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Operational deployment of LiDAR in Australian softwood plantations

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www.fwpa.com.au

FWPA Level 4, 10-16 Queen Street,
Melbourne VIC 3000, Australia
T +61 (0)3 9927 3200 F +61 (0)3 9927 3288
E info@fwpa.com.au W www.fwpa.com.au

Operational deployment of LiDAR in Australian softwood plantations

Prepared for

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by

Jerry Leech

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Researcher:
Jerry Leech
Forestry Systems

Forest & Wood Products Australia Limited
Level 4, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@fwpa.com.au
W www.fwpa.com.au

Executive Summary

LiDAR can deliver significant practical advantages to organisations intensively managing pine plantations, unlike most remote sensing technologies in the past. This has been demonstrated by ForestrySA where the age 9 ½ Site Quality Assessment has been replaced by a LiDAR based protocol that eliminates expensive strip cruising. Various organisations are at various stages in their deployment of LiDAR.

It is now time to review LiDAR, not with a view to determining research priorities *per se*, but to determine possible short term practical deployment strategies to assist routine pine plantation management.

The six largest pine plantation management organisations in Australia have formed a collaborative to determine if this deployment of LiDAR can be coordinated, and so reduce costs and share and spread expertise.

This report compares the status of LiDAR in each of the six organisations and suggests strategies for the near future, considered to be the next 2-3 years.

A meeting was held of all collaborative partners in Melbourne to briefly discuss the report and to discuss possible future options.

The options discussed included;

- the deployment of LiDAR to assist early age inventory of unthinned stands,
- the possibility of using LiDAR for later age, post first thinning pre-harvest inventory,
- the formalisation of the collaborative, and,
- how LiDAR system parameters might best be kept under continual review.

It is suggested that this later age inventory be the subject of a larger project to be funded in part by FWPA. Some draft details of the funding proposal were provided for the collaborative to discuss and, if they so desire, to act upon.

Abbreviations

ALS	Airborne Laser Scanning
CF	Clear Fell
dbhob	Diameter Breast Height Over Bark
DEM	Digital Elevation Model (or Digital Terrain Model (DTM))
dGPS	Differential Global Positioning System
FMIS	Forest Management Information System
FOV	Field of View
FPC	Forest Products Commission
HQP	HQPlantations
FWPA	Forest and Wood Products Australia
GIS	Geographic Information System
GPS	Global Positioning System
GTFP	Green Triangle Forest Products
h_q	Mean quadratic height of LiDAR heights
HVP	Hancock Victorian Plantations
INS	Inertial Navigation System
LAI	Leaf Area Index
LiDAR	Light Detection And Ranging
NDVI	Normalised Difference Vegetation Index
Pd	Pulse or point density, number of first returns /m^2
PLE	Probable Limits of Error
PSP	Permanent Sample Plot
SERIC	South East Resource Information Centre
SLICER	Scanning LiDAR Imager of Canopies by Echo Recovery
SPH	Stems Per Hectare
SRG	Sustainability and Resources Group, a committee responsible to FWPA
T1	First commercial thinning
T2	Second commercial thinning
TIN	Triangulated Irregular Network
TLS	Terrestrial LiDAR Scanning
TP	Timberlands Pacific

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Introduction

In February 2012 a collaborative submitted a Project Proposal to Forest and Wood Products Australia (FWPA). The collaborators were Glen Rivers (Hancock Victorian Plantations (HVP)), Jim O'Hehir and Jan Rombouts (ForestrySA (FSA)), Mike Sutton and Christine Stone (Forests NSW), John Tredinnick (Forest Products Commission (FPC)), Kevin Cooney (HQPlantations (HQP)) and Don Aurik (Timberlands Pacific (TP)).

The objective was to carry out a scoping study for the operational development and deployment of LiDAR in the foreseeable future, considered to be up to 2-3 years.

The desire was for a management focus not a research focus. The underlying requirement was to determine what is needed to enable LiDAR to be effectively and economically deployed in intensive softwood plantation management.

The project was approved as PRC281-1112.

Each member of the collaborative was interviewed about how they saw LiDAR fitting in to their forest management strategy, synergies were determined, and a potential course of action was determined. It was recognised that this can only be a recommendation as the collaborative themselves need to make the decisions going forward.

Elements of a Forest Management Information System

There was a need to understand each organisations Forest Management Information System (FMIS) to see how and where LiDAR might be able to improve the information available in a cost effective manner.

It was recognised that this would likely vary between the collaborative members. The six collaborators are the largest softwood plantation management organizations in Australia.

Description of Collaborators

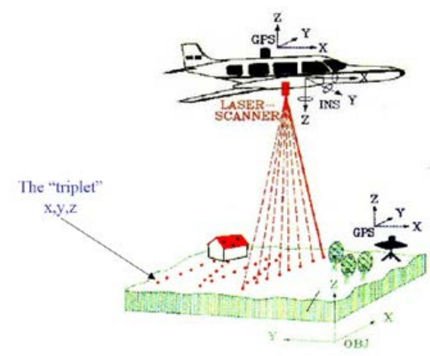
Hancock Victorian Plantations	Manages some 162,000 ha of plantation, predominantly radiata pine in Victoria.
Forest Products Commission	Operates as a Statutory Authority under an Act of Parliament in Western Australia. This enables the agency to engage in commercial forestry activities in State-owned native forests and plantations. FPC has over 100,000 ha of plantations and tree farms under its management.
ForestrySA	Manages plantations, primarily radiata pine, of which some 75,000 ha is in the south-east of South Australia, and a further 13,000 ha is near Adelaide and in the mid north of the state. There are also some plantations in Victoria.
Forests NSW	Manages 209,000 ha of softwood plantation forest (primarily radiata pine) and some 63,000 ha of hardwood plantations.

HQPlantations	Is Queensland's largest plantation timber company, managing the primarily Southern Pine plantation resource under licence from the Queensland Government. There are also areas of Araucaria plantation. HQP manages some 212,000 ha of plantations, primarily softwood.
Timberlands Pacific	Manages Taswood Growers which is 46,000 ha of plantations under a forest right in Tasmania. Taswood Growers is wholly owned by New Forests, a fund manager who acquired the previous joint venture asset from Forestry Tasmania and GMO.

Brief Overview of LiDAR

This is a very brief and superficial outline of LiDAR. For more detail consult the literature including Wikipedia, Silvilaser Conference proceedings and the references cited. This outline is oriented toward the objectives of this study, the practical application of LiDAR in intensively managed pine plantations in the immediate future.

These systems comprise a laser scanner, a GPS coupled with a ground station, an Inertial Navigation System (INS) and on-board computers (see illustration[1]). The scanner fires laser pulses to the ground below and then detects the energy reflected. The GPS and ground base station measure the position of the aircraft. The INS measures the change in the attitude angles of the aircraft. Knowing the position/attitude of the scanner and the time the pulse takes to return, it is possible to calculate the three dimensional coordinates of the reflecting source. Considerable computing power is required while airborne to process and integrate the data flows produced by these instruments, and more computing power is required to facilitate post flight processing.



(from Spencer B. Gross, Inc. web site; adapted from Flood and Gutelius, 1997, PE&RS)

The processed files are then provided to the users who then have to carry out considerable further processing. The term small footprint refers to the diameter of the light spot when the beam reaches the ground. The term discrete return generally means that only significant parts of the reflected energy waveforms are identified and stored as discrete points. This is less demanding on data storage.

Profiling systems limit the sampling to a line and this approach parallels a number of broad scale national forest inventories. Generally the approach is currently considered unsatisfactory for intensively managed pine plantations as it adds line sampling implications that currently would appear not to balance the extra cost of full area sampling.

Other studies have used a full-waveform, large footprint system such as SLICER (Scanning LiDAR Imaging of Canopies by Echo Recovery) that was specifically designed for vegetation assessment. The full wave-form approach may provide additional information (Lefsky et al., 1999a; Lefsky et al., 1999b; Means et al., 1999) but the extra information comes at a cost that may be considerable. Processing is more complicated.

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1 The diagram is copied from Rombouts (2011) who provides the accreditation of the source.

Terrestrial Laser Scanners are ground operated portable LiDAR instruments that can conduct scans of the surrounds. They are useful for the depicting stem quality and for determining a number of ecological parameters that are likely to become useful.

This particular study is limited to small footprint airborne systems, not because the other approaches do not have merit, but because they currently offer the greatest scope for rapid deployment in practical intensive pine plantation management. This limitation is unlikely to hold into the future.

Methodology and Results

Questionnaire

Appendix 1 details the more important components of the information that is embedded in most FMIS. It was deliberately left very general so as to allow collaborators flexibility in their responses. This was sent to all collaborators prior to the site visits in an attempt to get each organisation to focus on the same issues and thus facilitate comparisons.

In the discussions that follow the term logging coupe will be used to represent what some organisations refer to as harvesting units, resource units, logging units and logging categories. The terms are basically the same thing.

Review by Organisation

The six collaborating organisations all are at different stages of LiDAR deployment but all need to assess how LiDAR can best be deployed in their organisation and where additional research should be concentrated.

The following sections represent a summary of my perspective of each organisation's current LiDAR status.

HQPlantations

HQP describe their LiDAR involvement as being partly down a path but not wedded to any particular path. They have flown their whole estate with LiDAR, primarily to obtain a DEM and have used this information to provide other products useful to managers including a hillshade map, contours (at 0.25 m), a slope category map, drainage map, tree height and site index.

They use their slope map to define drainage patterns and have found that the use of percentages is more practical than degrees in this regard. The Araucaria estate uses degrees rather than percent more from historic use and familiarity than for any specific reason.

Their tree height map is used for pre-harvest stratification and they recognise that in absolute tree height terms the results may not be satisfactory. However they have used the tree top heights to estimate Predominant Height (PDH) and then have used growth models to predict site index, defined as PDH at age 25 for the Araucaria areas of the forest estate. It has also been used to identify poorly performing plantation areas as part of plantation re-design

They have not yet used LiDAR in conjunction with field plots for inventory and recognise this as potentially the most useful next step with LiDAR.

Under their new management they have recently canvassed for expressions of interest for uncommitted volume out to 2036, indicating the current focus of their new management on the longer term.

Determine gross area

HQP consider that LiDAR has some potential if it is cheaper than their current practice of using GPS (both differential and nondifferential) surveys supplemented by high resolution rectified aerial imagery and LiDAR products. LiDAR can be used opportunistically to rectify roads and other features.

Digital Elevation Model

HQP have a DEM at 1 m^2 resolution but recognise that slope maps are more useful if at 5 m^2 resolution as this more closely matches field usage and experience. It has been found though that for the Araucaria estate the use of 1 m resolution is better than 5 m as the 5 m will tend to blend out some of the detail that is critical in determining road and ramp locations, and harvest access, especially in steep terrain.

The DEM hillshade map has been used to detect potential erosion areas prior to harvest. Hillshade has been used to identify high mounding direction.

Their slope maps are produced in both degrees and percentages recognising that this reflects history in the southern pine and Araucaria management units.

Their DEM is bedevilled in some areas by lantana. Correction of this problem could be assisted by LiDAR post first thinning when harvesting equipment has knocked down the lantana and a more accurate DEM is possible. This could be interpolated across the bays using the past, possibly biased, DEM. Given that the maximum bias is about 2 m this is not a major concern with their current use of LiDAR.

Define plantation layout

Only about 2-4% of the current planting units are first rotation and the rest are generally established to the old plantation outlines. That said, LiDAR can be used to help with buffering around exclusion zones based on a combination of soil, water, slope, and erodability.

Slope maps are routinely used to position internal roads/tracks for the next rotation compartment design. It also allows more precise mapping of boundary, tracks and forestry roads where the mapped position differs from actual position.

Post planting survey

HQP consider that post planting surveys are unlikely to benefit from LiDAR as trees are too small and too hard to discriminate from other vegetation, although it may be feasible at about age 3. It would need to be later for the Araucaria estate due to the level of ground vegetation and difficulty in picking up the leader.

Early age silviculture

LiDAR could be used for determination of areas needing weed control, but generally this is considered unlikely

Early age inventory

HQP carry out an early inventory at about age 10 in the southern pines and 14 in *Araucaria*, using strips through the forest.

This is an area where LiDAR may be very useful indeed but HQP recognise that the technology is currently available and it is their challenge to work out how to implement it in their forest.

Logging coupe layout

Logging coupe layout benefits from having the DEM and slope maps. They can use the information to select which contractors are appropriate and which equipment may or may not be feasible.

Later age inventory

Currently most stands receive one thinning and the next harvesting operation is generally clear fall. HQP see the need for a post thinning inventory at some later age and consider that a project that can identify a methodology that will work in thinned stands of any age will be of great benefit.

Harvesting control and reconciliation

HQP consider that LiDAR is unlikely to be superior to their current methodology using rectified ortho-photo maps, but recognise that if LiDAR costs plummeted that it could be useful.

Later age silviculture

They see little use for LiDAR apart from possibly post first thinning stocking counts which are currently based on strip counts at 5%.

Area change determination

HQP see LiDAR being used opportunistically to pick up area changes such as landslides, areas of wind blow and mapping errors (such as where planted southern pine occurs on land mapped as unplanted).

Other

HQP noted that LiDAR may be useful to map fuel loads.

Lantana is a problem in that it influences the precision of the DEM. HQP currently consider that their use of LiDAR to stratify based on tree heights is adequate but recognise that absolute tree heights may be biased by errors in the DEM caused by the lantana infestation.

Forest Products Commission

The Forest Products Commission has carried out some preliminary assessments of the use of LiDAR. They recognise that LiDAR is one technology that may well be of considerable use but stressed that LiDAR was not the only issue that needs to be addressed. They also stressed that operational deployment of LiDAR would be dependent on the economics. They recognise that the dispersed nature of their plantation resource and the relatively low growth rates, especially with drought implications superimposed, will work against speedy deployment of any new forest mensuration procedures. Given the economic times they are strongly in favour of collaborative development.

Determine gross area

Most plantations are second or subsequent rotation and current mapping is considered at present to be quite adequate. They consider that aerial photography is more likely to be more practical.

Digital Elevation Model

Given the relatively flat topography a DEM is considered to be of lesser priority. It would be nice if it could be achieved as part of a LiDAR project but is not in itself considered a high priority.

Define plantation layout

Not considered an issue as plantations are predominantly replants to existing compartment outlines.

Post planting survey

Considered that LiDAR is unlikely to be of use.

Early age silviculture

Consider that LiDAR could be useful to pick up nutritional differences in very young plantations. Currently FPC are rebuilding the system of foliar analysis to assess nutritional requirements.

Logging coupe layout

LiDAR could be useful under some circumstances but logging coupe layout is generally relatively straight forward.

Inventory

FPC have recently carried out a baseline inventory for plantations aged between 8 and about 30 (Dash and Marshall 2011).

This was discussed in some detail. The results are better than was previously available but there are concerns about the accuracy of the stocking counts. It would seem that in this preliminary investigation the inability to specify the requirements in detail, mainly because requirements change as research progresses, has contributed to the difficulties.

On steep sites LiDAR was not available for all areas and some areas were based on ground plots alone.

FPC are currently considering how this data base should be maintained and updated. FPC recognise that it may be possible to use a similar approach to the ForestrySA approach for young unthinned plantations and believe that later age, post or pre thinning inventory is the area where LiDAR is most likely to be implemented most productively.

FPC recognise this later age inventory as the area where LiDAR is most likely to be satisfactorily deployed. They recognise that research is needed.

FPC see their greatest need as inventory at about age 9-10 as this sets the growth model for future yield prediction, including setting the thinning regimes. However stocking estimation will need to be better than has so far been achieved.

Harvesting control and reconciliation

FPC recognise that if LiDAR costs reduce considerably the technology may provide the ability to carry out the annual mapping of harvesting boundaries.

Later age silviculture

LiDAR may be an option but is likely to depend on LiDAR acquisition costs reducing considerably.

Area change determination

As for the above, LiDAR may well provide a way of mapping area changes but it is not considered a high priority task at present.

Terrestrial LiDAR

Terrestrial LiDAR (TLS) has been trialled (Murphy, Acuna and Dumbrell 2010). That study recognises some weaknesses that need to be addressed before TLS can be satisfactorily deployed in practice.

Specific Comments

FPC commented that they would prefer a collaborative development. They believe that deploying LiDAR in inventory is where the greatest benefits can be achieved.

They would like to see a mechanism that would enable someone else to monitor developments in LiDAR control variables as they consider that they have other more important issues to address with limited capability.

ForestrySA

The focus of ForestrySA management is on application oriented research that can put LiDAR into practice effectively, efficiently and economically.

Determine gross area

ForestrySA consider it unlikely that LiDAR can be used effectively to confirm gross area, recognising that the Torrens Title system operating in South Australia is very effective. It is not a priority issue.

Digital Elevation Model

ForestrySA have a DEM from the South East Resource Information Centre (SERIC) who coordinated a LiDAR assessment of the whole of the south east of South Australia and provided a DEM on 2 and 10 m grids. As a financial contributor to the project ForestrySA have access to a more intensive DEM as well as the raw data. It is considered to be quite adequate given the relatively flat topography and therefore the limited need for a detailed DEM.

A DEM would be desirable in the Ranges region but given that the plantation management there is not as intensive it is of lower priority and more difficult to justify economically.

Define plantation layout

The DEM may be used but is relevant only over a small proportion of the estate. The compartment boundaries generally avoid swamps and stone outcrops and if these can be demarcated by LiDAR easily and economically then the information could be used.

A DEM can assist in deciding the establishment technique, for example whether mounding is required or not. This cannot supplant the professional judgement of experienced operators.

A DEM would be more useful for defining the plantation layout in the Ranges region than in the south-east.

LiDAR can be useful for demarcating and subsequent protection of non timber assets. LiDAR can assist in setting up exclusion zones.

There are still some areas that were originally surveyed by compass and chain, almost all native forest areas and non plantation areas. Since the 1960's all plantation surveys have been carried out using theodolite, laser, or GPS, by professional surveyors.

Post planting survey

Currently plantation boundaries are satisfactorily surveyed by a professional surveyor using dGPS within 6 months of planting.

Survival counts are carried out within the first year to inform decision making regarding remedial planting.

Within the important first year LiDAR is unlikely to be of use as trees will not be able to be reliably detected. LiDAR could be used for stocking counts at about age 2 by which time it is too late to take any remedial action if that is deemed desirable.

Early age silviculture

LiDAR is a distinct possibility for carrying out age 2-5 nutrition surveys. Current practice is to measure a limited number of growth plots and to use these to determine whether or not to fertilise. Foliar analysis is performed in some cases.

In the mid 1980's Gary Archer carried out some pioneering work and the substitution of LiDAR for other remote sensing tools (believed to have been SPOT) is a possibility. It has not been followed up simply because of competing priorities. LiDAR can define structural differences whereas this analysis would seem to require multi-spectral information.

Early age inventory

Site Quality assessment (Lewis, Keeves and Leech 1976) is now carried out using LiDAR and field control plots (Rombouts 2011, Rombouts, Ferguson and Leech 2008, 2010, Rombouts, Ferguson, Leech and Culvenor 2010). This is a successful implementation of LiDAR into forest management practice.

The second operational survey is currently in progress. Contracts are in place with GTFP.

Although Dr Rombouts' analysis was carried out with a range of pulse densities it would seem that pulse densities of around 0.3 pulses per m^2 are adequate for this volume based inventory. It is possible that in the parts of the estate with steeper topography and more undergrowth a higher pulse density may be required. If stocking counts are required then ForestrySA consider that pulse counts in excess of 2.5 will be necessary.

Logging coupe layout

Currently LiDAR is considered unnecessary in the south-east. It could be useful in the Ranges region near Adelaide.

Later age inventory

This is considered by ForestrySA to be the highest priority for investigating the deployment of LiDAR.

Inventory is currently plot based with stratification based on the Site Quality Assessment. Plots are measured at least one year after thinning and growth to next harvesting operation is modelled. Basically it is a post-harvest inventory but is increasingly becoming pre-harvest, the only difference is the projection period[2].

ForestrySA have carried out preliminary research in this area and see a great opportunity for deployment of LiDAR as it is, in essence, an extension of their pioneering work on Site Quality assessment of unthinned stands less than age 10.

There are a number of issues to be considered apart from volume (or basal area), upper stand height, and stocking. There is a requirement for product volume, piece size and number, and the separation into the thinnings subpopulation and the main crop after thinning.

Given the need for the prediction of product information and the requirement to predict a sub-population of the stand ForestrySA believe that it is imperative that precise tree counts be achievable to arrive at measures of mean tree volume. They have some encouraging results with r^2 of 0.9. This was based on a smoothing algorithm based on age, unlike Scandinavian experience which suggests height is better.[3] The research indicates that pulse counts >2 per m^2 will be required which suggests that for any research project into the use of LiDAR in late age, post first thinning inventory, data densities of at least 4 pulses per m^2 are desirable.

[2] The terms pre-harvest and post-harvest inventory include inventory at any stage during the rotation post thinning, whether it be approximately one year after thinning (post-harvest inventory) or approximately one year before a thinning or clear felling (pre-harvest inventory), or anything in between.

[3] This could be a reflection of the situation in South Australia where, on the windswept coastal plain, height is generally not a good indicator of the forest productivity.

Harvesting control and reconciliation

LiDAR could be used to define harvesting boundaries but would require a significant reduction in cost as flying would have to be carried out at the end of each 6 month period and would ideally not be delayed, otherwise it would not provide the required information.

ForestrySA would like to carry out this reconciliation even more frequently than six monthly. If LiDAR was extremely cheap then this could be feasible.

The same information can be supplied by harvesters. The location of GPS sensors in the harvesting heads, and not just the cab, would be desirable.

The question is a matter of timing. Can the survey be carried out on the day required? Does the survey provide the required information, can it be adjusted for trees felled and not extracted and for log dumps in the bush?

Later age silviculture

ForestrySA are currently testing to see if LiDAR can be used to pick up fertiliser responses.

Work by CSIRO has demonstrated that the magnitude of fertiliser responses can be related to Leaf Area Index (LAI). Since LiDAR can be used to measure LAI it could also be used to pick up areas where later age fertilisation may be economically profitable. If LiDAR was cheap enough then it would facilitate repeated LiDAR coverage of the whole forest, enabling the establishment of trends over time.

LiDAR could be used to confirm pruning contracts (for example, the delineation of Fuel Modified Zones).

LiDAR could be used to delineate possible insect attacks.

These potential uses are in part feasible now but widespread use of LiDAR would require a significant cost shift that may only come with the use of drones, probably owned and operated by ForestrySA.

Area change determination

LiDAR could be used to identify where change to land use has occurred; fire boundaries, fire intensity, lightning strike deaths, and to confirm revocations.

Biodiversity corridors and native forest management

Given that the native forest areas are not as well mapped as the plantation areas, LiDAR is potentially useful to determine external boundaries, internal strata boundaries, swamps, open areas, and to facilitate potential changes in access track design.

If LiDAR was cheaper and could be carried out more frequently then it could be useful in determining fuel loads.

Other

ForestrySA believe that LiDAR can potentially be used for weed mapping, especially of bracken extent. This could be either prior to establishment or prior to clear felling so that bracken control treatment can be started before clear felling.

Undoubtedly LiDAR can be used opportunistically for various *ad hoc* surveys.

Terrestrial LiDAR

ForestrySA have some twelve logging coupes where terrestrial LiDAR has been used to investigate the capability of the technology (including Murphy, Acuna and Dumbrell 2010).

They have trialled technology to investigate different cutting strategies, and recognise that the technology is at an early stage of development.

LiDAR may be useful as a companion to tree mapping as a mechanism for determining products at time of inventory.

ForestrySA believe that they are some way off, perhaps 1-4 years, being able to deploy TLS in an operational manner. They have some operational concerns that will need to be addressed and need to confirm the economics.

They also believe that there is scope for TLS to be used in the measurement of Permanent Sample Plots (PSPs).

Continuous stratification

ForestrySA consider that LiDAR offers the possibility of avoiding mapping classes in favour of mapping all the area using a continuous variable. It could change the way ForestrySA look at using their site potential classification. It is likely to lead to regression sampling rather than stratified random sampling.

See also specific possible research questions later and possible development paths.

Priority issue

ForestrySA strongly believe that the LiDAR project priority should be to satisfactorily deploy LiDAR for pre-harvest inventory. This would obviously encompass post-harvest inventory too as the two just vary in timing, not scope. They see two significant areas of concern. First, that not all companies may see this as the most important next step in the deployment of LiDAR which could lead to an unsatisfactory compromise. Second, that although their own experience suggests that they have their Site Quality inventory under total control, pre-harvest inventory is more complex in that the focus is not on total volume available but on product size, number and grade, and in the case of thinnings, on a subset of the tree population not the total population. This will require stocking to be determined, not just volume.

My immediate reaction to the ForestrySA comments was to suggest that pre-harvest inventory may be able to extend the techniques developed by Dr Jan Rombouts for Site Quality assessment, the concern being the accuracy of the predictions of product size, number of pieces, and class. In terms of systems logic this may simply be a function of the number of control plots that have to be measured in order to gain the desired precision. The use of regression estimators to predict the variables of interest at a pixel[4] level offers scope for improving prediction precision or reducing inventory cost.

Processing

ForestrySA expressed the strong opinion that processing of production LiDAR data requires an industrial strength processing capability. They believe that any number of packages can be used for research into LiDAR, including interpretative packages, spread-sheets and the like, but that for production processing of large data sets, especially for determining tree counts over large areas, that well structured, well designed and well implemented software is essential.

Production processing must be fast, automated, and must not require a user to make any subjective decisions even if such subjective decisions may provide practical advantages when applied to a limited data set.

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[4] Pixel here does not refer to the LiDAR pixel, but to a regular shape that covers the whole of the area of interest. It therefore could be as small as the LiDAR pixel, or could be (say) the plantation spacing or even larger.

Possible development paths

Dr Jan Rombouts suggested that there are a number of possible development paths for the future and believes that different paths should be explored to ensure that each is clearly understood and that the most appropriate method be adopted by each collaborator.

One option is to use the regression approach as used in Rombouts (2011). For this to be extended to later age inventory will probably require accurate tree counts to be used as predictor variables. For ForestrySA this approach is closest to current forest management planning practice.

Another approach is that underpinning operational forest inventory in Finland, and also under development in Tasmania. This approach uses a LiDAR coverage of the forest estate and a number of control plots. Knowledge of the LiDAR parameters for each of these control plots, as well as any useful ancillary variables, then enables any area of interest to be assessed to see which of the control plots have the closest LiDAR signature. The objective is that the plots can then be modelled into the future in order to achieve the required future predictions.

Another approach is that proposed in New Zealand, to use a zigzag line through the forest measuring individual trees until a satisfactory tree population can be assessed. This is then multiplied up with the LiDAR based stocking counts to determine the stand based predictions for a logging coupe.

The use of LiDAR with diameter distributions also can be considered a possible path for the future.

There are a number of other possible research paths.

ForestrySA would like to see a number of alternative paths investigated to determine which is likely to be the best approach under particular circumstances.

Miscellaneous

ForestrySA believe that there is potential for combining sensors in the future and they are maintaining a watching brief.

ForestrySA strongly believe that a major constraint is people. There are no longer sufficient staff to carry out field work to the same extent as was feasible in the past and so implementation of technologies such as LiDAR is the only way forward.

ForestrySA are also concerned about both confidence and confidence limits, commenting that some of the paths briefly described above may not readily lead to the prediction of confidence limits. They suggested that confidence may come from the reconciliation of harvester information with the predictions made using LiDAR.

Data possibly available

In conjunction with HVP, ForestrySA arranged for DeBruin Spatial Technology to acquire some data at high resolution (specified as 4 pulses per m^2 but actually about 5 pulses per m^2). There are some 4000 ha of ForestrySA and some 1500 ha of HVP forest so covered. It would seem likely that this combined data set could be considered one consistent campaign. It would need to be investigated whether there is a sufficient number of logging coupes with a sufficient range of thinnings.

ForestrySA are currently establishing inventory plots in these areas and intend to use the data to compare alternative pre-harvesting inventory methodologies.

Forests NSW

Forests NSW have collected a considerable amount of LiDAR data (over 1 million ha) predominantly in native forest but also in pine and other plantations. They have an in depth understanding of LiDAR but as yet have not deployed LiDAR in practice to any great extent in planted forests.

Forests NSW have published extensively on the use of LiDAR chiefly led by Drs Christine Stone and Russell Turner. See Stone et al 2011 and Turner and Stone 2011 for extensive reviews and guidance.

Development opportunities

Forests NSW believe that the key areas for research should be focused on;

- Improving tree identification/counting methodologies,
- Improved sampling design with the specific objective of reducing field-based measurements, and,
- Developing techniques, processes and the programming/systems development needed to transfer these results into operational use.

Determine gross area

One option is to use LiDAR to determine gross plantation boundaries but use of conventional aerial photography can achieve similar results. It is believed that operations foresters would consider that LiDAR is most relevant to them if it can improve the updating of net stocked area.

Digital Elevation Model

The provision of a DEM for the area of pine plantation is high priority and at present only about 10% has a LiDAR derived DEM.

Forests NSW have a need to quantify the vertical DEM errors due to blackberry and lantana, and the degree to which this source of error impacts stand height metrics. Blackberry can be partly handled by collecting LiDAR in the leaf-off phase but lantana is evergreen.

If the stocking is >1000 per ha then the blackberry may be shaded out, but if the stocking is <1000 per ha then blackberry infestation can become quite severe. It is believed that about 20% of the Hume region (Tumut area) is affected and the extent there and elsewhere is unfortunately increasing.

Forests NSW consider that for practical use of slope characteristics 5 m^2 pixels are more useful than 1 m^2 pixels that produce a salt and pepper effect. They recognise that data should be stored at a higher resolution, if possible at about 1 m^2, as this enables any spatial resolution to be used.

Define plantation layout

There are few green fields sites planted currently and almost all areas planted are re-establishment of clear felled plantations.

Considerable benefit can be gained from LiDAR modelled streams where existing topographic stream mapping is inadequate. LiDAR could be used to adjust areas around watercourses and exclusion zones, but this is more an adjustment of existing boundaries than the layout of new boundaries. Potential exists for use of LiDAR to identify/map existing roads and planning for harvest road design.

Post planting survey

Forests NSW require identification of failed areas particularly in stands having variable tree densities as a result of poor establishment, wind throw, frost, drought, pests or diseases. Once trees have reached a reasonable height, around age 5, LiDAR can accurately map areas that are not effectively stocked. Prior to age 5 other remote sensing technologies may provide an alternative to expensive ground survey.

Early age silviculture

Forests NSW consider LiDAR unlikely to be of much use in identifying weed species in young plantations as it defines structure, although this has not been investigated. Forests NSW consider that multi-spectral or hyper-spectral information would be of much greater utility. At present LiDAR sensors use only one near infra-red spectral band and are therefore not considered suitable for categorising vegetation composition including weed species. The potential to map the presence of weeds in radiata pine plantations using structural metrics alone could be investigated.

Stocking

Within Forests NSW there is a shift towards site based management and local stocking (SPH) is an important parameter guiding their decisions. At present compartments are planted at 1000 stems per hectare, thinned between the ages 13 and 17 years old down to 450-500 stems per ha (T1), then thinned again after 23 years down to 200-250 stems per ha (T2). Most compartments are harvested before 35 years of age. Accurate stocking counts would significantly improve their ability to manage for the prescribed stocking targets.

Early age inventory

Forests NSW carry out an inventory of unthinned stands at age 10 using conventional plot measurement. This is not currently based on LiDAR although they recognise that much work (e.g. Rombouts 2011) has shown that it is feasible.

This is an area that Forests NSW wish to explore further as indications are that significant reductions in ground-based measurement are possible. Forests NSW needs to customise existing stand volume models and methodologies and calibrate these with LiDAR-derived tree and stand metrics. Forests NSW anticipate that the modelling approach applied to early age inventory will differ from that required for pre-harvest inventory.

Logging coupe layout

Forests NSW have carried out some work with LiDAR but coupe layout is predominantly by aerial photography interpretation.

Coupe layout is primarily based on age class, treatment history and slope. The inclusion of a productivity-based stratification would make it possible to define harvesting coupes that require different harvesting systems.

Later age inventory

Later age inventory, along with mid-rotation and early age inventory, is recognised as an area where LiDAR is most likely to be used to advantage, especially where this results in a reduction in ground-based measurement.

Field inventory in NSW currently aims at one circular plot per 4 ha, with the size fixed within a logging coupe but varied between coupes to achieve approximately 25 trees per plot. Measurements include dbhob, stem description, and 5 trees heighted per plot to facilitate development of a height – diameter model using a Pettersen curve. Forests NSW consider that for any project involving tree counts or volume estimation, accurate plot location information is necessary to link plot locations with the LiDAR image. For tree-based modelling, they consider that it will also be necessary to accurately survey the exact location of individual trees so as to facilitate registration of the stems with the LiDAR image.

Plots are measured by contract crews and rigorously defined protocols are in place. Forests NSW have identified specific needs for LiDAR research projects covering tree count methodology and sampling strategy, and the improvements that these can offer over conventional inventory. The issue of plot measurement for product volumes and log quality needs to be addressed as these are currently determined by conventional inventory.

Plot measurement is almost impossible in blackberry infested areas and the potential bias introduced by not being able to measure these plots has to be addressed. A LiDAR-based sampling design that accounts for areas of high weed infestation and secondly provides the capacity to estimate volume through a reduced ground measurement program would be beneficial.

Accurate plot and tree location information is important for any LiDAR-based research project. A significant amount of these data have already been collected.

There is a key need for the development of optimised sampling strategies based on LiDAR for either manual or TLS ground-based measurements. Recent overseas studies have demonstrated improvements in product yield predictions based on modelling metrics derived from both area and individual tree based LiDAR data. These include tree structural attributes such as crown depth. It may be that an integrated approach using TLS and ALS is the most cost effective approach, although ease of use of TLS in steeper terrain will need to be considered.

Harvesting control and reconciliation

LiDAR data acquisition costs would need to drop substantially for this to be feasible on a regular basis. Some combination with the computer output from harvesting equipment is likely to be the most efficient approach.

Forest health

Although LiDAR can provide some crown information, simultaneous capture of LiDAR and digital camera imagery or multi-spectral LiDAR may provide additional information on the health and condition of individual crowns.

These issues should be on the watch list but at present it is considered complex.

Area change determination

Significantly lower LiDAR data acquisition costs may make this feasible, although the applicability of other forms of remotely sensed data should be investigated. Forests NSW consider that temporal change detection will depend on frequency of data capture. Of particular interest is the feasibility of other data sources to provide an updated canopy height model that could be combined with a LiDAR-derived DEM to detect change in height and site productivity.

Other

Forests NSW suggested that LiDAR could be useful for monitoring fuel loads. During the discussion it was suggested that knowledge of the extent and intensity of blackberry infestation would be very useful information to assist with planning of field work and with fire control activities. Lack of knowledge of this information is potentially an occupational health and safety issue.

Forests NSW are also monitoring the use of site-specific management to determine how these techniques may reduce treatment costs, avoid issues with exclusion zones, and generally improve the precision of treatment applications.

Better categorisation of canopy structure could improve biomass prediction, a spin off from the other advantages of knowledge about tree canopies.

Possible data sets

Forests NSW have two data sets that may be of considerable utility to any future project.

They have some LiDAR and field data from northern Green Hills SF, which cover the full range of age classes and silvicultural treatments present in a large plantation.

They also have data from about 15,000 ha at Walcha from unthinned stands with a range of ages. This area has been used for a "proof of concept" study to demonstrate to operations staff the feasibility of using LiDAR information to assist forest management. Results of trials at Green Hills and Walcha suggest that stocking counts with r^2 of 0.8-0.85 can be achieved using object-based interpretation. It is likely that an r^2 of 0.9 is achievable. This was with LiDAR data captured at 2 points (pulses) per m^2.

Data collected for these trials, combined with data collected by other agencies, would suggest that sufficient data exist and that efforts should be focused on developing techniques, processes and the programming/systems development needed to transfer these results into operational use.

Processing

Forests NSW have a range of scripts that can process various data sets in a variety of different ways but recognise that broad scale deployment of LiDAR for (say) post thinned stand inventory must be accompanied by a significant investment in calculation algorithms, biometrics and software processes to ensure interpretation of, and ease of access to, the analysis products.

Hancock Victorian Plantations

HVP can justify LiDAR on the advantages of obtaining a DEM. They expressed concern that they will find it difficult to justify future LiDAR data acquisition due to costs associated with acquisition and processing.

Their goal is to cover the whole estate. Currently they have covered >60% but have some concerns about the utility of some of the earlier information and believe that possibly 20% has sufficient data for determining stand level metrics.

Ideally they would like to cover the whole estate every 3-5 years.

Determine gross area

HVP use LiDAR opportunistically to review, control and adjust gross areas. They recognize that imagery other than LiDAR can be used.

Digital Elevation Model

There is a critical need for a DEM and current work shows just how useful LiDAR is in this regard.

HVP operations staff prefer to use maps at 5 or 10 m resolution even if the DEM is available at higher resolution.

They find that LiDAR provides a good hydrology layer that is useful for planning as it enables buffers to be better defined. LiDAR is also used for planning of cable harvesting on steep terrain.

They now have a historical range of information that spatially varies somewhat from year to year. There would seem to be a control issue, but it could be a processing issue. It is also a data management issue.

Define plantation layout

Most areas are replants. Some adjustments of past plantation boundaries are necessary. LiDAR is one of the tools that can be used.

Post planting survey

HVP survey the plantation outlines using dGPS for some regions, aerial photography for others. They aim at determining plantation boundaries at about 9 months. They are thinking of using LiDAR at ages somewhere from 4 to 9 years to review, refine, and correct the net stocked area boundaries.

Possibly some areas will need remapping at a later age and LiDAR could be very useful.

Early age silviculture

HVP believe that multi-spectral information will be more useful than LiDAR.

LiDAR could possibly be used for determining canopy density and that may possibly be useful for determining where remedial nutritional treatment may be necessary.

Early age inventory

Early inventory is used to determine site productivity (mean top height at age) and stocking. This is generally carried out at either age 8 or age 10. Generally they establish one plot per 4 ha but the sampling level does vary between stands.

HVP see potential advantages in using LiDAR to reduce the sampling intensity. Any change in practice will depend on the change being economically advantageous.

They are working on a variant of the LiDAR processing and analysis technology currently available. They are well aware of the potential benefits but are constrained by lack of staff and by other activities being considered of higher priority.

Logging coupe layout

HVP see LiDAR being used for roading analysis. LiDAR can locate old settings and can also assess top of slope compared with mid slope roading alternatives. LiDAR can also be used to define cable settings.

Later age mid rotation inventory

The current objective is to carry post-harvest inventory within one year of harvest using 1/4 ha plots. HVP inventory varies over the life of the forest with a more detailed tree description being recorded for harvest prior to clear felling. Basically it is an extension of the same techniques used at age 10. They place emphasis on obtaining better prediction of products at the pre clear felling inventory.

Some 30-40% of estate will probably remain unthinned and in these areas HVP need a mid-rotation inventory (as well as an early age and pre clear felling inventory) to assist strategic planning.

Harvesting control and reconciliation

This is relatively simple at present. They are using dGPS on some harvesting equipment.

LiDAR could be useful, especially if the cost of data acquisition decreases considerably. Timing will also be an issue; the length of time to process the data, the timing of the data acquisition, and the need to monitor the difference between the area felled and the area that accounts for the volume invoiced.

Later age silviculture

HVP consider LiDAR is unlikely to be useful for later age silvicultural purposes.

Canopy density at later ages could be useful, and it could be useful if green crown height and depth could be determined.

Area change determination

LiDAR can be used, as can other imagery, to opportunistically determine area changes, especially storm damage, wind damage, lightning, insect damage and fires.

If they had consistent LiDAR imagery, year on year, then it would be feasible to automate the delineation of area changes.

Other

LiDAR could be a useful tool for stratifying the forest, (most likely to be based on the DEM, slope, hydrology etc.)

Blackberry is a problem, especially at Shelley. This may affect the DEM as any bias in the DEM flows through to stand parameters. The use of LiDAR in blackberry infested needs to be investigated.

HVP consider that LiDAR might be useful for assisting the management of custodial areas (native forest areas).

Specific comments

In general terms, HVP want the detailed practical specification of the protocols to process LiDAR data based on research.

HVP expressed concern that with the massive amount of data from LiDAR (and other sources) they need robust programming solutions to assist in managing that data.

HVP believe that a collaborative approach to the sharing of knowledge about LiDAR is the best long term strategy.

Timberlands Pacific

Timberlands Pacific (TP) have contracted Forestry Tasmania to collect LiDAR data as part of their larger LiDAR acquisition project. They will have coverage of the whole estate by the end of 2013. They will be provided with a DEM, 5m contours, hillshade map, drainage layer and a point cloud that facilitates height and other modelling.

The ownership structure will cause some challenges to funding any LiDAR proposal.

TP could use Forestry Tasmania as LiDAR consultants. TP however have 5 GIS personnel in New Zealand and Tasmania who have some LiDAR expertise.

Determine gross area

LiDAR is not needed. They prefer to use ortho corrected aerial photographs and ground based dGPS. They also use RapidEye.

Digital Elevation Model

They will have a complete DEM when the contract with Forestry Tasmania is completed.

Define plantation layout

The hillshade and slope maps from LiDAR inform plantation layout. TP consider it important to find old tracks and waterways.

Post planting survey

TP do not see LiDAR assisting in post planting surveys.

Early age silviculture

LiDAR can pick up wattle and eucalypt and could pick up stocking variations in early age maintenance operations. LiDAR would be more advantageous if it can be acquired annually or perhaps biennially.

The LiDAR point cloud can delineate height productivity variations and so assist determining when and where pruning might be carried out. It can also aid rate setting for variable height pruning by knowing the tree heights across a strata.

Early age inventory

TP carry out an inventory of the unthinned stands at age 10. They currently use ground plots with 1 plot per 5 ha. Plot size varies between plantations and is consistent within a plantation. The objective is to measure 15 trees per plot. For each plot and for each stand or coupe, TP estimate the stocking, basal area and volume by piece size. TP carry out the first thinning from age 10 to about 14, the stocking being taken from approximately 900-1300 down to about 500-600. They aim at 5th row outrow.

Site index (mean top height at age 20) has been determined at about age 10 using LiDAR data which is planned to be acquired every 3 years or so.

This early age inventory is important as a more accurate value of the estate can be determined at age 10.

Logging coupe layout

The hillshade, drainage and slope maps, together with the various GIS layers, inform the layout of the logging coupes.

Later age inventory

After the first thinning at age 10-14 the next harvesting operation is generally clear fall at age 25-35.

TP currently do an age 20 inventory and also a pre-harvest inventory generally 1-2 years prior to harvest. The age 20 inventory is mainly to assist modelling future wood availability.

Plot size is based on measuring 15 trees per plot. Plot size is kept constant within a stratum. The sampling objective is to obtain a PLE within 10% within a stratum.

TP see these inventories as a potential use for LiDAR.

Harvesting control and reconciliation

Slope maps derived from the DEM are important for harvesting rate setting and determining any difficult areas to be considered for alternative felling and extraction methodology.

Every quarter they use dGPS to define the harvesting boundaries on every logging coupe in progress. They estimate the log dumps and logs felled in the bush and add to the volume delivered to utilisation plants, and reconcile this total with the summary of plots that have been felled. LiDAR could be useful if it could be carried out at this frequency economically. RapidEye[5] has been trialled and TP believe it will be more useful than LiDAR.

Later age silviculture

TP are not sure if LiDAR can assist with later age fertilisation. TP believe that multi-spectral will be more useful than LiDAR.

TP use height differences to pick up fertiliser responses. They leave small areas unfertilised and this enables the change to be modelled. They use LiDAR for this response determination.

Area change determination

LiDAR can be used opportunistically to check on area changes.

LiDAR can also be used opportunistically to check other aerial photography and multi-spectral imagery.

Specific Comments

TP believe that there may be issues comparing old and new LiDAR spatially.

They are interested in TLS but have done nothing in this area.

Synthesis

Although each of the collaborative partners have different levels of expertise and experience there is a common thread running through all the responses.

There is general agreement on where LiDAR may be of greatest assistance in the short term, and recognition of where it may be of use in the future if the cost of collecting LiDAR data reduces considerably.

There are differences in the challenges that each organisation will need to overcome for them to successfully deploy LiDAR in practice. Each collaborator will need to assess how the results from any collaborative project can best be used by their organisation. It is most unlikely that there will be a "one size fits all" solution.

The table below summarises the information very simply. The table is not totally accurate in that an "O" signifying opportunistic is recorded if the organisation said that they would/might use LiDAR for this aspect. A blank does not mean that the organisation would not take any opportunity that presents itself.

[5] Currently at 5 m pixel resolution. Coverages of about 50,000 ha have to be acquired and then tailored to meet the needs.

Subject	FNSW	FPC	HQP	FSA	HVP	TP
Area determination	O		O		O	
Roads, hydrology	X		O	X	X	X
DEM	X		O	O	X	X
Post planting survey						
Early age silviculture		O		O		O
Early age inventory	X	X	X	X	X	X
Logging coupe planning			O		X	O
Later age inventory	X	X	X	X	X	X
Harvest control & reconciliation		O		O		
Later age silviculture				O		
Area change			O	O	O	O
Other	Fuel load Tree models		Fuel load	LAI		
Key: X = Yes O = Opportunistic or some potential depending on cost						

The conclusion is that although there are a whole range of possible research topics the overarching question is how to reliably conduct pre-harvest inventory using airborne laser scanning with control plots, in a way that provides size class and product information? What is the best path towards achieving that objective? How can stocking best be obtained? Can diameter distributions be determined? Can products be estimated satisfactorily? What variables do each organisation need? These questions need to be answered with the simplest, most cost effective method.

Rather than try to design a single methodology appropriate for each organisation, as that would seem impractical, it is desirable that any large research project develops the metrics that will enable each organisation to put together an inventory package that is both economic and appropriate for them.

To conduct this research is expected to require data sets that are more extensive than may be needed for practical deployment.

All organisations measure inventory plots (commonly stocking, upper stand height, basal area and/or volume), use these measurements to determine the base variables of interest (commonly stocking, basal area and/or volume, perhaps by product) and feed this information into a package to determine yield table(s).

All organisations model plots not trees although there are cases where tree models are used to predict plot attributes. All would seem to prefer to use LiDAR at a plot level not a tree level.

There is general agreement that this project could benefit from a collaborative approach.

Extrapolation back to the simpler early age inventory case will be feasible and may lead to an alternative solutions.

The amount of work each collaborative partner will have to carry out to implement any LiDAR based inventory procedure is likely to vary. Implementation in an organisation's FMIS will depend in part on how well their FMIS has been designed. It is impossible to be definitive about implementation cost as each FMIS has its own characteristics and idiosyncrasies. However incorporating a modified later age inventory procedure is not expected to be very difficult for any collaborative partner.

Given that this scoping study is a FWPA funded project, it would seem that a late age inventory project is likely to receive endorsement from the Sustainability and Resources Advisory Group (SRAG) of FWPA. Further, all collaborative partners are levy payers. Before discussing a proposed FWPA funded project to investigate the use of LiDAR for inventory, predominantly at later ages, it is sensible to briefly discuss some more specific aspects of LiDAR.

Discussion

General LiDAR Considerations

The objective of this section is to identify some aspects where work may be needed on aspects of LiDAR. With most topics a suggestion is made about how the collaborative may address the issue into the future. The suggestions are personal suggestions based on my perception of the subject. It is recognised that the collaborative, or individual members of the collaborative may have different opinions. It is hoped that if the collaborative agree on a suggested line that this may provide the basis for future action.

It must be recognised that LiDAR technology is advancing at a considerable rate and so the conclusions may also change in the future.

LiDAR system settings

The various LiDAR system settings need to be specified to the LiDAR data provider before any LiDAR data are collected.

Aspects include:
- Pulse repetition rate,
- Scan rates,
- Scan overlap,
- Pulse or point sampling density (Pd), the number of first returns /m^2,
- Field of view (FOV), commonly ≤15° of vertical,
- Beam divergence rate,
- Flying height above ground, this is important as the ideal would be for the pulse to travel as short a distance as possible, but lower flying heights increases data acquisition costs per unit area,
- Flying speed, and,
- Flying conditions.

Suggestion

There should be some general agreement on what are the most appropriate settings to meet a particular forest management objective. It will vary between uses and users. It may vary between LiDAR supply companies.

All the components interact and it would seem that there is a need for an interface group between the LiDAR provider and most LiDAR users.

Other sensor variations

A loose aggregation of a number of possible issues including alternatives to monochromatic light, power, wavelengths recorded, and improvements in collimation. Research on these is likely to be carried out by LiDAR scanning systems manufacturers.

Suggestion

Maintain a watching brief as they may be very useful in the future.

Height measures

If LiDAR is used to predict any forest variable of interest then the important factor is the correlation between the variable and LiDAR. This does not mean that there needs to be any agreement between users on the definition of upper stand height as each can use whichever definition they prefer.

Rombouts (2011) found that Hq, or the average of the squared first return heights was the most efficient variable for predicting stand volume of unthinned stands at an early age.

Number of control plots

The number of control plots required will depend on the precision required for the variable of interest on the area of interest and will also depend on the techniques used.

The objective is always to determine the most cost effective method of achieving a desired precision. Although LiDAR can undoubtedly be used very effectively in many different circumstances the question remains as to whether it can be deployed economically in a production environment.

Stratification

LiDAR provides a pixel coverage over all of an area of interest. Provided that the pixel size is relatively small, perhaps less than initial planting spacing, then LiDAR can effectively be used to stratify the forest into classes.

In essence this is what Rombouts (2011) and others have done on a practical level over a wide area of forest.

This leads one to ask whether stratification by productivity class is superfluous. With 100% coverage in small pixels, regardless of whether the pixel coverage is LiDAR or some other form of remote sensing, it is feasible to use regression methods based on a limited number of control plots. This approach is statistically more efficient than stratified random sampling.

If one doubts this conclusion then take any sample of plots with a linear regression of Y on X, for example volume against diameter (dbhob). Then calculate:

1. the precision of the sample mean,
2. the precision if the data are stratified into (say) 2 or 3 classes,
3. the precision if calculated using a regression, and,
4. the precision if the X variable is rounded to the strata mean and regression analysis is used.

The precision of 2 is better than 1, the advantages of stratification. The precision of 3 is better than 4 simply because in 4 the X variable has been rounded. Alternatives 2 and 4 are similar, with 2 generally having a lower standard error but when the confidence limits are calculated the change in the effective degrees of freedom means that the two have similar values.

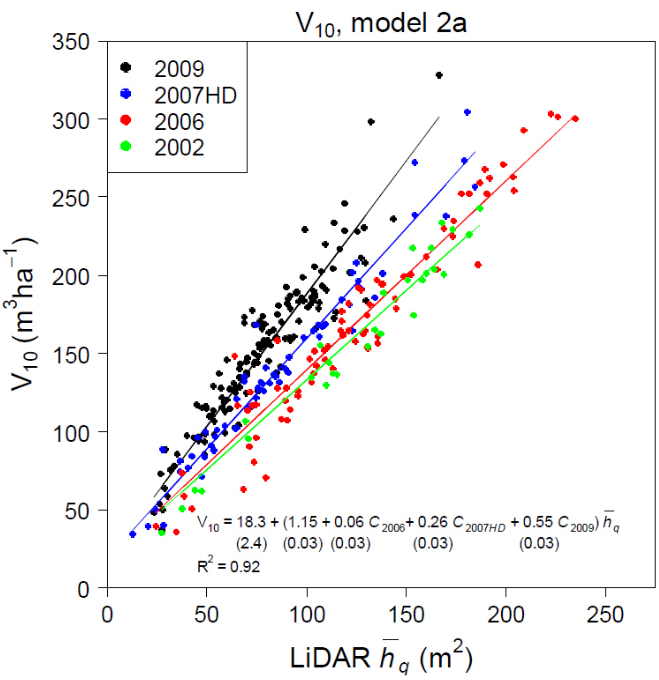
LiDAR offers the chance to trade the reduction in the number of samples required (e.g. inventory plots or control plots) against the cost of the LiDAR information acquisition. This trade-off needs research that will enable each collaborating organisation to make the decisions that are most appropriate for them.

It should be remembered that the principle is the same whether LiDAR or some other technology is used to define the pixels. What matters is the correlation with the variable of interest.

There is little doubt that stratification into the equivalent of logging coupes will remain a significant mechanism for improving prediction precision.

Campaign effects

Can the differences between different LiDAR data acquisition campaigns be eliminated?



Rombouts (2011) suggests that it is necessary to recalibrate LiDAR each time it is used. In his thesis he has an intriguing graph (page 83) that is reprinted with his permission. It shows the linear trend between volume and Hq derived from LiDAR, a trend that suggests that there is ongoing incremental improvement on the ability of LiDAR systems to detect the pulse returns.

It is evident that there is a satisfactory relationship between volume (m3/ha) and LiDAR derived Hq based on the data from the pooled data from all four campaigns but that the trend is a significantly better fit if the data are separated by campaign.

The real concern is that the use of any trend based on past LiDAR campaigns is likely to seriously overestimate volume if estimated from future LiDAR information. Based on this analysis pooling the data from the first three campaigns would provide a satisfactory model, with an r^2 value of probably >0.85, but if that model was applied to data from the fourth campaign the volumes would be biased by 25-40%.

Suggestion

There is little doubt that the advances in the LiDAR systems technology will continue in the future and so consideration of campaign differences will likely become increasingly important.

A Bayesian approach may also be useful, in which case the amount of LiDAR information required to control these campaign differences may be quite limited.

Some research is needed to assess how extra LiDAR data collection might possibly be used to determine the correction needed to bring past campaign information up to a consistent base and what effect this might have on prediction precision. Comparisons of the extra LiDAR information with the various past campaigns will of course be partly confounded by growth in the various stands, but it would seem likely that a simple correction might suffice if high precision is not required, so perhaps only a relatively small amount of extra LiDAR data may need to be captured on an area consistent with previous LiDAR campaigns. Design of such a protocol will require considerable care.

Profiling LiDAR systems

Profiling LiDAR systems record records pulses along a line. For broad area sampling this approach offers some advantages; somewhat cheaper cost as only the line is sampled, and limited data acquisition leading to the easier ability to manage the data. The disadvantage is that it provides a line sample and therefore line sampling theory has to be incorporated into the complexity of the calculations. For intensive pine plantation management the advantages of area sampling and elimination of the need to consider the line sampling complexities would seem to make profile sampling of lesser utility.

<u>Suggestion</u>

Maintain a watching brief, but be aware of the possibilities.

Full wave-form LiDAR

Full wave-form LiDAR offers scope for improving the prediction precision available from currently used approaches. That comes at the extra cost of data acquisition and the extra data that needs to be analysed. Work is needed.

<u>Suggestion</u>

Full wave form LiDAR offers considerable scope for increased information. Research is needed to show just what extra information is possible, but until that time it is suggested that the collaborative maintain a watching brief.

It is believed that some full wave form data has already been collected in plantations.

Terrestrial LiDAR

Terrestrial LiDAR systems offer considerable scope for the future, especially if the size of the equipment can be further reduced, the speed of data capture can be increased, and the cost of obtaining and analysing the data can be reduced.

<u>Suggestion</u>

This is one area where the collaborative may wish to support other research proposals to FWPA or other funding bodies as terrestrial LiDAR has already shown what is feasible, although it is believed that its practical use in plantation management has not yet been fully demonstrated.

Software

There are a plethora of software solutions that can be used very effectively to carry out LiDAR research and to analyse relatively small data sets.

If LiDAR is to be used for later age inventory over considerable areas then these solutions are unlikely to be satisfactory.

For research the analyst wants flexibility, the ability to carry out alternative analyses, and a package that is intuitive and easy to use. User involvement in the decision making at various stages is possible, and indeed desirable.

For practical use on large data sets covering large areas of plantation forest it is generally unnecessary to carry out alternative analyses. The package does not need to be intuitive and command line use is probably desirable. Use is by experienced staff. User involvement needs to be minimised or if possible avoided completely. What is needed is a computationally fast, robust, industrial strength processing solution.

The two requirements are quite different.

<u>Suggestion</u>

The collaborative may decide that it is sensible to arrange for the development of software package, or packages, which will be limited in capability and flexibility but which can very effectively and very efficiently carry out parts of the processing.

In essence this would replace methods used for the application research.

Is Lidar a Flash in the Pan?

A general look at remote sensing applications in forestry over the past 30 years or so indicates that there has never before been a widespread acceptance of the utility of these technologies to assist intensive forest management practice. LiDAR is the first such technology that would seem to have widespread acceptance that it can be used in intensive plantation forest management practice.

Perhaps one parallel is the Geographic Information Systems (GIS) technology. When GIS was evolving some 40 years ago Research Working Group 2 (now RWG2 Forest Measurement and Information) led the way and included the then new technology in a number of sessions of their biennial meetings. This evolved over the next decade into the development of a spatial information working party that was independent of RWG2. Eventually GIS became so developed that it was recognised for what it really is, an extremely useful tool for forest management. Currently that spatial information group no longer exists and the GIS technology is simply considered one of the tools used by forest managers to effectively manage the forest. GIS research can be separated between theoretical and application considerations.

The history of computing technology is similar. It has evolved over some 50 years. There is now a computing profession but computing technology is considered simply a basic tool of forest management. Computing science research is generally separated between theoretical and application considerations.

I suspect that LiDAR will follow a similar path. Currently the Silvilaser conferences provide a good mechanism for dissemination of research and applications findings but the question remains, is LiDAR a technology that requires shorter term research and development so that the technology can be effectively and efficiently incorporated into forest management practice, or is it something completely different?

I suggest the former rather than the latter. If this is agreed then this means that LiDAR should be treated as an embryonic tool for forest management not an end in itself. If this philosophy is generally accepted then the research will be focused on achieving forest management objectives not LiDAR objectives. The question is how best to manage the forests, not how can LiDAR best be used in forest management.

To me it would seem likely that LiDAR research will become increasingly separated into theoretical and application considerations. In this sense it is likely that many of the theoretical aspects of LiDAR research will become almost irrelevant to forest managers seeking to apply LiDAR effectively and economically within their operations. Subjects such as pulse repetition rate, scan rate, pulse density, beam divergence rate and flying parameters such as height and speed will be largely based on the recommendations of the LiDAR information suppliers. However there may still be challenges if these settings are not near optimal.

The Way Forward

One possibly useful vehicle could be to continue to use RWG2 (Forest Measurement and Information) to disseminate the LiDAR information to the wider forestry community. Most of the collaborators already have members in that group and in my opinion the others should nominate a member. This is especially relevant if there is agreement that LiDAR may evolve like GIS and computing.

When this project was proposed there seemed to be a range of possible alternative paths forward but the earlier sections lead to the conclusion that there are four areas where the collaborative may wish to move forward in their use of LiDAR. Three of these are discussed below, followed by one which could be a larger research project partly funded by FWPA.

As discussed earlier, the collaborative members all suggested that LiDAR could best be used to assist later age inventory. That is the focus of a suggested research project. However to make the most effective use of LiDAR, especially in the short term, there are three areas that also ought to be considered.

Monitoring of LiDAR system parameters

It would seem inefficient for each collaborative member to maintain a watching brief on the various alternative LiDAR system parameters. It would be better for the collaborative to arrange for two or perhaps three people to monitor this aspect and to provide a limited consulting service, perhaps to a total of <3-5 hours per year to each collaborative partner, so that all collaborative members have access to the expertise.

The collaborative may wish to consider a mechanism for funding people to carry out this monitoring and to provide advice. I would envisage that Drs Christine Stone and Jan Rombouts will continue to continue to carry out the monitoring of all aspects of the technology. Dr Christine Stone suggests that it is part of her research role. It is also possible that the experience of Dr Russell Turner may be available for a relatively small consideration. ForestrySA may require some financial consideration for Dr Jan Rombouts to provide this service.

It might be that the provision of $4000 per year would engage Dr Russell Turner and $2000 per year would allay any thought by ForestrySA about providing Dr Jan Rombouts time and expertise. However this is only one of many possible structures that the collaborative might decide is appropriate. I would envisage questions from other collaborative partners to be about 2-5 hours per year, with the advice provided over the telephone.

Collaborative structure

The collaborative partners should consider whether there is a need for a more formal structure, such that the senior members meet at 12-18 month intervals to compare notes and to monitor progress.

The collaborative may decide that a group of about 4-8 more technically oriented people should get together to discuss various aspects of LiDAR; what LiDAR parameters should be used, what development paths have the greatest potential for success, and more importantly, define some of the limitations that should be placed on any future project to be jointly funded with FWPA.

Early age inventory of unthinned stands

ForestrySA have implemented a system of using LiDAR and control plots to carry out site quality surveys based on volume at about age 8-10. This is based on the work of Dr Jan Rombouts (2011).

Suitable arrangements would need to be negotiated between ForestrySA and any collaborative partner desiring to implement the technology in their plantations. Options could include;

- The provision of Dr Rombouts PhD thesis (2011) with the collaborative partner implementing the technique themselves,
- Provision of consulting support by Dr Jan Rombouts, including the provision of the software and protocols, and,
- Provision of a contract to carry out the whole survey.

Or the collaborative member may desire to implement their own technology themselves independently of the collaborative.

It would seem that there is no need for any FWPA funded contract to specifically assist the deployment of this technology to assess volume at an early age.

To me the key is that there is little need for further theoretical research before deployment, it needs localised applications research by each organisation. I envisage that in the future practical research may identify further economic gains; reduction in control plots, better specification of LiDAR acquisition variables, and better software solutions.

This addresses the need to predict volume. Prediction of stocking is different and could come under the proposed research project.

Conclusion

This scoping study has achieved the objectives set out (see Appendix 3). The collaborative partners now need to determine exactly what their joint objectives are and to come to joint agreement on the best way to achieve those objectives. This report provides advice and enables those decisions to be made.

The report scopes aspects of a project to use LiDAR for later age inventory that should enable the collaborative to make decisions on joint needs and to prepare a detailed project proposal that can be put to FWPA, a project proposal that is believed to have a good chance of success.

The report summarises the data sets that might be made available. A detailed description of LiDAR, and field data sets can only be made only after the collaborative agree on the two Principal Researchers and they determine the exact data structures they require. Then organisations need to give their formal approval for their data to be used for this study. If this approval is not forthcoming then the report broadly scopes the necessary data acquisition.

This report also suggests immediate action in three areas that does not require FWPA involvement; the collaborative structure, monitoring of LiDAR system parameters, and early age unthinned inventory. These are believed essential activities if the proposed FWPA late age inventory project is to be successfully implemented in practice.

Recommendations

Proposed Research Project

The collaborators generally agree that investigating whether LiDAR can be effectively deployed for the forest inventory of pine plantations is the highest priority. Primarily this would address inventory in later age thinned and unthinned stands.

Although there are some differences in objectives, and there may well be differences in the way LiDAR will be used in practice, there is a consistent need for the development of the metrics that will enable each organisation to make their own judgement on the protocol that is most appropriate for them.

This project could build on work already carried out, but there are other approaches that could well be followed to advantage such as those adopted in Finland and Tasmania and also in New Zealand.

Inventorying thinned stands either pre- or post-harvest, which extends the objective to probably include volumes by product and to inventory the sub-population that is to be harvested in the next operation, will be more difficult than for early aged inventory.

Studies by Forests NSW (Stone et al 2011) report r^2 for mean tree height of 0.94, for number of trees per ha 0.85, and for basal area and volume 0.81. This suggests that precision will vary depending on the variable of interest. An alternative way of looking at this is that, if a regression approach is used, more field plots will be necessary for some variables of interest than others if a desired precision is to be achieved. Their study provides a benchmark for any future project.

There are a number of alternative development paths including one based on a regression approach. If regression sampling is used rather than stratified random sampling then a control sample of plots is measured and the variables of interest are regressed against the LiDAR variables for each of those plots. This predictive model can then be applied to each pixel, or groups of pixels in (say) a plot configuration, to predict the variable of interest on the area of interest. This is an extension of stratified random sampling and theoretically has considerable advantages, not the least of which is that no strata need to be defined.

As discussed earlier by ForestrySA, there are other alternative developmental paths that may be followed. Research is needed to determine the advantages and disadvantages of these different philosophical paths.[6]

In designing a project it is believed essential to ensure adequate control of current LiDAR against LiDAR information from previous campaigns.

Area scope

If no suitable data are available it is considered that the data set that should be analysed should include two regions, each with approximately 10 logging coupes averaging some 30-100 ha in area, each of which should be sampled by a minimum of 10 inventory plots.

The exact details are for the collaborative to determine, possibly after some discussion with FWPA about the level of future funding possibilities.

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[6] If I understand the Finnish / Tasmanian approach correctly then my suspicion is that there could be confounding effects over time if silvicultural activities occur, because the higher growth rates generally obtained in pine plantations will impact on any lag effects dues to any differences in the timing of any subsequent plot measurement and LiDAR acquisition. This will need careful consideration.

Project objectives

These objectives would need to be agreed by the collaborative members.

On either data already available, or if not, then on each of two regions, each with 10 logging coupes of about 100 ha each, to carry an analysis to determine the following.

- Which is likely to be the best path to be followed? It is expected that the research may indicate at an early stage just what the advantages and disadvantages of each path are.
- How best to determine stocking? This could vary between regions, and is likely to vary depending on age and the actual stocking. What is the stocking for each of the logging coupes? What is the trade-off between pulse density and the precision of the stocking estimate? Is there a trade-off with other LiDAR system attributes? How does the actual stocking impact on the protocol? What is the trade-off between number of control plots and precision?

  How best to determine the stocking in unthinned stands? This protocol should be able to translate back in time for those organisations that want stocking at the early inventory at ages 8-10.
- What is the most effective protocol for predicting a range of other variables of interest, for example volume by product (size and quality class) but also basal area? Estimate for each logging coupe.

  What is the precision for each of the various variables of interest?
- Model the trade-off between the number of control plots and LiDAR pulse density and possibly other LiDAR parameters. The objective is to determine overall prediction precision for a variable of interest from the combination of LiDAR and plot attribute information. The economics will necessarily be organization dependent.
- Model the trade-off between the number of plots and the area of the logging coupe.
- Model the implications of having and not having individual tree coordinates to assist in registering the field plots with the LiDAR information.
- Specify procedures to carry out major processing. This will enable the collaborative to go out to contract for the software development.

It is expected that the project will provide the metrics so each organisation can best determine the most appropriate protocol for them.

Given that there are many alternatives possible it is recommended that there be two teams, each headed by a Principal Researcher, each investigating various alternatives in an effort to provide the metrics that will enable each organisation to determine just what is economically the best option for them.

This duplication is not a waste of resources but will provide a wider range of protocols and metrics that will enable each collaborative member to determine which components will provide them with the most effective strategy for implementation.

It is expected that the Principal Researchers will address the issues of updating LiDAR and field plot information over time.

Processing

There is a need for a robust processing procedure to be developed. This should be developed by a software developer experienced in efficiently processing large data bases, and if possible experienced in LiDAR processing.

Although I have some experience in software development contracts and believe that the amount specified is reasonable, it is not possible to be definitive until the detailed specifications have been set after the two Principal Researchers have reported.

My perspective of what this may look like follows.

1. Take the pixel information and intersect it with the area of interest to get a reduced pixel file for the area of interest in the right format for later processing.
2. Determine the stocking for each of these areas of interest. This will probably predict the stocking at an aggregated pixel level. The level could be 2x2 m, or 4x4 m or whatever the user specifies. There would be a map of stocking at this aggregated pixel level and also a single average stocking figure for the area of interest.
3. Carry out a similar analysis for height, perhaps a range of height measures. There may also be a number of other analyses, perhaps crown depth and crown height, depending on the results of the research but it is possible that stocking and a height measure will be sufficient to predict product volume. The essential feature is to predict for the pixel surface the variables that will be used in the subsequent prediction model.
4. Take a file of plots (or it could be trees) with various attribute information (perhaps up to 5 attributes). Take the pixel information from the area of interest. Intersect these and produce for each plot (or tree) a range of pixel attributes.
5. The user then has to calculate a regression model that predicts the variables of interest from the plot pixel information. This will require manual intervention as the nature of the equations may differ between organizations, but it may be feasible to automatically calculate some particular simple linear regressions and build those structures into the protocol.
6. These equations have to be coded and input into a procedure that predicts the variables of interest over the whole of the pixel surface.

Note that the protocol uses any pixel information and general plot or tree information. It is therefore very flexible. The key is to do the processing quickly and effectively.

Steps 2, 3, 6 and possibly 4 can be carried out using the new procedures developed by the software engineer. Steps 1 and 5 and possibly 4 are likely to be organisation dependent as each organization would require procedures to convert the attribute plot or tree information into the right data format for processing.

Each of the Principal Researchers should define a processing specification. They should define just what is required from the software developer. These can then be compared, contrasted and discussed so that the optimum processing specification is determined.

LiDAR data acquisition costs

There is a need to ensure that there is sufficient LiDAR data collected from a large enough discrete data collection so that with adequate field control plot data campaign effects can be controlled.

The data collection costs in the table below are indicative figures kindly provided by DeBruin Spatial Technology who accept that the figures are to be used in this report and recognise that if and when a research proposal is put forward that it is likely that any LiDAR acquisition will be the subject of a tender process. DeBruin Spatial Technology have a recently acquired ALTM Orion scanner from Optech. Their VulcanAir P68C aircraft can travel at relatively slow speed.

There are a raft of possible LiDAR configurations possible and the indicative costs presented are based on Dr Jan Rombouts specifications for data ForestrySA has acquired for preliminary investigation of later age inventory possibilities. He suggests defining the LiDAR parameters on the pulse density desired, specifying that the data should be evenly spaced, that the flying height should be <3000m and the scanning angle less than 15° from vertical. The assumption was also made that all logging coupes in either region would be within a 50 km radius. If LiDAR data are to be collected for any project then this specification will need to be revisited and the cost estimate revised.

ForestrySA have recently collected LiDAR to these specifications (at >4 pulses per m^2) over some 4000 ha. In the same acquisition contract HVP collected data over some 1500 ha.

Similarly, Forests NSW have two large data sets that they may be prepared to make available. The Green Hills data set has enough logging coupes. The Walcha data set of unthinned forest of various ages could provide a third data set that can be used for analysis of stocking in particular.

The cost table below includes costs to collect alternative data although the collaborative may well be able to leverage off other data acquisitions, either by providing some funding to the suppliers or at least recognising that the data providers would be providing a considerable "in kind" contribution. It would of course be up to the collaborative and the data providers to make any such decision. HVP may also be able to provide data.

Both data sets would need to be reviewed in detail to determine if the collaborative agrees that they are appropriate. However given the considerable cost of data collection it may be that the collaborative consider that the effects of any limitations are less than the cost of acquiring new data, be it LiDAR or field data. These decisions can only be made by the collaborative, perhaps after a small group consider the data in some detail, that is assuming that the data sets can be made available.

Field data cost

Assuming 2 regions, 10 logging coupes and 10 plots per logging coupe the field data collection costs are approximately $30,000 based on an estimated plot measurement cost averaging $150 per plot. This is based on two approximate estimates of the likely plot measurement costs. The actual cost will depend on exactly what data are collected.

As this data set will be actual relevant production forest management data for two collaborators the exact fee that should be recouped for providing such data should logically be less than this figure.

Dr Christine Stone strongly suggests that the accurate location of each tree in the field plots must be recorded. This adds to the field data acquisition cost. The collaborative needs to decide whether this information should be collected at both regions, or perhaps only on one, or perhaps the cost of collecting the data at all is prohibitive. My preference would be to collect the accurate tree location data on both regions, but collection of the accurate tree location data on one region might be a cost compromise.

Table of costs

The following table of costs is indicative only and does not take into account the data that may be provided by collaborative partners either at a fee or as an "in kind" contribution. Any fee will need to consider the possible transfer of the rights to the intellectual property to FWPA. The table reflects a total figure to complete the task with no provision of LiDAR or field data from any collaborative member.

The collaborative may decide after detailed review of this scoping study that the costs have been under-estimated and may prefer a different funding model. That is, of course, their decision as they will be submitting any bid for funding.

	Actual $	In kind $	
LiDAR supplier, perhaps 10 logging coupes in each of two organisations	$45,000	$0	Depends on mobilisation costs, the number of regions, the number of logging coupes and the area of each coupe.[7]
Contract Manager	$5,000	$10,000	To manage the contract and perhaps to coordinate the preparation of a combined report
Field data collection: Forests NSW	$15,000	$10,000	Plot intensity should be about double the normal inventory rate to allow for optimisation
Accurate tree survey: Forests NSW	$10,000	$0	
Field data collection: ForestrySA	$15,000	$10,000	As above
Accurate tree survey: ForestrySA	$10,000	$0	Based on Forests NSW information
Principal Researcher 1: Dr Christine Stone	$40,000	$80,000	The exact composition of the team needs to be determined
Principal Researcher 2: Dr Jan Rombouts	$40,000	$80,000	The exact composition of the team needs to be determined
Review of reports	$0	$30,000	In kind support of $5,000 to be provided by each collaborative partners
Determining the best protocol for each collaborative member	$0	$80,000	Say $20,000 for each collaborative members not part of a team
Production software development	$40,000	$0	
Testing software	$5,000	$18,000	In kind support of $3,000 to be provided by each collaborative partners
Total	$225,000	$318,000	

[7] The indicative response by DeBruin Spatial Technologies provided a figure lower than this, but they cannot give a firm quotation as the cost will vary depending on exactly what the collaborative desire to be done. It is considered that $45,000 should cover the range of reasonable alternatives possible.

Possible funding arrangement

Below is a table of the possible contributions by various partners. This is purely indicative and will need to be negotiated.

It is suggested that Drs Christine Stone and Jan Rombouts be engaged as Principal Researchers to either carry out the research, or to head a team carrying out the research, so that the best approach may be adopted. It is considered likely that each collaborative partner will want to cherry pick the most appropriate components of the two solutions so as to determine the strategy that they consider will be most effective for them. This duplication of research is essential if each organisation is to be in a position to determine the right strategy for LiDAR deployment in their organisation.

Funding source	Cash ($)	In-kind ($)	Total	% by source
FWPA	$135,000	$0	$135,000	24.9%
Forests NSW	$15,000	$98,000	$113,000	20.8%
ForestrySA	$15,000	$98,000	$113,000	20.8%
FPC	$15,000	$28,000	$43,000	7.9%
HQP	$15,000	$28,000	$43,000	7.9%
HVP	$15,000	$38,000	$53,000	9.7%
Timberlands Pacific	$15,000	$28,000	$43,000	7.9%
Total	$225,000	$318,000	$543,000	100.0%

The project would need the specification of milestones satisfactory to both the collaborative and to FWPA. Some possible milestones are as follows.

Phase 1

- Meeting to review possible LiDAR and field data sets to determine whether they are satisfactory or not. Given the cost of LiDAR and field data acquisition it may be that a somewhat unsatisfactory data set that can be made available at minimal cost is a better proposition than a more robust data set that would require considerable expense to acquire.
- Meeting of Principal Researchers (plus perhaps some other technicians) to discuss the narrowing of the range of possible paths for development down to a workable list.
- Acceptance of the data sets, or acquisition of new ones.
- Selection of two research teams.
- Carry out the research and prepare reports.
- A meeting to present interim findings.
- Presentation of draft report.
- Presentation of final report and a meeting to determine what software, if any, needs to be developed.

Phase 2

- Specification of the software for production use.
- Selection of software developer.
- Receipt and acceptance of software.

Phase 3

- A wrap up report of the project, perhaps a seminar on deployment and technology transfer.

The project would need a contract manager. This task will take some effort and it is unreasonable for the appointed contract manager to carry out all the work as part of his organisations normal activities. The contract manager could also prepare (or arrange to be prepared) the brief amalgamated report for the project, perhaps with all other reports as annexes.

It may be politically desirable for the project to be divided into two with the development of industrial strength software processing capability being a separate project. Consideration of the initial research will inform the specification of software to be developed. It is difficult to assess at this stage just what software development will be needed.

This scoping report details one approach with some variants but the collaborative partners may consider that the scope needs to be expanded or narrowed down and that the range of developmental paths may need to be restricted.

One thing I believe is highly desirable for this project, although it is not often considered politically correct by accountants, is that there should be duplication of development. I strongly believe that a minimum of two research teams are required not one single research team.

I believe that after this project is complete each collaborating organisation will need to expend considerable effort on application research to determine exactly which path they believe is the best one for them to follow. I do not believe that there is a one path fits all strategy possible.

Alternative funding arrangement

I deliberately set up the tentative project to include collecting new data, both LiDAR and field data, while recognising that some collaborative partners may well be prepared to provide data sets in an effort to bring the total project size down to a more practical level.

Any owner of a data set will need to;

- agree to provide both the LiDAR and field data,
- confirm that their organisation is happy to release the data for use by the collaborative, and,
- will need to consider the possible reassignment of intellectual property rights.

This alternative assumes that these conditions can be met.

Table of costs

The following table of costs is indicative only.

	Actual $	In kind $	
Contract Manager	$5,000	$10,000	To manage the contract and perhaps to coordinate the preparation of a combined report
Principal Researcher 1: Dr Christine Stone	$40,000	$80,000	The exact composition of the team needs to be determined
Principal Researcher 2: Dr Jan Rombouts	$40,000	$80,000	The exact composition of the team needs to be determined
Review of reports	$0	$30,000	In kind support of $5,000 to be provided by each collaborative partners
Determining the best protocol for each collaborative member	$0	$80,000	Say $20,000 for each collaborative members not part of a team
Production software development	$40,000	$0	
Testing software	$5,000	$18,000	In kind support of $3,000 to be provided by each collaborative partners
Total	$130,000	$298,000	

Possible funding arrangement

Below is a table of the possible contributions by various partners. This is purely indicative and will need to be negotiated.

Funding source	Cash ($)	In-kind ($)	Total	% by source
FWPA	$90,000	$0	$90,000	21.0%
Forests NSW	$0	$88,000	$88,000	20.6%
ForestrySA	$0	$88,000	$88,000	20.6%
FPC	$10,000	$28,000	$38,000	8.9%
HQP	$10,000	$28,000	$38,000	8.9%
HVP	$10,000	$38,000	$48,000	11.2%
Timberlands Pacific	$10,000	$28,000	$38,000	8.9%
Total	$130,000	$298,000	$428,000	100.0%

References

Australian Government (2009) AUSTRALIA'S FORESTS AT A GLANCE. Department of Agriculture Fisheries and Forestry, Bureau of Rural Sciences, 96pp.

Dash, Jonathan and Marshall, Hamish (2011) SAMPLING DESIGN FOR FPC INVENTORY. Unpublished, 7pp.

Lefsky, M. A., Cohen, W. B., Acker, S. A., Parker, G. G., Spies, T. A. & Harding, D. (1999a). Lidar remote sensing of the canopy structure and biophysical properties of Douglas-fir western hemlock forests. *Remote Sensing of Environment,* 70**,** 339-361.

Lefsky, M. A., Harding, D., Cohen, W. B., Parker, G. & Shugart, H. H. (1999b). Surface lidar remote sensing of basal area and biomass in deciduous forests of eastern Maryland, USA. *Remote Sensing of Environment.,* 67**,** 83-98.

Murphy, Glen E., Acuna, Mauricio A., and Dumbrell, Ian (2010) Tree value and log product yield determination in radiata pine (*Pinus radiata*) plantations in Australia: comparison of terrestrial laser scanning with a forest inventory system and manual measurements. *Can.J.For.Res* 40 p2223-2233.

Rombouts, Jan (2011) ASSESSING SITE QUALITY OF SOUTH AUSTRALIAN RADIATA PINE PLANTATIONS USING AIRBORNE LIDAR DATA. Doctor of Philosophy thesis, Department of Forest and Ecosystem Science, School of Land and Environment, The University of Melbourne, 189pp.

Rombouts, J., Ferguson, I.S. and Leech, J.W. (2008) Variability of LiDAR volume prediction models for productivity assessment of radiata pine plantations in South Australia. Paper presented at Silvilaser 2008, 8th international conference on LiDAR applications in forest assessment and inventory, 8pp.

Rombouts, J., Ferguson, I.S. and Leech, J.W. (2010) Campaign and Site effects in LiDAR prediction models for Site Quality assessment of radiata pine plantations in South Australia. *International Journal of Remote Sensing*, 31, p1-19.

Rombouts, Jan, Ferguson, Ian, Leech, Jerry, Culvenor, Darius (2010) An evaluation of the field sampling design of the first operational LiDAR based Site Quality survey of radiata pine plantations in South Australia. Paper presented at Silvilaser 2010, Freiburg Germany.

Stone, Christine, Russell Turner, Amrit Kathuria, Catherine Carney, Peter Worsley, Trent Penman, Hui-Quan Bi, Julian Fox, and Duncan Watt (2011) Adoption of new airborne technologies for improving efficiencies and accuracy of estimating standing volume and yield modelling in *Pinus radiata* plantations (PNC058-0809). FWPA Report, 80pp.

Turner, Russell and Stone, Christine (2010) Guide to Acquisition and Processing of Remote Sensing Data for Softwood Plantations. FWPA Report, 55pp.

Acknowledgements

Thanks to all the collaborators who gave up their time to meet and discuss their organisations use, and potential use, of LiDAR.

Thanks to Glen Rivers for acting as the Contract Manager and to Chris Lafferty for making the arrangements with FWPA work so smoothly.

Thanks also to DeBruin Spatial Technology for providing the LiDAR acquisition cost information.

Appendix 1 – Simplified Forest Management Information System Questionnaire

Information requirements

The following is a very simple table of the information flows in a Forest Management Information System. It is oriented more to spatial than attribute data as the reason for the diagram is to assist focus on those aspects of softwood plantation management that may be improved by the deployment of airborne LiDAR.

Given the understanding of the variations between different organisations and their different focus on the various components required from a FMIS, this table is necessarily very general. However each organisation should be able to look at each task (or module) and determine their current protocol for providing the necessary forest management information.

It would be useful, if possible, for each organisation to provide a schematic of your organisations FMIS. Indicate where you think LiDAR may be usefully deployed and what you believe needs to happen to assist deployment.

	Airborne LiDAR		
#	Possible Input	Possible Task / Module	Possible LiDAR application. This is my personal view and I would expect each organisation to have a different perspective.
1	Confirm title, Possibly GPS.	Determine gross area.	More likely Aerial photography and GPS. Is there a role for LiDAR?
2	Slope classification, derivation of operation type	Digital Elevation Model.	LiDAR may provide DEM. May be external or internal to the organisation.
3		Define plantation layout.	Assisted by DEM. Is there any other possible role?
4		Plant, replant.	
5	Survey of plantation, survival.	Post planting survey; • survival stocking, • failed areas such as swamp and stone.	Is LiDAR applicable at this early age?
6	Plots, aerial survey.	Early age survey of nutritional status.	Has anyone done any research on this with LiDAR?
7	Initial inventory	First inventory (age 5-12, unthinned); • stocking, • basal area, • upper stand height, • volume.	E.g., Site Quality assessment in SA. Who else does what prior to first thinning?

8	Ground inspection, Inventory plots.	Coupe layout and scheduling of thinning.	Anything apart from DEM, knowledge of row directions and stocking?
9	Thinning inventory	Thinning or clear felling operations.	
10		Pre- or post-harvest inventory. • stocking, • basal area, • upper stand height, • volume, • products.	More complicated than initial inventory as stand thinned and information of thinnings sub-population may be required.
11		Harvesting control and reconciliation.	Progress at end of reporting period?
12		Other later age silvicultural treatments; • Fertiliser, • Pruning, • ?.	
13	Survey, field cruising.	Definition of areas lost; • fire, • lightning strikes, • revocations, • insect damage, • flood damage, • ?.	
14		Native forest included in plantations; • biodiversity corridors, • health	
15		Any other component?	

Questionnaire, Airborne LiDAR

At each stage along the FMIS information path each organisation is asked to determine.

- How they do it now.
- What would they do differently.
- What scope does the organisation see for LiDAR at this stage.
- How important is the activity to the organisation.

Some components will not be important to some organisations. This questionnaire is partly to determine each organisations priorities about each topic/module and where LiDAR might be used to assist.

Questionnaire, Terrestrial LiDAR

Does your organisation use Terrestrial LiDAR in practical applications?

If so, what applications?

If so, what is needed to make it deployable in practice?

Does your organisation believe Terrestrial LiDAR has an application in your organisation in the near future (say <5 years)?

Appendix 2 – People consulted

This is a list of all the people consulted, but some were for a relatively short period of time.

Forest Products Commission

John Tredinnick
Andrew Lyon
Andrew Milne
Sean Sawyer
Troy Sawyer
Allan Seymour

HQPlantations

Kevin Cooney
Col Reugebrink

ForestrySA

Jim O'Hehir
Jan Rombouts

Forests NSW

Mike Sutton
Tony Brown
Christine Stone

Hancock Victorian Plantations

Glen Rivers
Jeremy Gibson
Rod Lewis
Henry Lieshout
Adam Newnham

Timberland Pacific

Don Aurik

DeBruin Spatial Technology

Rick George
Mary-Anne Larkin
Jud Wheatley

Appendix 3 – Extracts from Supply Agreement

The extracts below are from the Supply Agreement signed with FWPA.

Project Description
This scoping study will identify commonalities/differences in resource assessment and planning systems used by a collaborative of softwood growers. This will be used to identify opportunities to progress development of LiDAR based tools and applications that provide maximum shared benefit to participating collaborators. A consultative process through phone interviews, face-to-face meetings and questionnaires with representatives from each company will be undertaken and the information synthesized into a report that will be used to develop a detailed project proposal. This study will leverage off the findings already presented in the FWPA Investment Plan for Improving Wood Quality and Yield, and Tools for Forest Management (September 2011). The resultant report will provide recommendations on the structure of a larger FWPA project proposal aimed at the operational deployment of processed LiDAR data into resource systems currently in use by the collaborators along with associated research opportunities.

This report will enable the collaborative to develop a project for submission to FWPA and the collaborative members. Based on the report the collaborative will be able to make decisions about the direction they consider appropriate for the project and will have sufficient detail to enable the submission to be prepared.

Project Deliverables
1) This scoping study will deliver a Report prepared by the consultant providing a synthesis of the results and recommendations for the collaborative of softwood growers who will then develop a larger FWPA project proposal aimed at the operational deployment of LiDAR data into resource assessment systems.
2) A detailed project proposal for FWPA to be submitted before the end of August 2012.

This report delivers the requirements under section 1 and facilitates the submission by the collaborative of a detailed project proposal under section 2.

Objective
Through a series of face-to-face consultative meetings and other forms of communication, the consultant will: 1) identify commonalities/differences in resource assessment and planning systems; 2) inventory LiDAR datasets, tools, applications already available, 3) identify opportunities for the application of LiDAR data in resource assessment and planning systems, and identify where these opportunities overlap for the participating forest growers; and 4) suggest R&D strategies that provide maximum shared benefit to prospective project participants. This process will rely on the active participation of all collaborative partners

This report meets the objectives. What is now needed is a detailed inventory of the LiDAR datasets that collaborative members agree can be provided. It is necessary that the Principal Researchers agree on the exact data format to be provided.

Deliverables and Milestones
Deliverable 3
Description
A draft version of the report covering off on field visit outcomes which documents FMIS process, identifies where collaborators see LiDAR being able to be integrated/deployed, where they are at as well as what they see as the next step and so on.
Delivery Date 1 June 2012

Deliverable 4
Description
Meeting with collaborators to review and discuss final draft and to discuss larger project components to enable deployment and suggest R&D opportunities. Seek endorsement from collaborators.
Delivery Date 20 June 2012

This report delivers almost on time. The report (Deliverable 3) was provided to the Contract Manager 2 weeks before the meeting date (Deliverable 4) to be held on 22 June.