Forest health assessments and relationship with volume increment and LiDAR

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EXECUTIVE SUMMARY

OBJECTIVE

The specific objectives of this report are to:
1) summarize the crown transparency and needle retention scores acquired by experienced assessors, and compare the needle retention scores with those obtained earlier by LUCAS field teams,
2) examine the usefulness of crown transparency, needle retention, and LiDAR metrics for predicting spatial variation in stem volume growth rate; and
3) Discuss the potential to monitor tree health attributes over time, including the use of repeated LiDAR measurements.

KEY RESULTS

As part of Forest Condition Monitoring work, crown health attributes were assessed in 11 stands in the North Island where crown transparency and needle retention were each assessed by experienced observers and results compared with needle retention assessments made by field teams measuring LUCAS plots. Crown transparency and needle retention (NR) scores by Scion teams were strongly correlated with each other, with needle retention explaining 68% of the variation in upper crown transparency – this result was almost identical to that reported for Puruki forest in relation to milestone 1. The relationship between Scion and LUCAS needle retention scores was relatively weak (R^2 = 43%), with the poor relationship mainly due to 4 plots assessed by both LUCAS teams having much lower needle retention scores compared with Scion assessors.

Relationships between crown transparency, stem volume increment, and LiDAR metrics were examined at Puruki forest. The 300Index model was used to estimate current annual increment (CAI) in stem volume from stand age 9 – 10 years, based on ground measurement of 36 plots in Puruki forest. Crown transparency, NR, and stem volume increment were all strongly correlated with each other. One LiDAR metric (p50fp) was strongly correlated with spatial variation in crown transparency. This same LiDAR metric also explained 53% of the variation in stem volume increment, and analysis showed that this LiDAR metric provided more explanatory power than other stand variables examined, including mean top height and basal area data.

More research on the usefulness of LiDAR to predict carbon sequestration at Puruki using repeated LiDAR flights four years apart is planned for 2010 as part of the LUCAS research programme Scion is undertaking for MfE. There is therefore an opportunity to link into this work, to assess the usefulness of LiDAR as a tool to assess changes in forest condition.

APPLICATION OF RESULTS

Crown transparency and NR influence tree growth, primarily through their effect on leaf area, or crown health. At Puruki, aspect (solar radiation) has a strong influence on crown transparency and growth variation at small spatial scales, and one LiDAR metric (p50fp) can detect this variation. To what extent LiDAR can be used to detect changes in forest condition over time is currently untested, but there is an opportunity to address this question in 2010.

FURTHER WORK

LiDAR points will penetrate deeper into the crown, and the point cloud mean height will therefore be lower down, in unhealthy stands compared with healthy stands. The effect of changes in tree health scores over time on LiDAR relationships with stem volume therefore remains uncertain, and warrants further research, if there is interest in predicting stem volume and growth rate from LiDAR information.

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INTRODUCTION

Forest condition monitoring provides a basis for determining whether changes are occurring in forest health over time. A number of crown attributes are currently being considered in New Zealand for assessing forest condition, using a network of Forest Condition Monitoring plots (Bulman 2008), including crown transparency, needle retention, and LiDAR. Of these attributes, crown transparency, needle retention, and some LiDAR height metrics can be expected to influence stem volume increment because they were all correlation with leaf area to varying degrees (Beets et al., 2008). Given the strength of these relationships, there was interest in further exploring the use of LiDAR for assessing crown health and stand growth.

It was proposed as part of milestone 3 of this Forest Condition Monitoring study to assess crown transparency and needle retention in several planted forest plots that were being installed and measured in 2008 as part of LUCAS (New Zealand Land Use and Carbon Analysis System). Measurements undertaken in LUCAS plots include stem diameter, height, prune height, and needle retention. In addition, LiDAR data were acquired for all plots. The results of the assessments made of crown transparency and needle retention in relation to milestone 3 and relationships with LiDAR metrics are reported here.

In a previous report, Puruki plot data were examined to test relationships between crown transparency, needle retention, stem total volume and LiDAR metrics. That report documented three trials used at Puruki (as copied below for completeness). One trial, FR443/5 included several seedlots in 20 plots, each plot purposefully established on either high or low solar radiation aspects, whereas the 16 plots in the other two trials included large within-plot variation in aspects. Trial FR443/5 the variation in growth rate between plots was large over small spatial scales. In this report we further analyse these data, with a focus on predicting spatial variation in growth rate (volume increment) in relation to crown health and LiDAR metrics.

For growth rate, we estimated volume increment using the 300 Index growth model, based on plot measurements undertaken in 2006, when Puruki stands were 9 years old. The predicted stem volume increment from age 9 – 10 year was estimated for each plot, and these increments were examined in relation to the transparency and needle retentions assessments undertaken in the spring of 2006. While increment was predicted using a model, the crown health assessments are independent of the model predictions, and therefore the strength of these relationships will provide an initial indication of how reliable the 300 Index volume predictions are likely to be.

The specific objectives of this report are to:

1) summarize the crown transparency and needle retention scores acquired by experienced assessors, and compare the needle retention scores with those obtained earlier by LUCAS field teams,

2) examine the usefulness of crown transparency, needle retention, and LiDAR metrics for predicting spatial variation in stem volume growth rate; and

3) Discuss the potential to monitor tree health attributes over time, including the use of repeated LiDAR measurements.

MATERIALS AND METHODS

Forest Condition Monitoring study (MS 3)

For LUCAS plots, crown transparency and needle retention of 40 trees per plot were assessed by experienced Scion observers during August-October 2008. A total of 11 LUCAS plots in the North Island were visited. Transparency of the upper 50% of the crown and also the whole crown were assessed by Lindsay Bulman. Needle retention was assessed by Stephen Pearce. Needle retention was assessed by LUCAS assessors earlier in 2008.

Puruki Trials

This forest is located at the southern end of the Paeroa Range mid-way between Rotorua and Taupo, where a pasture site was converted to radiata pine in 1973 (Beets and Brownlie 1987), and the forest subsequently harvested and replanted with radiata pine in 1997, at which time a number of trials were established there (Beets et al., 2003). The terrain is moderately steep to steep, with elevation ranging from 530 – 650.m, and pumice soil originating from the Taupo eruption centre (Beets and Brownlie 1987). Crown health and tree growth were assessed in three trials established in Puruki Forest (Beets et al 2004).

Trial FR443/5 is comprised of 20 plots planted with four seedlots (GF0, GF7, GF30, High Wood Density), with each plot containing seedling origin material from a single seedlot. Plots were installed on either high or low radiation sites at two elevations in a randomised block design with six replicate plots per seedlot (except GF0, with material available for only 2 plots, which were installed on low radiation aspects). The plots were nominally 30 x 30 m square, although some plots were rectangular in shape to ensure all trees in the plot were on planted on a similar aspect face. Crop trees (approx. 380 trees/ha) were pruned to a nominal height of 6 m, with followers still present.

Trial FR443/1 is comprised of six 50 x 50 m plots each established with fascicle cuttings developed from seed collected from GF7 stands at Nelson and Puruki (1st rotation), and were established as one contiguous block. The plots were stocked at approximately 1600 trees/ha, and subsequently thinned to approximately 1000 trees/ha, after which all trees were pruned to a nominal height of 6 m.

Trial FR443/2 is comprised of ten 50 x 50 m plots, with each plot containing a mixture of GF30 and GF7 material, planted in alternating rows, at a stocking of 600 trees/ha. Crop trees (approx. 380 trees/ha) were pruned to a nominal height of 6 m, with followers still present.

Definitions

The following terms are defined:

Crown transparency

This index of foliage projected area is based on a transparency score of individual tree crowns relative to standard photographs. It was assessed by viewing each tree crown from an oblique angle, and allocating a score given as a percentage, in 5% steps. Separate assessments were made for the upper half of the crown (in order to avoid the effects of suppression or branch removal by pruning in the lower crown), and for the entire crown. Crowns are expected to have low transparency (indicating low needle loss) if the foliage is dense and largely obscures the stem, and medium to high transparency if the crown is thin. Crowns can be thin because needle retention is low owing to needle diseases, however crown transparency can also be low when trees are healthy. For example, on south facing aspects, trees can be healthy but the crowns may be thin, due to low solar radiation levels. In such situations, the stand growth rate will be slow, which will result in thin crowns and low stem volume increment per ha.

Needle retention (NR)
Needle retention is a count of number of needle age classes evident in the lower third of the green crown of individual tree crown. Needle retention is expected to be 3 or more years in healthy radiata pine trees. Where needle retention is less than 3 years, premature needle loss is likely to have occurred. Note that crown length (specifically, the number of years of height growth from top to crown base) determines the maximum needle age class count that is possible, which may be less than 3 years in recently pruned trees. Needle diseases such as Cyclaneusma and Dothistroma reduce needle retention and thereby also reduce stand growth rates.

LiDAR
Light **D**etection **A**nd **R**anging refers to an active laser-scanning technology that allows accurate 3-D measurement of forest vegetation and the ground surface based on laser pulse return times. A range of metrics can be calculated from LiDAR returns that arise from light reflecting back from surfaces (mostly needles) at different depths within a pine forest canopy (first returns) and other surfaces including the ground.

P50fp
P50fp is one of many LiDAR height metrics. It refers to the height above ground corresponding with the 50^{th} percentile of the point cloud above a base height, which was set at 0.5m in both studies (LUCAS plots and Puruki plots). The metric reflects the degree of light penetration into tree crowns. This metric is high up in the crown when light penetration is low, as would be the case in crowns with low transparency, and low down in the crown when light penetration is high, as would be thecase in crowns with high transparency.

%veg
%veg is the percentage of first returns above a base height – it is an estimate of canopy cover.

Statistical analysis

Relationships between various the crown health attributes (transparency in upper 50% and total crown, NR) were examined using GLM procedures of SAS (Windows Version 9, SAS Institute Inc., Cary, NC, USA). Relationships between crown health attributes, growth rate, and LiDAR metrics were also explored.

RESULTS

Forest Condition Monitoring results

LUCAS plots

Stand summaries for plots installed and measured by LUCAS teams, and revisited by Scion are given in Table 1. The 11 plots re-assessed by Scion ranged in age between 9 and 18, which is less than the age range found across the LUCAS plot network. Mean crown transparency and needle retention scores by Scion and assessments of NR made earlier in the year by LUCAS teams, are given in Table 1.

Table 1. Plot summary data for plots installed and measured as part of the planted forest LUCAS plot network. NR and crown transparency were re-assessed in 11 LUCAS plots during August-October 2008 by Scion.

	11 LUCAS plots revisited by Scion			206 plots with NR scores by LUCAS teams		
	Mean	Min.	Max.	Mean	Min.	Max.
Stand age (yrs)	15	9	18	12	5	18
Trees/ha	524	83	1283			
MTH (m)	22	5	31			
BA (m2/ha)	33	3.8	50			
300Index	27	10	39			
NR (LUCAS team)	1.2	0.9	2.0	1.9	0.0	3.0
NR (Experienced observers)	1.6	0.6	2.6			
Transp (upper 50%) %	33	17	44			
Transp (whole crown) %	56	20	69			

Transparency in the upper (50%) crown was significantly less (prob > F = 0.0005) than total crown transparency, due to the greater density of foliage in the upper crown. Total crown transparency explained 76% of the variation in upper crown transparency:

(1) Transp (upper 50%) = 3.8 + 0.528 x Transp (total crown)

Transparency of the upper crown decreased as NR (Scion assessment) increased (R^2 = 68%, which was highly significant statistically Pr > F = 0.0019). Clearly, the low upper crown transparency assessments reflect high needle retention in the upper crown as well.

The plot mean NR scores in 2008 by the LUCAS field teams averaged 1.2, which was less than the mean score assigned by Scion (1.6), which is surprising because needle retention can be expected to decline following the LUCAS assessment. The LUCAS and Scion scores were only weakly related, mainly due to four plots receiving particularly low needle retention scores when assessed by LUCAS teams (Fig. 1).

Needle retention could not have increased in these plots between the two assessment dates, and therefore the scores assigned by the LUCAS teams can be considered to be far too low for those 4 plots, while the remaining 7 plots were consistent.

Upper crown transparency tended to decrease as NR (LUCAS assessment) increased, but the R^2 was weak (22%), and not statistically significant ($Pr > F = 0.14$).

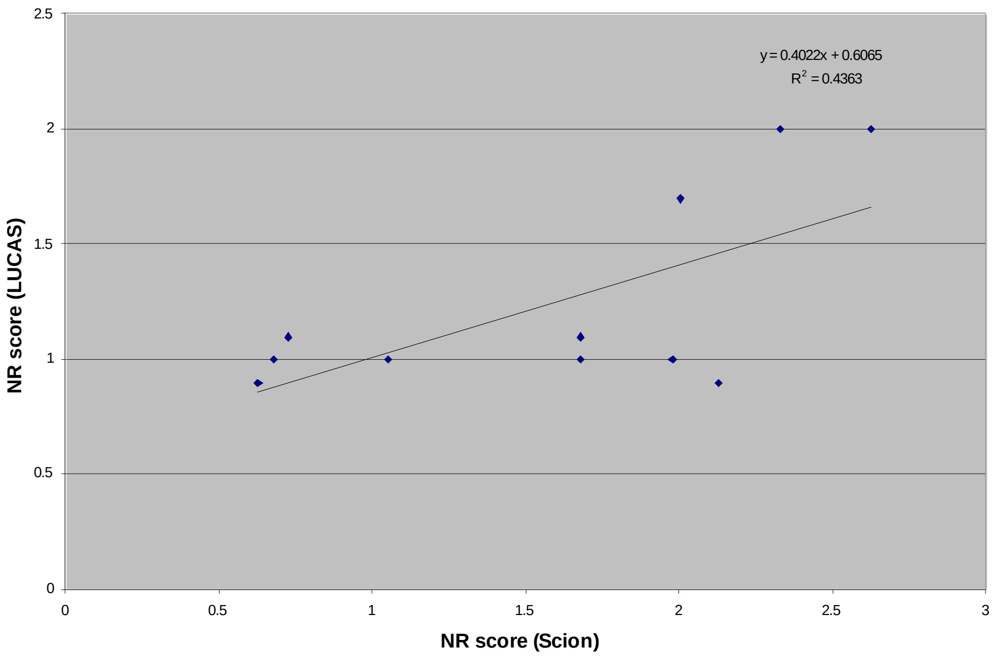

Fig. 1. NR scores undertaken by Scion and LUCAS teams

The correlation between transparency and NR in 2007 was slightly stronger using the upper crown transparency scores (R^2 = 68%), therefore the upper crown transparency data were of interest in relation to LAI and LiDAR.

Puruki

Stand summaries for plots at Puruki are given in Table 2. The 20 plots of FR443/5 with either low or high solar radiation levels are reported separately. Means for these 20 plots are generally similar to those based on the 36 plots, however, variability in volume growth rate and 300 Index can be related to aspect for plots in Trial FR443/5. Needle retention in 2006 was higher than when the plots were assessed in 2007/08, although the assessments were undertaken at a different time of the year so can be assessed directly.

Table 2. Summary of stand attributes for 9 year old trials (FR443/1, 2, & 5) at Puruki Forest, based on 36 plots where current annual increment (CAI) from the 300Index model and needle retention were assessed in Aug 2006. Transparency and needle retention were assessed in the 20 plots of trial FR443/5 in Dec 2007/Feb 2008.

	36 plots in all three trial			20 plots in trial FR443/5		
	Mean	Min.	Max.	Mean	Min.	Max.
Trees/ha	720	423	978	809	622	978
MTH (m)	13.4	11.0	16.0	12.9	11.0	16.0
BA (m2/ha)	26.1	12.5	48.9	31.5	20.4	48.9
$Volume_{ib}$ (m^3/ha)	129	61	260	153	88	260
300Index	28	22	36	29	25	36
CAI (m^3/ha/yr) age 9 – 10yrs	36	26	49	35	29	42
NR score (2006)	1.9	1.0	2.6	2.1	1.0	2.6
NR score (2007/08)				1.4	0.5	2.0
Transp (upper 50%) %				28	20	39
Transp (whole crown) %				42	31	56

Transparency in 2007/08
Solar radiation (Prob > F = 0.018) and seedlot (Prob > F = 0.0475) jointly explained 59% of the spatial variation in upper crown transparency, with transparency averaging 26% on high and 31% on low radiation aspects. Transparency was least 24% for GF30 material, and greatest for Museum (approx. GF0) material.

Needle retention in 2007/08
The results for needle retention were similar based on the 2008 assessments. Solar radiation (Prob > F = 0.0044) and seedlot (Prob > F = 0.1844) jointly explained 56% of the spatial variation in NR assessed in 2008, and averaged 1.6 on high and 1.2 on low radiation aspects. NR differences were not statistically significantly different between seedlots, although the trend was that GF30 material average higher retention (1.6) compared with the Museum material (1.2).

Stem volume increment in relation to transparency of upper crown.
Transparency (Prob > F = 0.0151) explained 29% of the spatial variation in stem volume increment. This result provides independent evidence that stem volume increment predictions from the 300Index model are related to crown condition.

Growth and transparency in relation to LiDAR
In the previous report for MS1, it was shown that transparency was moderately strongly related to two LiDAR metrics – p50fp and %veg. It was also shown that these same two LiDAR metrics were strongly related to stem total volume. The relationship with volume increment is now of interest.

One LiDAR metric, p50fp (Prob > F < 0.0001), explained 53% of the variation in stem current annual volume increment (CAI). The %veg metric that was significant for stem total volume was not significant for stem volume increment. This analysis included data from all 36 plots at Puruki. Further data analysis showed that the successive inclusion of important stand variables within the LiDAR based regression equation, including stem volume (Prob > F = 0.6501), mean top height (Prob > F = 0.5540), and basal area (Prob > F = 0.7366) did not improve the fit. Including both MTH and basal area with the p50fp metric did not improve the fit either. This analysis provides strong additional support of the validity of the volume increment predictions from the 300Index model, and shows that stem volume increment can be predicted using LiDAR.

If the p50fp metric is excluded, then stem volume increment can be predicted from two stand variables, MTH (Prob > F = 0.0016) and basal area (Prob > F = 0.0067), which then jointly explain 40% of the variation in stem volume increment – but this is appreciably less than the p50fp LiDAR metric on its own explained.

These LiDAR based relationships apply to 9 year old stands with more-or-less closed canopies at Puruki. As stands age, the p50fp height metric will rise, because the height of the canopy above ground will rise. This implies that some measure of age (or perhaps height) may be required in LiDAR regression equations to monitor stem volume increment over time.

LiDAR height percentile will be the same irrespective of stocking, but volume increment will depend on stocking. It may therefore be necessary to include stocking in regression equations for predicting volume increment, although this is less certain, as additional LiDAR metrics may suffice. The two LiDAR metrics (p50fp, %veg) suffice when the canopy is open, although other LiDAR metrics (not derived for this study) intuitively seem more appealing.

DISCUSSION

Assessments

The poor correlation between Scion NR scores of the 11 plots and those made by the LUCAS team in the same plots earlier that year reinforces the need for assessments to be made by well trained, experienced assessors who are supported with appropriate documentation.

Monitoring health over time

LiDAR seems to be a useful technology for assessing crown condition, although the analyses presented here focus on a single site and stand age. Leaf area is clearly responsible for spatial variation in stem volume increment, and this could be predicted from a single LiDAR metric, p50fp. If tree health changes over time (for example, needle retention improves) then this should be evident in successively acquired LiDAR point clouds. While the present study shows that LiDAR is potentially a useful tool for assessing changes in canopy condition and growth rate over space, it is evident that repeated LiDAR data acquisitions, which are necessary for monitoring change in canopy condition over time, do not appear to have been made.

Based on what we know about pine tree canopies, the width and depth of tree crowns comprising a forest canopy are very responsive to silviculture, and the intensity and timing of these operations may be expected to influence LiDAR metrics. These changes may complicate analysis of long term trends in forest condition, particularly if silvicultural practices change over long periods.

As part of LUCAS research, it is intended that LiDAR data be acquired over Puruki in 2010, and that the plots be remeasured, to more directly determine stem volume and biomass carbon stock changes in plots over the 4 year period since the forest was last flown. This new study will help determine what happens to LiDAR height metrics over time, in situations where for example, the health of stands may changes over time, and the height of the tree canopy increases due to growth.

CONCLUSIONS

To examine trends in health at Puruki over time it will be useful to discuss options.

1. Consideration will need to be given to season when plots should be remeasured for growth and crown health.
2. Needle retention and transparency should presumably also be assessed when the plots are measured using LiDAR.
3. If diseases such as Cyclaneusma needle cast are visible, then it may be worthwhile scoring tree in the spring prior to rhe LiDAR data beung acquired.
4. The proportion of crown affected by Dothistroma needle blight could also be scored when plots are measured.

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