07/99	44.9	43.7	34.9	36.2	5.3	6.9
11/99	44.5	43.4	36.2	35.9	6.8	9.5
02/00	45.3	43.8	36.6	35.5	8.0	9.0
05/99	45.0	45.2	37.1	35.7	8.3	8.7

Table 5. Maximum tallest tree height recorded by the laser across all monitoring dates and transects within a site

	Control		Harvest		Regrowth	
Date	Transect 1	Transect 2	Transect 1	Transect 2	Transect 1	Transect 2
02/99	36.7	31.5	25.7	25.7	2.5	2.6
05/99	35.6	30.9	22.1	26.4	2.9	2.8
07/99	33.9	30.0	27.4	25.9	3.1	3.2
11/99	32.1	29.2	24.9	25.3	3.9	3.7
02/00	37.2	31.4	25.7	25.7	5.0	4.7
05/99	35.6	35.2	21.8	23.9	4.8	5.0

Table 6. Mean tree height recorded by the laser across all monitoring dates and transects within a site

Control Site

Consistently high tree heights were obtained at this site, with minimal fluctuation in measurements (Tables 5 and 6). These results are consistent with the sites status as a mature, closed forest without external disturbance from logging.

Harvesting Site

While this site also represents a mature forest stand, it is subject to disturbance from selective logging. The lower heights recorded at this site then, (when compared with the control site) are most likely the result of this disturbance regime.

Regrowth (Plantation) Site

Canopy height was measured very effectively at the regrowth (plantation) site. An increase in tallest tree heights were recorded over time, as the Gympie Messmate (*Eucalyptus cloeziana*) trees continued to grow. The pattern of regrowth was very clear at this site, however it should be noted that the homogeneous nature of this site i.e. uniform height class and same species trees, allowed for a simple pattern of regrowth to be observed. It is expected though, (with the success of monitoring tree growth at this site), that regrowth monitoring even in heterogenous forests may be effective. Knowledge of species type at a site, either through field assessment or interpretation of high resolution digital video, may be used to aid in the interpretation of laser data from heterogeneous forests e.g. different species growth information may aid in the interpretation of laser data.

Species and Growth Stage

The use of digital video data to determine species type and growth stage (as described in species and growth stage sections of assessing biodiversity variables), could also be used to monitor changes in species composition, diversity and growth stages over time with the analysis/interpretation of digital video data captured over successive dates.

Decision Rules for improved measurements of biodiversity variables

As it has been highlighted throughout this report, laser altimetry provides accurate measurements of tree/canopy height and FPC. Such information may be used for a variety of applications including the provision of structural information and change across a landscape. Particular values of FPC and tree height may be grouped into classes of structural formation similar to those outlined by Specht et al. (1995). For example, the Mark IV Version of structural formations in Australia shows that an area with trees greater than 30 m height and FPC 70% – 100% is classified as tall closed-forest, while trees less than 5m height and FPC 10% – 30% is classified as very low woodland (Specht et al. 1995). Such classifications could therefore be applied across a landscape using the measurements obtained through laser altimetry, and digital video may be used to further verify the structural changes. The use of digital video may also be valuable in viewing the detail of ecotone areas.

Abrupt changes in canopy height and FPC could also be used to delineate areas of disturbance and regrowth. It is recommended that the digital video be accessed to verify these changes, and provide further detail on the nature and intensity of the disturbance.

Repeatability of data capture for estimating condition variables

The ability to replicate flight lines is an important aspect in the assessment and monitoring of biodiversity condition using laser altimetry. Further explained, in order to compare results over time from laser measurements, the same area of study needs to be assessed. Three runs were therefore flown at a 60 m flying height at each site for each date, in order to assess the ability to replicate a flight run on the same day under the same conditions. The means and standard deviations of FPC for each replicate run are displayed in Appendix 3.

The majority of the standard deviations are quite low, with 88% of the results having a standard deviation of 5% FPC or less, and 62% of the results having a standard deviation of 2% FPC or less. While these results indicate that flight replication is relatively accurate, it should be noted that 12% of the results had a standard deviation of greater than 5% FPC, with the highest standard deviation reaching 12% FPC. While these results indicate that flight replication over the two year monitoring sites was very good, some caution is still required in interpreting results collected over time. As discussed by Weltz et al. (1994), even when every effort is made to repeat the same flight line, variations in aircraft location are unavoidable.

An additional issue of transect length may also be related to high standard deviations on replicate flights. As the laser is a sampling tool, it should be possible to fly in any direction over a homogeneous area/patch of forest and receive similar FPC results. The issue then arises of how long a transect needs to be (for laser and ground measurements) to represent the variation in FPC for a forest type, as a small fraction of an area may not be representative of the entire area (Weltz et al. 1994). Appropriate transect lengths are likely to vary depending upon such factors as vegetation type, disturbance history and geographic location e.g. the lower density and sparser distribution of vegetation in western Queensland when compared to coastal Queensland may mean that longer transects are required in these western areas to represent the consequent variations in FPC.

FPC was calculated for individual western sites as a total 200 m transect, and was then calculated on smaller subsets of the overall transect i.e. at 100 m and 50 m lengths. These FPC results could then be compared to determine the level of variation between segments and the length at which the variation appears to 'even out'. It was found that the 50 m segments were quite variable when compared to other 50 m segments as well as to the overall 200 m FPC result. The 100 m segment values though were generally quite close in value to the overall 200 m FPC value (generally within 5% difference), and did not differ greatly from each other.

Conclusions/Discussion

It is clear from this study that laser altimetry provides detailed and accurate information on vegetation height and density, and that when combined with high-resolution video data, detail on species type and growth stage may also be sought. The laser altimetry data collected over time was successfully processed, analysed and applied as a monitoring tool. For example, the harvest event at the harvest site was very evident in the FPC results and the forest stands gradual recovery after this event was also clearly monitored. Further, a decrease in FPC at the regrowth site (when an otherwise steady increase in FPC was observed over time) appears to be attributed to a loss in foliage density through dieback. The results for assessment of FPC (R^2 of 0.92, 0.94, 0.96) and tree height (R^2 of 0.91, 0.93, 0.91) present strong correlations between laser and field data.

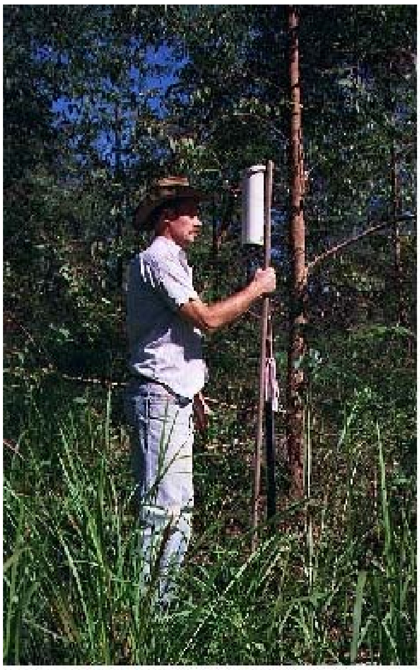
Laser altimetry, in combination with digital video, offers a cost-effective tool that can contribute to comprehensive monitoring systems, particularly when considering the high costs, and low spatial and temporal coverage involved in fieldwork (Pitt et al. 1997). The results obtained in this report further convey the potential of laser altimetry in this role.

It is expected that some of the variations found within the datasets e.g. replication of flights (Appendix 3) may be attributed to the laser data having been flown on first return only. As described by Hunsaker et al. (1998), the vertical mixing of ground and vegetation is a primary factor affecting accuracy, and without any separation between first and last return data (as in this study), delineation of the ground in densely forested areas was more difficult. Although the quality and accuracy of the results presented throughout this report appear to be very high, separation of first and last return data would allow for an even higher level of accuracy in results.

It should also be noted that while this project has assessed the use of a laser profiler system as a monitoring tool, that a number of projects have been completed and/or are currently underway using laser scanning systems. For example, a project currently underway in the Injune area of central Queensland involves the assessment of forest carbon content and possible monitoring of carbon fluxes using remote sensing technologies, including laser scanning.

Laser scanning involves the setting up of a base station and hence offers spatial accuracy of better than 30 cm. Such accuracy enables the monitoring of ‘exactly’ the same trees over time. In comparison, the laser profiler system utilises differential GPS locations with a spatial accuracy of five to ten metres. The laser profiler can therefore never guarantee exact repeatability but is a good tool for sampling areas or patches of forest (providing a single profile). The decision to use a profiler or scanning system then is likely to depend upon the given application of a project, and may also include considerations of cost and data storage capabilities.

Appendix 1: Fieldwork Photos



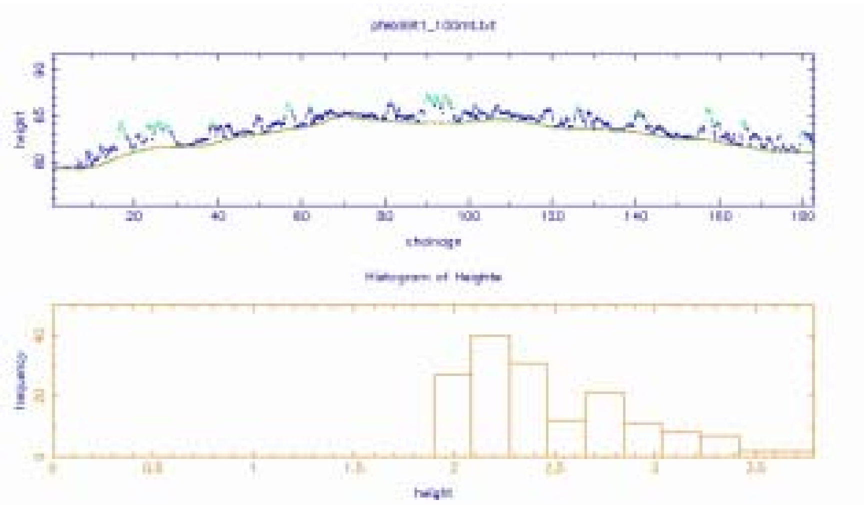
FPC field measurements were recorded at all sites at one metre intervals using a tube and crosshair method developed by Specht (1970). This method uses a tube with a crosshair attached to a rod two metres above the ground. A mirror placed at 45 degrees at the bottom of the tube allows an operator to record the presence or absence of green leaf (GL), dead leaf (DL) or branch (BR) in the canopy vertically above.

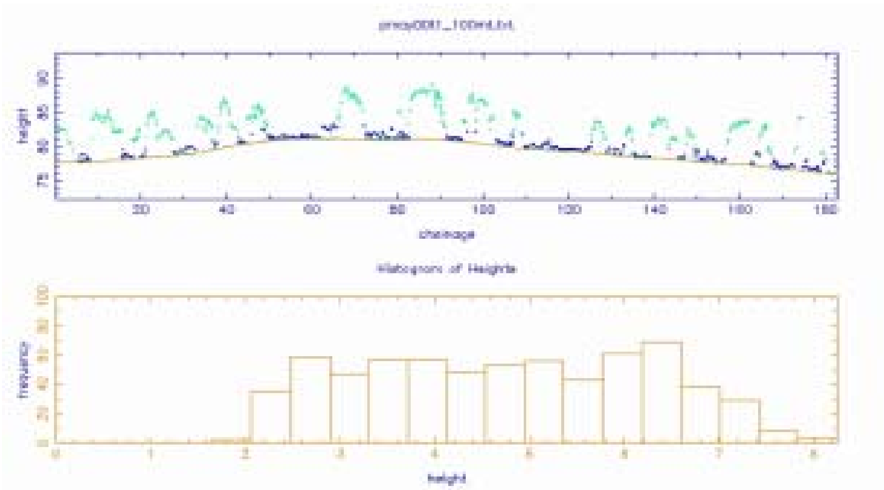
Transects for each of the two year monitoring sites were permanently marked with a clearly visible object (i.e. blue tarps) to ensure the best possible repetition of the transects by the helicopter pilot

Appendix 2: Change in Laser Profiles for the Plantation (Regrowth Site)

February 1999

May 2000





Appendix 3. 60 metre flying height replicates – mean and standard deviation FPC values

Site		**Feb-99**		**May-99**		**Jul-99**		**Nov-99**		**Mar-00**		**May-00**	
		Mean FPC	SD FPC	Mean FPC	SD FPC	Mean FPC	SD FPC	Mean FPC	SD FPC	Mean FPC	SD FPC	Mean FPC	SD FPC
Control	T1	97.39	3.06	95.98	0.58	94.98	0.88	92.31	1.46	97.67	0.52	94.42	3.09
	T2	95.65	0.61	96.12	0.83	93.34	1.72	94.06	1.60	97.44	0.40	97.16	1.19
	T3	93.96	0.71	95.32	0.96	96.51	0.68	96.61	0.80	96.28	2.11	97.72	1.34
Harvest	T1	87.56	0.79	69.24	1.74	65.33	2.14	61.55	4.06	73.53	1.59	75.34	0.96
	T2	92.63	2.18	65.98	0.70	73.08	12.04	71.30	3.01	80.25	7.28	72.72	7.26
Plantation	T1	10.95	1.51	25.91	4.29	29.40	2.85	38.27	6.11	47.30	1.82	35.83	5.19
	T2	10.95	0.91	18.31	0.36	20.54	1.80	27.62	4.06	43.42	1.72	33.99	4.22

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