Forest Condition Monitoring End of Project Report to FOA Executive and the Sustainable Farming Fund

Project Title:

Integrated Monitoring and Protection of New Zealand's Production Forest Industry

New Zealand Forest Owners Association Inc
Level 9, 93 The Terrace
Wellington 6143
Tel 04 473 4769 Fax 04 499 8893

www.nzfoa.org.nz
August 2011

TABLE OF CONTENTS

1. Executive Summary

Forest industry and Sustainable Farming Fund money has been invested over a three-year period (ending June 2011) to develop a Forest Condition Monitoring system. At the end of the funding period we now have a system that is:

a. plot based;

b. reliant, (like other international approaches to the same issue), on a defined visual and ground based system for assessing crown condition as an indicator of crop health; and

c. uses soil sampling to estimate soil parameters that can be influenced by forest management.

The project evaluated the application of remote sensing technology, specifically LiDAR, and determined that at present the technology is not developed to the point where it can adequately replace visual assessment. However, continued effort is underway (outside the original project funding) to further develop the application of remote sensing technology and put the Forest Condition Monitoring system into operation.

Project Objective

The projects objective was to develop a Forest Condition Monitoring system to enable the forest industry and the Government to better report on the condition of our plantation forests.

A successfully operating Forest Condition Monitoring system would provide a much more defensible indicator of sustainability than what we have now and would demonstrate through trends if forests are becoming less healthy for whatever reason and thereby trigger remedial action.

Project Achievements – relevant to Objectives

A Forest Condition Monitoring system has now been developed but more work is needed to improve the cost-effectiveness. Current efforts are investigating remote sensing technologies.

The project has produced a number of valuable reports that will be made available on the FOA website and can serve as reference material to finalise an operational FCM.

Opportunities

More than ever the forest industry requires a Forest Condition Monitoring system to track changes in forest condition. The opportunity is to revise the current system, based on new research and development results, and apply it on a regional or national basis.

There is also an opportunity to link the FCM system in with the government's requirement to report through the Montreal Process.

Next steps

Current effort by the FOA Forest Biosecurity Committee is to work with Future Forests Research (FFR) to further develop LiDAR and RapidEye remote sensing technologies to assess forest condition. In particular efforts are underway to determine if these technologies can be used to detect and monitor red needle cast disorder. Research is also assessing the usefulness of these technologies to apply to forest inventories and even monitor individual tree dimensions.

When remote sensing technologies are adequately developed they can then be combined with the knowledge that has been developed in the Forest Condition Monitoring project.

In the meantime the database that was developed as part of this project is being used to capture forest data that can be compared to data captured in subsequent years to determine changes in forest health.

2. The Project Outputs and Where to Find Them

The project produced several reports and an integrated database that can be used now and in the future. The reports below are located on the FOA website (www.nzfoa.org.nz)

MS#	Report
1	Crown transparency criteria to estimate forest health
1a	Soil quality indicators
2	Relationship between LAI and LiDAR
2a	Transparency classes developed for manual
3	FH assessments and relation with volume and LiDAR
4a	FCM sampling strategy

4b	Photos for FCM manual
4c	FCM data collection manual
4d	Training manual
5	LUCAS plot measurement summary report
6a	Database
6b	FCM manual
7	Task 1 Data analysis
	Task 3 Variability
	Task 5 Relationship between FCM measures and LiDAR
8	FCM Cost model
9	Final report (this one)

Appendix 1 - Forest Condition Monitoring Project Status Report 7 June 2011 (updated August 2011)

Project Title

Integrated Monitoring and Protection of New Zealand's Production Forest Industry

Summary

The current assessment of the Forest Condition Monitoring system is that we now have a system that is: a) plot based, b) reliant, (like other international approaches to the same issue), on a defined visual and ground based system for assessing crown condition as an indicator of crop health and c) uses soil sampling to estimate soil parameters that can be influenced by forest management.

Evaluation of the remote sensing technology considered to be the most appropriate to lower the cost of assessing canopy condition, (LiDAR), and as a means to reducing errors in assessment, indicated that this technology is not, as yet at least, developed to the point where it can adequately replace visual assessment.

Continued effort is underway to further develop the application of remote sensing technology and put the Forest Condition Monitoring system into operation.

Background

MAF's Sustainable Farming Fund approved the FOA Forest Condition Monitoring proposal to commence December 2007 as a two-year project.

The projects aim was to develop a Forest Condition Monitoring system to enable the forest industry and the Government to better report on the condition of our plantation forests.

A successfully operating Forest Condition Monitoring system would provide a much more defensible indicator of sustainability than what we have now and would demonstrate through trends if forests are becoming less healthy for whatever reason and thereby trigger remedial action.

The initial approach was to develop a system that would:

Integrate crown transparency monitoring (as an indicator of forest health and nutritional status) with the existing Permanent Sample Plot (PSP) system that monitors stand production.

Include Permanent Health Plots (PHPs) that could be used to assess the forest health status, including both tree and soil condition, and

Include organisational aspects that enable all forest owners to use the system to monitor and report on the condition of their plantation forests.

The budget for the project was approved at a total of $410,625 cash – split $260K to SFF and $150K FOA; plus $192K in-kind (which included $80K in-kind from Scion for their crown transparency system).

Progress

The project kicked off in December 2007 and the first milestone was delivered in March 2008.

Scion had previous experience in using crown transparency as a measure of stand health, having adapted overseas methodology. They contributed intellectual property, in the form of their crown transparency methodology to the project. This was later modified and used by Interpine and it formed the basis of the ground-based system and was a component of the MS1 report.

The project consisted of the following milestones and reports:

#	Milestone description	RP	Report	Date Delivered
1	Crown transparency criteria	Scion	Crown transparency criteria to estimate forest health	Mar 08
1a	Soil criteria	DW	Soil quality indicators	Feb 08
2	Crown transparency model	Scion	Relationship between LAI and LiDAR	Apr 08
2a	Photos – transparency class	Scion	Transparency classes developed for manual	June 09
3	PHP data correlation with LiDAR	Scion	FH assessments and relation with volume and LiDAR	June 09
4a	Design ground-based FCM	IP	FCM sampling strategy	Mar 09
4b	Photo manual	Scion	Photos sent to Interpine	Feb 09
4c	FCM manual	IP	FCM data collection manual	Mar 10
4d	Training	IP + Scion	Training	June 10
5	Sample LUCAS pre-1990 plots as pilot project	IP	LUCAS plot measurement summary report	Oct 10

6a	Data integration – incl enhanced FHS database	Cent	Database enhanced and data integrated	Feb 11
6b	Update FCM manual	IP	Task 2 Update manual	May 11
7	Organisational requirements		Task 1 Data analysis	May 11
			Task 3 Variability	Mar 11
			Task 5 Relationship between FCM measures and LiDAR	Mar 11
8	Implement system	IP	Task 4 FCM Cost model	Jan 11
9	Final Report			

Milestone 1 – Crown transparency criteria to estimate forest health

The results from this project were promising and indicated that crown transparency was the key criteria to focus on for estimating forest condition.

Objective

"The objective of this study is to review and discuss criteria used to estimate forest health condition, with particular reference to New Zealand conditions. Data on the precision and repeatability of assessments of key tree health attributes will be presented.

Key Results

Crown transparency is the single most important tree health attribute. Assessing the entire crown and the top 50% of the crown will reduce error significantly. Assessments should be carried out annually and as close to the same time of year as is logistically possible – although the need for annual assessment was not completely justified. Other attributes such as stem visibility, crown depth, shoot dieback, Dothistroma needle blight and Cyclaneusma needle-cast, are able to be quickly and reasonably accurately assessed and should be included in whatever system is ultimately developed.

Application of Results

This review will contribute to the development of a forest condition monitoring system in New Zealand.

CONCLUSIONS

Crown transparency is the single most important tree health attribute. Assessing the entire crown and the top 50% of the crown will reduce error significantly. Assessments should be carried out annually and as close to the same time of year as is logistically possible. Other attributes such as stem visibility, crown depth, shoot dieback, Dothistroma needle blight and Cyclaneusma needle-cast, are able to be quickly and reasonably accurately assessed and should be included in whatever system is ultimately developed."

Other Early Milestones – and Extension to Project

Milestone 3 was delivered in June 09, nine months behind schedule, necessitating a request to MAF/SFF to revise the timeline. The results from Milestone 3 also indicated that LiDAR would not be as useful as hoped and as previously indicated in Milestone 2. This meant that the project needed to re-focus away from relying heavily on remote sensing to a ground-based approach. Milestones were redrafted accordingly and a new timeline developed.

A ground-based system was designed in Milestone 4 by Interpine, basically using Scion's system but taking a fresh approach. Scion staff were consulted for input to the design. The result was the FCM Manual (MS 4c), which was used to train staff to sample LUCAS plots as a pilot project (MS 5).

The FH Database (MS6a) was enhanced and modified to accommodate condition monitoring. Scion agreed to host the database in return for access to the data for research purposes.

The Manual was updated (MS 6b) based on the experiences gained in measuring the LUCAS plots (MS5).

Crunch Time!

As a consequence of the pilot trial measuring the LUCAS plots (MS5) there was adequate data to develop a reasonable cost model (MS 8 – Task 4) to see if it would be likely that the costs would be reasonable. See summary below.

There was also now enough data to determine how reliable the results of ground-based assessment were, and because of new LiDAR data (from LUCAS) a further analysis of the relationship between FCM measures and LiDAR could be made. This led to MS 7 and Tasks 1, 3, and 5.

MS8 – Task 4 – Cost Model

As shown in the table below, the cost of measuring the LUCAS plots for FCM only is very expensive at $198K, whereas the additional cost of measuring FCM to the LUCAS measurement programme would only be in the order of $43K. Note – the costs are based on assessing 106 plots, which was the number of plots identified as being required to identify average canopy condition nationally within the desired level of precision.

Interpine assessed the potential costs of measuring the existing 16km by 8km nationwide LUCAS grid. The results are provided below:

COST SUMMARY	No FCM	FCM and Inventory	FCM Only
Plot Rate	1.7	1.6	1.7
Plot Measurement Costs	$50,400.00	$53,600.00	$50,400.00
Disbursement Costs	$77,276.00	$80,684.00	$77,276.00
Re-measurement Costs	$-	$20,142.60	$19,151.40
Audit Costs	$12,767.60	$13,428.40	$-
Project Management Costs	$14,044.36	$16,785.50	$14,682.74
FCM Calibration Costs	$-	$12,900.00	$12,900.00
Data Management Costs	$23,400.00	$23,400.00	$23,400.00
TOTAL	**$177,887.96**	**$220,940.50**	**$197,810.14**

Interpine determined that the biggest influence on plot measurement costs is attributable to the time it takes to travel between plots. When these times are short (e.g. 15 mins), the addition of FCM variable measurement can reduce plot rates by up to 35%. If they are large (e.g. 3 hours), the addition of FCM variable measurement can reduce daily plots rates by approximately 11%.

The costs for plot measurements are higher than those originally calculated by Scion. From 16 Feb 2011 Steering Committee meeting – "Interpine found it was taking a lot longer to measure FCM variables than Lindsay published in his report. But LB didn't measure defoliation. Assumption was that it was LB's enthusiasm and experience that made him faster."

The general conclusion from the cost model report is that provided inventories are being made the cost of the additional FCM measurements is reasonable, however, the main concern is that the results from FCM might not be all that useful at this stage. Read on.

MS7 – Task 1 – Analysis Report

This document provides a presentation and interpretation of the data collected in 2010. Specific reference is given to identifying geographical patterns, rather than temporal patterns in the data, as no time series data is available yet.

Discussion

Key Findings

P 26 - "The defoliation assessment data collected in 2010 indicates that only 4.3% of trees were damaged (defoliation score of more the 25%) with the remainder showing no or only slight defoliation."

"Plots with higher defoliation scores were focused in central Northland whereas plots in the Central North Island showed little evidence of defoliation."

"All trees exhibited some degree of transparency and both the Crown Transparency of the entire crown and the upper crown were found to be strongly correlated with tree age with the entire crown exhibiting the stronger correlation. This finding indicates that upper crown transparency may be a more reliable crown condition indicator than entire crown transparency."

"An analysis of the geographical spread of CT scores shows that trees in the Auckland and Southland areas tended to be the least transparent for both the entire crown and the upper crown measures."

Section 5.1.2 Adjusting for Age Effect

"It has been identified that several crown condition indicators, notably crown transparency, are strongly correlated with tree age. This means that if the age structure of the national resource changes then there will be a change in crown condition despite the fact that there is no change in tree condition. This is highly problematic for forest condition monitoring schemes as it may provide an inaccurate impression of forest condition change. Section 4.9 details a methodology which can be used to mitigate the effect of age using a function which includes the regression coefficients which describe the relationship between crown condition and tree age."

If only the top half of the crown is assessed for transparency then the effect of age diminishes, however, assessment of the top half only would fail to assess Dothistroma (and other) impacts.

MS7 – Task 3 – Variability Report

Abstract

"Interpine were commissioned to carry out an experimental field trial with the aim of understanding the sources of variability in visual assessment of crown condition indicators by Interpine's field teams. 755 tree assessments were made across 18 plots by three operators following an experimental design aimed to control sources of variability wherever possible. Analysis of the results showed that significant between operator variability remained in the dataset which suggests that significantly more effort and funding is required for training and calibration of field teams. A comparison of the sources of variation for the key crown indicators when assessed from a common or unique assessment position was carried out which suggested that the assessment position was important for the transparency indicators. A graphical and statistical analysis of the additional crown indicators is also provided."

Objectives

"The objective of this study was to quantify the sources of variation in the visual assessment of crown condition as undertaken by trained assessors from the 2010 survey. The between operator variability was of particular importance.

Key results

A field experiment was designed where experienced operators carried out assessment on plots in Kaingaroa Forest which were part of the 2010 FCM survey. The results were analysed through the development of a mixed effect model, which partitioned the variation in the data set. The model output indicated that the between operator variation remains significant for both transparency measures and for defoliation. This suggests that significant effort must be spent on training and quality assurance in future measurement periods to reduce the between operator variability. The defoliation indicator was found to be more variable than the measures of crown transparency assessed, this indicates that defoliation is more difficult to assess consistently and that the communication of effective assessment of defoliation is a difficult process. Both transparency measures were less variable but the model indicated these indicators are highly correlated with tree age and this must be taken into account when interpreting the FCM dataset. The results of the model analysis also indicated that assessment of crown condition from a known position reduces between operator variability.

Application of Results

The results of this research mean that we have an understanding of the nature of the variability which exists in the assessment of crown condition and we can utilise this in the interpretation of data with relation to changes in forest condition. The between operator variability provides a measure of the consistency of assessment between individuals and through training and documentation we should endeavour to reduce this where possible. Continuation of similar projects in the future will facilitate monitoring of the between operator differences in the crown condition assessments."

MS7 – Task 5 – Relationship between FCM measures and LiDAR

"The ***objectives*** *of this study were to summarise the crown condition assessment data collected during the 2010 FCM survey and to process and extract metrics from the LiDAR dataset which was obtained for FCM plots. Once this data was collated the aim of this project was to investigate relationships between crown condition and LiDAR metrics and attempt to build predictive models for crown condition base on LiDAR data.*

Key Findings

LiDAR point clouds for the study plots were successfully isolated and used to generate metrics for use in the modeling work in this study. Good relationships were found between crown condition indicators and LiDAR metrics and predictive models were produced. The transparency of the entire crown indicator was notably successful with a model produced, which accounted for more 77% of the variation in the crown condition indicator. The relationships with the transparency of the upper *crown and needle retention indicators were weaker but still very promising, but no strong relationship was found between LiDAR metrics and defoliation. A pilot study for the segregation of the LiDAR point cloud associated with individual trees based on tree locations has been produced and is promise but requires validation.*

Application

The predictive models for crown condition mean that crown condition indicators can be predicted using LiDAR metrics for radiata pine forests in New Zealand established before 1990. This means that it is likely that the number of plots measurements required to monitor forest condition can be reduced. With further validation it is also possible that the model can be used for the prediction of crown condition at a regional or estate level.

Further work

Interpine recommends that the following projects will provide significant benefits in relation to this topic:

- *Further validation of the predictive models and investigation of alternative model types.*
- *Investigation of the effect of incorporating remote sensing upon the sampling design required to monitor forest condition nationally.*
- *Development of a methodology to validate the predictive models for use at a regional or estate level. Further study into the pilot study approach to isolation of the point cloud associated with individual trees presented in this paper.*
- *Investigation of the capability of alternate remote sensing technologies for predicting crown condition."*

Current Status of the Project

Currently (as of June 2011) we have the following situation:

1. A Forest Condition Monitoring system that has been field tested and shown to be capable at providing crown transparency and defoliation data for radiata pine forests across New Zealand, and which can be linked, or not linked, to the LUCAS carbon measurement plots. However,

2. The data is reasonably expensive to obtain, especially if not linked to the LUCAS plot measurement. Costs can be reduced by reducing the frequency of assessment and also by tying the system in with the government's frequency of reporting under the Montreal Process (five yearly – or split the FCM programme into five annual installments). There is also an issue of reliability – primarily because of the considerable variability that can occur between operators, but also because the current system does not appear to accurately depict the true state of forest condition throughout NZ. These problems can be reduced by more training and quality control, and by assessing individual trees from the same position.

3. Remote sensing technology, and in particular LiDAR, appear to be useful for assessing crown condition but further work is required in this area. A main issue with LiDAR was its inability to accurately measure defoliation – a key variable. It was thought by the Steering Committee that others should fund developments in remote sensing and that we should stay aware of developments for possible application to FCM.

4. Once remote sensing technology is developed to a point that it can reliably monitor forest condition then we have a ground-based system that can be used to verify results (or vice versa).

Appendix 2 – Original milestones from December 2007

12. Milestones (estimated costs ex GST)				
No.	**Description** [List the major activities and outcomes of the project.]	**Due Date (mm/ yy)**	**Est. Cost ($000)**	
			SFF	**Total**
1	Develop crown transparency assessment criteria for PSPs and LUCAS and link with PSP measures of productivity. Report. Investigate soil and biodiversity sampling protocols and produce report recommending best option.	03/08	15	30
2	Investigate existing data to consider genetic and geoclimatic variations in crown transparency required to establish benchmarks for assessment. Produce crown transparency/productivity model to be used in condition monitoring system.	06/08	20	40
3	Carry out PHP data collection synchronised to allow for correlation against LIDAR data in central north island plots. Report on success of correlation.	09/08	25	50
4	Modifiy methodologies as required and document. Develop training manuals to achieve synergies in integration of PHPs, PSPs and LUCAS (ground based and LIDAR). Produce manuals – (1) methodology (2) training	12/08	37.5	75
5	Determine data integration requirements. Produce report.	3/09	17.5	35
6	Refine crown transparency/productivity model. New model and report.	4/09	10	20
7	Put in place the organisational, contractual, operational, auditing and reporting requirements to ensure the effectiveness and longevity of the system for forest management and monitoring. Produce necessary manuals, reports, and contracts.	6/09	15	30
8	The third and final year would be implementation of the integrated system and any residual monitoring requirements. Report on success.	11/09	15	30
X	**Final Report** that documents all components of the project.	06/10	5	10

Appendix 3 – Revised milestones from September 2009

#	Milestone	Due	SFF	Total
4a	Design ground-based FCM. Link to LUCAS ground-based system. Allow for future links with LIDAR. Design as a 3 Level system with Level 1 – LUCAS plots; Level 2 – additional PSPs; Level 3 – optional soil sampling and other components. Design specs RFP needs to include frequency of sampling and number of plots with information on the number of plots required to achieve more than one level of confidence. The specs RFP will also include evaluating the use of the 200 LUCAS plots to be measured in 2010 and the potential use of PHPs (i.e., not based on PSPs). It is anticipated that Level 1 plots will provide some national assessment but Level 2/3 will be required to get regional/forest assessment. Design needs to include geo-location capture using high-grad GPS. Ensure there is some estimate of annual operating cost in design. Expectation is that data collection is electronic and feeds to database.	12/09	21.37	33.75
4b	Produce crown transparency photo set (manual) for assessing forest condition	9/09	8.91	14.06
4c	Produce FCM manual. Test manual and data capture software	3/10	14.25	22.50
4d	Training	6/10	7.12	11.25
5	Sample LUCAS 200 pre-1990 plots as pilot project – including training. This will be done in conjunction with the LUCAS programme and the data collected will be described in Milestone 4a.	8/10	14.25	22.50
6a	Determine data integration requirements to interpret results – including enhanced FHS database; Level 1 – 3 plots; PSP data with transparency data etc. and tying this all into a database. Basically develop database. This needs to link with LUCAS database but does not likely need to store duplicate data.	9/10	28.50	45.00

6b	Update FCM manual	11/10	3.56	5.63
7	Put in place the organisational, contractual, operational, auditing and reporting requirements to ensure the effectiveness and longevity of the system for forest management and monitoring. Produce necessary manuals, reports, and contracts, including auditing requirements.	2/11	21.37	33.75
8	Implement the system and design, develop, and implement any residual monitoring requirements. Report on success.	5/11	14.25	22.50
9	Final Report that documents all components of the project.	06/11	7.12	11.25
			140.7	222.19