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Forestry Innovation

# Sampling Strategy for a New Zealand Forest Condition Monitoring Program

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# 1 EXECUTIVE SUMMARY

The New Zealand Forest Owner's Association engaged Interpine Forestry Ltd to determine an appropriate sampling strategy for the forest condition monitoring of New Zealand exotic forests. The monitoring systems discussed in this report relate predominantly to crown condition attributes as key indicators of forest heath.

A global perspective on crown condition monitoring was explored through an extensive literature review on existing programmes in the northern hemisphere. Measurement techniques and sampling strategies are discussed in Sections 4.

A sampling strategy was explored and is suggested in Section 5. Much of the analysis on sampling levels and procedures is predicated on earlier work by Bulman & Kimberly (2005), and Bulman (2008). More specifically, the statistical analyses performed in this study are based on work by the aforementioned authors in relation to crown transparency measurements.

With this in mind, the following recommendations are made:

- Approximately 24 trees should be measured per plot for crown characteristics. It is desirable, but not essential, that the same number of trees are assessed in each plot;
- Approximately 100 plots should be established on a grid with random origin covering the target population (i.e. the New Zealand radiata pine estate) ;
- Each plot should be measured annually. It is expected that at least 10 years of measurement would be required before long term trends (if any) became identifiable;
- At least three measurement operators should be used;
- At least 18 plot measurements should be conducted using a blind re-measurement by the same or another operator; and
- After three years at this level of intensity, a review should be conducted to re-confirm the target number of plots, operators, and timing between measurements.

Interpine recommends the use of 16km by 8km grid LUCAS plots as it would provide an excellent sample for crown condition measurements targeting the New Zealand national exotic forest. The statistical allocation of the LUCAS plots complies with the necessary randomisation needed for an unbiased sample. PSPs should only be used on an estate level if they are randomly allocated and this will depend on the PSP allocation strategy of the company(s) involved.

Interpine estimates that maintaining a forest condition monitoring system of approximately 100 country-wide plots would cost between $125,000 and $200,000 annually.

# 2 CONTENTS

# 3 INTRODUCTION

Over the past 100 years, New Zealand has developed a significant exotic forest estate resource that now provides the foundation for one of the largest industry sectors in New Zealand's economy - the forestry and forest products industry. Alongside the commercial benefits of New Zealand's exotic forest resource sit an array of community and environmental values, not least is the contribution of these resources to New Zealand's impact on global climate change. Recognising these values has prompted the New Zealand Forest Owner's Association (NZFOA) to commission the development of a system to monitor the health of New Zealand's forest over time. This report focuses specifically on the development of a Forest Condition Monitoring (FCM) system using techniques that assesses the health of tree crowns.

Stimulated by concerns about forest health decline, there has been a trend towards the use of FCM techniques across Europe and North America in recent decades. While most techniques have focused on crown health, integrated approaches have been adopted that assess tree health across a variety of observable characteristics.

In New Zealand there has been no concerted effort to monitor forest condition and all reports on the decline of forestry species have been based on anecdotal evidence. Small scale research projects, which include aspects of FCM used in the Northern Hemisphere, have been carried out in recent years (Bulman 1997, Bulman 2003) but no systematic FCM program has been established. Interpine Forestry Limited (Interpine) has been contracted by the NZFOA to develop a sampling design and field manual for an FCM system specific to New Zealand's exotic forest estate. The following sections include a review of some of the global literature relating to FCM, an analysis of the variability in forest condition measurements from previous studies, an indicative costing study, and a set of recommendations relating to a New Zealand FCM program.

## 3.1 DEFINITIONS

The topic of FCM is unique and many of the terms used to describe conditions or techniques require specific clarification. The following section has been included to provide definitions on certain terms that, when used in this document, relate specifically to FCM.

1. Tree Health

Tree health is defined as the "well being" of trees within a forest, where "well being" may be described as the expected unhindered biological activity of a tree given the species and site capacity. Tree health is directly attributable to wood production and can be affected by biotic factors (such as disease) and abiotic factors (such as wind damage).

2. Tree Condition

Tree condition can be considered a symptom of tree health and is a general term referring to the above-ground appearance of trees within a forest.

3. Tree Vigour

Tree vigour generally relates to the overall growth of trees (height, diameter, crown size). In FCM, tree vigour is stated in the context of a hypothetical optimum growth level (Innes 1993).

4. Crown Condition

Crown condition refers to the health of the tree crown and is a good indicator of tree and forest health. In FCM there are many different techniques used to measure crown condition although each technique has important discernable differences. The technique/definition used in this report crown transparency. In previous work relating to FCM in New Zealand (Bulman 2003, Bulman and Kimberly 2005) the terms crown transparency and crown density have been used interchangeably (L. Bulman pers. comm.); however, for the purposes of clarification, the following definition applies:

*Crown Transparency refers to the total transparency of the tree crown. The measurement technique can encompass all branches and includes the gaps between branch whorls. The measurement is recorded as a percentage of total skylight visible through the crown (e.g. 80% crown transparency means that approximately 80% of the total crown area is 80% transparent).*

5. Survey Plots

In the European literature on FCM, there are two types of survey plots being used to measure forest condition. These plots are commonly referred to as level one and level two plots. The data collected in level one plots is designed to provide a periodic overview on the spatial and temporal variation in forest condition in relation to anthropogenic and natural influences. Level two plots constitute a more intensive monitoring programme which aims to better understand the relationship between forest condition and stress factors through intensive monitoring of the inputs into a forest ecosystem (UNECE, 2006). The FCM program discussed in this document refers to the implementation of level one plots only.

## 3.2 Assessing Tree Condition

Assessments of forest health need to satisfy the objectives of any FCM system (as defined by the forest stakeholder's needs) but also need to be scientifically valid and economically viable to collect (Stone et al. 2003, Innes 1993). There are a wide variety of techniques used to assess tree condition although the indicators to be considered in the New Zealand system are summarised in Table 1.
Further information on international techniques can be found in international literature (please see Reference List in Section 8), though in particular, Innes (1993) provides an extensive review of various techniques.

Table 1. Descriptions and scales used for tree condition indicators.

| Indicator | Description | Scale | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | |
| **Crown Transparency** | The percentage of skylight visible through the live, normally foliated portion of the crown | 1-100% in 5% classes | | | | | (Bulman L. S., 2003) |
| **Stem Visibility** | The amount of stem visible through the foliage and branching | | Dense branching, stem totally obscured | One or two small (<0.5 m) parts of stem visible | Large (>1 m) parts of the stem visible, more than 2 small parts visible | Stem visible throughout the crown | (Bulman L. S., 2008) |
| **Needle Retention** | The number of needle age classes (to nearest year) present in lower third of the unsuppressed green crown | 1-year-old needle age-class absent. Exclude immature flushes of needles from your assessment | 1-year-old needle age-class present | 2-year-old needle age-class present | 3-year-old and older needle age-classes present | | (Payton, 2010) |
| **Crown Density** | The percentage of crown stem, branches, twigs, shoots, buds, foliage and reproductive structures that block light penetration through the crown | 0-100% in 5% classes | | | | | (Schomaker, Zarnoch, Bechtold, Latelle, Burkman, & Cox, 2007) |
| **Crown Dieback** | The recent dieback of branches with fine twigs in the upper and outer portions of the tree | 1-100% in 5% classes | | | | | (Schomaker, Zarnoch, Bechtold, Latelle, Burkman, & Cox, 2007) |
| **Crown Depth** | The depth of green foliage present in the crown | | Green foliage present in the lowermost quarter of the unpruned crown | Green foliage present in the lower-mid quarter of the unpruned crown | Green foliage present in the upper-mid quarter of the unpruned crown | Green foliage present in the uppermost quarter of the unpruned crown | (Bulman L. S., 2008) |
| ***Dothistroma*** | *Dothistroma septosporum* causes needles to turn brown with red bands | Percentage of total crown foliage with infection (1-100%, 5% classes) | | | | | (Bulman, Gadgil, Kershaw, & Ray, 2004; Chapman, 1999) |
| ***Cyclaneusma*** | *Cyclaneusma minus* causes needles to turn yellow | Percentage of total crown foliage with infection (1-100%, 5% classes) | | | | | (Bulman, Gadgil, Kershaw, & Ray, 2004; Chapman, 1999) |
| **Resin Bleeding** | Resin on the outside of the stem caused through stress to the tree | | Absent or very rare | 5-20% of log covered with resin | 21-50% of log covered with resin | Over 50% of log covered with resin | |

### *3.2.1 Crown Condition*

There are a wide array of biotic and abiotic factors which affect tree and forest health; the effects of these factors often manifest themselves in the physical appearance of the tree crown. Consequently, tree crown characteristics can be a major determinant of a tree's net primary productivity and are a key component of forest ecosystem health (Schomaker et. al. 2007). Tree crown condition is correlated with tree survival (Kramer 1966) and defoliation has been found to inhibit increment rates due to decreased carbohydrate or nutrient levels (Vose et al. 1994).

Crown condition is the most commonly used and widely accepted indicator of tree health (Innes 2003, Smith and Conkling 2004). It has become a universal indicator of forest health and is used as the cornerstone of the forest health monitoring programmes of many countries (Innes 1993, Brand 1997, Ferretti 1997, Stone et al. 2003).

Crown transparency is strongly correlated with crown condition and is considered a scientifically valid technique for measurement in FCM programmes. Most importantly, crown transparency can be measured in sample inventory programmes, providing a condition indicator which is both practically feasible and financially viable to measure. Due to the history of measurement on radiata pine in New Zealand, the strong correlation to crown condition, and the practicality of measurement, this report (and the sampling strategy contained herein) specifically relates to crown transparency measurement.

## 3.3 Forest Condition Monitoring in New Zealand

As the principles of sustainability and the environmental movement gain prominence, foresters throughout the world are under pressure to monitor forest condition and provide details on any perceived decline. The forest industry in New Zealand has lagged behind many of its counterparts elsewhere in systematically monitoring forest condition, although a forest pest surveillance and detection system has been in place since 1956 (Kershaw 1989). The isolated nature and relatively low level of industrial development in New Zealand means that the forest industry here does not come under the same level of public scrutiny to quantify the effects of acid rain and pollution as those in Europe or North America.

The New Zealand forest health surveillance system currently in place focuses on pest detection around high risk areas, points of first entry (such as ports), and urban areas (Bulman and Kimberley 2005, Bulman 2008b), as well as over the larger area of New Zealand's exotic forest estate.

In 2005 the NZFOA agreed that a new forest monitoring system was required to identify and quantify any changes that may occur in New Zealand's forest health over time; such a system that includes a permanent network of condition monitoring plots (Bulman and Kimberley 2005). The New Zealand forest industry is now in an enviable position of being able to learn from systems elsewhere in the world during the design of a program for monitoring forest condition at a national level.

# 4 Literature Review: An Overview of Forest Condition Monitoring Around the World

Interpine assessed the FCM techniques used across different countries particularly in the Northern Hemisphere, a brief summary of which is discussed in this Section (Section 4). The knowledge collected during this review was used as a foundation for understanding how a sampling strategy should be established in the context of a New Zealand system.

## 4.1 Great Britain

An FCM system in Britain was first established in 1984 (Binns et al. 1985) and condition has been monitored via a systematic permanent plot network since 1987 (Hendry et al. 2004) although it is believed that this FCM system has recently been abandoned due to funding cuts (L. Bulman pers. comm.). The FCM network in Britain was independent of the national woodland inventory and used crown density as the primary indicator of tree health (Innes and Boswell 1987, Hendry et al. 2004).

The FCM network in Britain comprised 344 plots measured annually (in summer months) and focussed on stands containing the five species of the greatest economic and cultural value (see Table 2) This British FCM plot network provided data on approximately 2,665,125 hectares of forested land across the country. For sampling purposes, the network was split into 12 regions based on climate and growth characteristics. A minimum of five plots of each species were sampled in each region. Plots were located on a 16km grid and where possible, a spread of older and younger stands was sampled (Innes 1990). In some regions where the 16km gird was not adequate to cover all the local species, additional plots were established.

The plots consisted of 24 trees located in four subplots of six trees each. Although between 29 and 33 features of tree health were assessed and recorded, it was considered that crown density was the most important factor measured (Hendry et al. 2005).

Crown density is an index of the degree of opacity of the crown and is estimated in 5% classes. Until 1993, crown density was recorded in comparison to a photograph of an 'ideal tree' carrying maximum possible foliage. More recently however, the comparisons were made to a photograph of a tree growing with full foliage under local conditions. This change in technique was implemented to bring Britain's data collection in line with many European countries.

Table 2. The species composition and plot numbers for the British forest condition monitoring network (Hendry et al. 2005)

| Primary species | Number of plots |
|---|---|
| Sitka spruce (*Picea sitchensis* (Bong.) Carr); | 57 |
| Norway spruce (*Picea abies* (L.) Karst); | 52 |
| Scots pine (*Pinus sylvestris* L.) | 81 |
| Oak (*Quercus spp.*) | 86 |
| Beech (*Fagus sylvatica* L.) | 65 |
| Mixed Sitka spruce and Scots pine | 3 |
| **Total** | **344** |

Between-observer bias in the British system had been a consistent problem in FCM measurements since the scheme's inception. Initially it was found that increased training resulted in a skewed measurement of density, (Innes et al. 1986) however an extensive training and quality assurance scheme was undertaken to remedy this. In 2004 it was found that the effects of between-observer bias had been negated, despite the use of unrelated regional data collection teams. To understand the between-team variation, almost a third of all plots across all regions were re-assessed by experienced assessors (Hendry et al. 2005).

The systematic forest condition monitoring network in Britain was established for 23 years and even over this extensive period of time there were very few statistically significant trends uncovered (Hendry 2005). The crown density scores recorded annually are presented in Figure 1; a downward gradient in the figure would indicate deterioration. For all species sampled in Britain (with the exception of Norway spruce and oak), there was no significant trend. In the author's view, the results were biased by the high density scores recorded in the early measurement years: these high score are reported that have been the results of insufficient training of data collection teams (Hendry 2005).

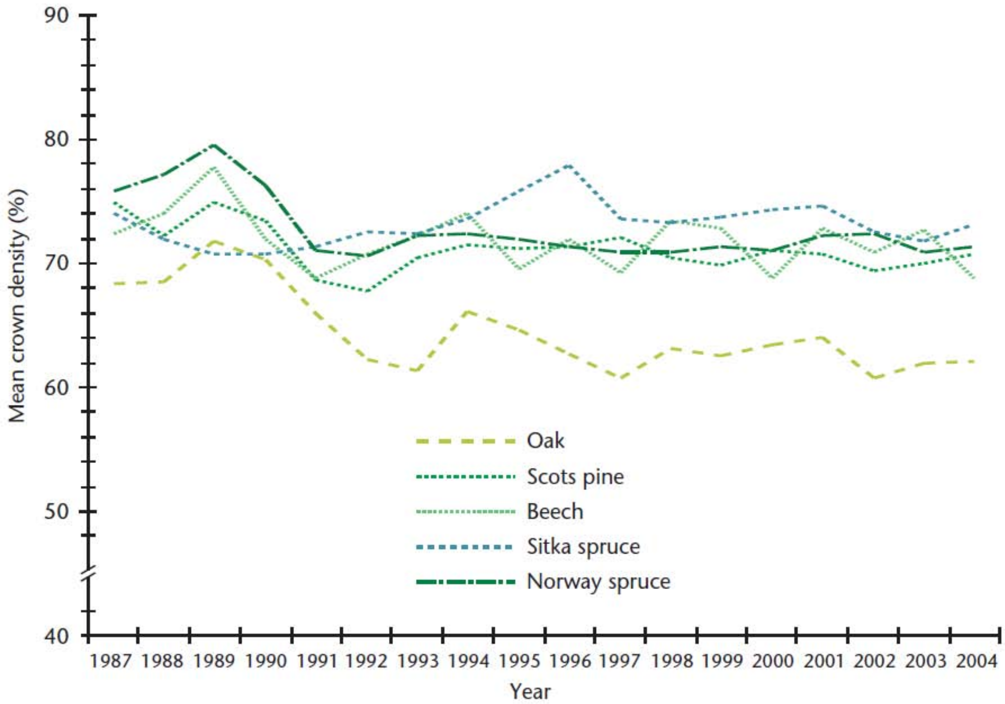


Figure 1. The mean crown density assessed annually for the period 1987 - 2004 in the British FCM network (Source: Hendry et al. 2005)

Vanguelova et al. (2007) report that the plot network used to monitor crown condition consisted of level one type plots and provided information on changes in tree condition over time. However, it became evident in the 1990s that detailed assessments of environmental factors were needed to identify the causes of the observed changes and to better understand forest health at an ecosystem level. To achieve this, a network of level two plots was established across Britain representing a broad range of climatic conditions over 20 separate sites. Each site contained a 0.1 hectare mensuration plot where five yearly measurements of tree growth occurred. In addition to the growth data, additional information was collected including:

- Air quality and meteorology;
- Atmospheric deposition;
- Litterfall;
- Soil and soil solution chemistry;
- Foliar biomass and chemistry;
- Crown density; and
- Ground vegetation composition.

In the most recent measurements some trends begun to emerge which provide a comprehensive picture of forest condition in Britain. It is not clear on whether the combination of level one and level two plots

## 4.2 Germany[1]

The health of Germany's eleven million hectares of forest is assessed by a long established permanent FCM plot network. The FCM scheme was established in response to widespread concern in Germany over forest decline caused by acid rain and air pollution. Today, the German system represents one of the most well-established and sophisticated FCM programmes in the world.

The German FCM plot network is based on a 16km grid, which is sufficient to provide reporting at a national level; however at a regional level different sized grids are used. Plots are assessed annually in summer and trees are selected for inclusion based on their proximity to set sample points within a stand. Significant emphasis is placed on the provision of extensive training. A five day training course led by experienced assessors is attended by data collection teams before each measurement period. A very thorough approach to quality control is also taken with blind re-measurement applied over 20-25% of plots.

The German system is based on a level-one sample approach where crown defoliation[2] is the most important indicator collected. A range of other characteristics are also recorded including:

- Yellowing;
- Defoliation due to biotic damage;
- Damaging species;
- Non biotic causes of damage (storms, snow, etc);
- Fructification (fruit or seed bearing);
- Reason for mortality; and
- Reason for replacement of trees.

The data collection from level one plots is often complimented by information collected from a series of level two plots situated across Germany. The benefit of this approach has not been researched.

[1] All information stated in this has been provided Dr. A Bauer

[2] Crown defoliation is a crown condition measurement technique that is distinctly different from crown transparency or crown density measurements. For that reason, throughout this document the term has been omitted to avoid confusion with the techniques proposed for the New Zealand system.



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## 4.3 ICP Forests – A transnational approach

The International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) was launched in 1985 under the Convention on Long Range Trans-boundary Air Pollution of the United Nations Economic Commission for Europe (UNECE). The ICP Forests project, as reported by Lorenz et al. (2008), has increased to incorporate 41 countries including Canada and the USA but is focussed on Europe where the programme began. The ICP Forests trans-national survey consists of both level one and level two plots. The level one plots are based on a 16 x 16 kilometre grid of sample locations across Europe, which provide data on spatial and temporal variation of forest condition at the European-wide scale. Crown condition is assessed in around 5,000 plots annually and plots are distributed throughout Europe to incorporate all of the climatic regions. In most cases the plots which constitute the trans-national survey are a sub-sample of each country's national FCM system. Lornez et al. (2008) report that the grid size used in national surveys for ICP Forest member states varies from 1 x 1 km to 32 x 32km dependent on the size and structure of a country's forested area and it's forest policy.

Now in its 25$^{th}$ year, the ICP forests project is a long running endeavour which is now yielding results across the European continent. Species specific crown deterioration has been recorded most notably in the Mediterranean species of *Quercus ilex, Quercus rotundifolia,* and *Pinus pinaster.* Meanwhile *Quercus robur*, *Quercus petrea* and *Picea abies* have seen a decrease in their defoliation levels since 2004, reportedly in response to severe drought (Lorenz et. Al. 2008).

## 4.4 United States of America

In the USA, the FCM program has been combined within the Forest Inventory and Analysis (FIA) Programme since 1999 (Smith and Conkling 2005). The FIA is comprised of remote sensing activity (Phase 1), forest inventory (Phase 2), and forest health measurement plots (Phase 3) (Figure 2). The inventory program includes all forested lands in the US regardless of ownership or availability for harvesting. Forest condition is monitored on a subset of the 7,861 FIA plots. FCM plots are located on a permanent hexagonal based grid approximately 22 miles apart. The plots are measured on a 4-year cycle such that one quarter of the plots systematically covering the state (known as a panel) are measured every year. In addition, one third of the previous year's panel are also re-measured. This sampling methodology, referred to as the "FHM rotating panel design", is illustrated in Figure 3.

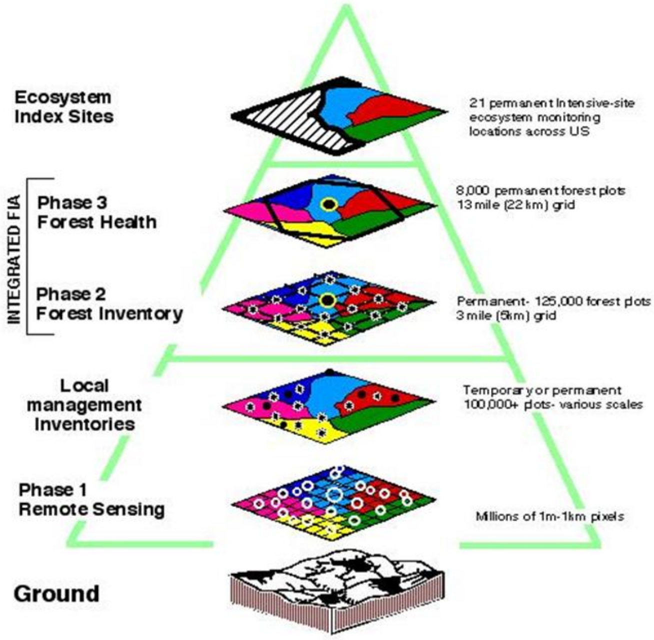


Figure 2. The composition of the USDA FIA program (Betchold et al 2005)

| Year ⇒ / Panel ⇓ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 0 | X | x/3 | | | X | x/3 | | |
| 1 | X | X | x/3 | | | X | x/3 | |
| 2 | X | | X | x/3 | | | X | x/3 |
| 3 | X | | | X | x/3 | | | X |

Figure 3. The year to year sampling design of the USDA FHM network (Betchold et al 2005)

The objective of the sophisticated FHM rotating panel design is to provide precise estimates of change over short temporal rather than fine geographical range. Making annual assessments using the FHM rotating panel design allows the prediction of plot values in unmeasured plots, which is of particular importance in the effective statistical analysis of this type of dataset (Smith and Conkling 2005).

# 5 ANALYSIS AND FINDINGS

This section outlines Interpine's approach and findings with regard to the establishment of a New Zealand FCM strategy.

## 5.1 OBJECTIVES OF SAMPLING STRATEGY

Interpine's analysis is predicated in the objectives provided by NZFOA. More specifically, during a meeting with Interpine in Rotorua on 15th February 2010, NZFOA stated that:

> "The survey should be capable of detecting a long term trend in crown transparency with a rate of change equivalent to 10% over 25 years with reasonable confidence."

That is 10% of the assessed crown, not 10% of the initial transparency, and equates to 0.4% of the assessed crown per year. It is assumed that this is after adjusting for the effects of changing tree age.

It would be possible to measure a sample of plots now and then again in 25 years time with the sole aim of seeing whether crown transparency had changed by more than 10% (assuming that natural change in transparency due to increasing age is already known) . The problem is that one could not be sure whether the change in crown transparency was the result of a trend or a random difference between measurement years.

Thus, the detection of a trend requires measurement of plots at more than two points in time; the more the better. As such, the approach suggested in this document assumes the results analysis will be of a time-series of data rather than the paired comparison of two measurements at different points in time.

## 5.2 SOURCES OF VARIATION IN CROWN TRANSPARENCY MEASUREMENT

Bulman and Kimberley (2005) and Bulman (2008) identified a number of sources of variability in crown transparency; each source of variability needs to be understood before implementing a sampling strategy. This section discusses the sources of sampling variability.

### *5.2.1 Spatial or "point-in-time" variation*

Spatial / point-in-time variation refers to variation that can be observed across measurements taken at approximately the same time. This type of variation can be broken into three key areas:

1. Variation of individual sites or plots about the national average crown transparency. This will result from as some sites will consistently have better or worse crown transparency scores than others. Measuring more plots within the population can help "explain" this source of variation.

2. Variation of individual trees about the plot mean. Variation of this type results from natural variability that occurs between trees. Measuring more trees in each plot can help to counter this source of variation.

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3. Variation between operators assessing the same tree. As the crown transparency measurement techniques rely on assessor interpretation, there can be a source of variation that arises from the interpretive differences between assessors.

### *5.2.2 Temporal variation*

Temporal variation refers to the variation that may be observed between measurements taken at one time versus measurements taken at a later date, where the duration of time is expected to impact on the state of the trees.

1. Changes in the national average transparency from year-to-year. For example, the national average transparency is likely to change from year-to-year in "random" ways as a response to changing weather conditions. These changes are likely to be correlated between years; e.g. a few good years followed by a few bad years.

2. Variation in plot average transparency between years, for example, plots with above-average transparency one year may be below-average in another year. It is expected that these departures from the national average will be correlated between consecutive years. For example, a plot may have several good years followed by several bad years. Measuring more plots or the same plots for more years helps to counter this source of variation.

3. Variation between individual trees and plot averages from year-to-year. Individual trees will change relative to the plot mean between years. Measuring more trees in each plot or measuring for more years both counter this source of variation.

4. Variation that occurs from systematic seasonal change. This source of variation is related to the timing of measurement where average transparency values may be lower in summer than winter for example. Measuring at consistent times each year helps to reduce this variation.

5. Variation as a result of tree age - as trees age, we expect the crown transparency to change. Over time, a model to predict crown transparency changes as a result of tree age will need to be developed.

6. Variation as a result of changes in the population of assessment operators. As expected, over a long period of time the population of assessors will change significantly. Well-designed manuals and photosets are likely to help reduce this source of variation.

7. Variation that may result due to changes in assessment practices. This could occur where quality control feedback result in a change to techniques or reference materials.

8. Variation from long-term trend in crown health (if any).

Some of the variation discussed in this section can be reduced by controlling measurement practice; for example, re-measuring a plot at the same time of year reduces between-year variation. Other sources of variation can be countered by using more plots, trees, years-of-measurement and/or operators. Determining how many of each (trees in plots / plots in sample) are required to achieve the objectives of the survey is dependent on some knowledge or informed assumption about the magnitude of each of the sources of variation.



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## 5.3 QUANTIFYING SOURCES OF VARIATION

Interpine collated and analysed sources of existing data on crown transparency measurement to quantify the expected sources of variation. This variation was then used to determine a sampling strategy commensurate with the sampling objectives of the NZFOA. All of the data were collected and made available by Lindsay Bulman of Scion, whose contribution is gratefully acknowledged.

### *5.3.1 Between-operator variation*

The data used to quantify between-operator variation is described in Bulman (2008a). Five operators (assessors) each assessed crown transparency on 50 trees over three sites. Trees were measured on three separate occasions by the same assessor. All operators assessed the same trees. The measurements occurred on different days of the same month. One of the operators was experienced while the other four were novice assessors with only brief training[3]. Only summarised data was available for Interpine's analysis. The average assessment for each group of 50 trees, as shown in figure 6 of the Bulman (2008), is reproduced in Figure 4.

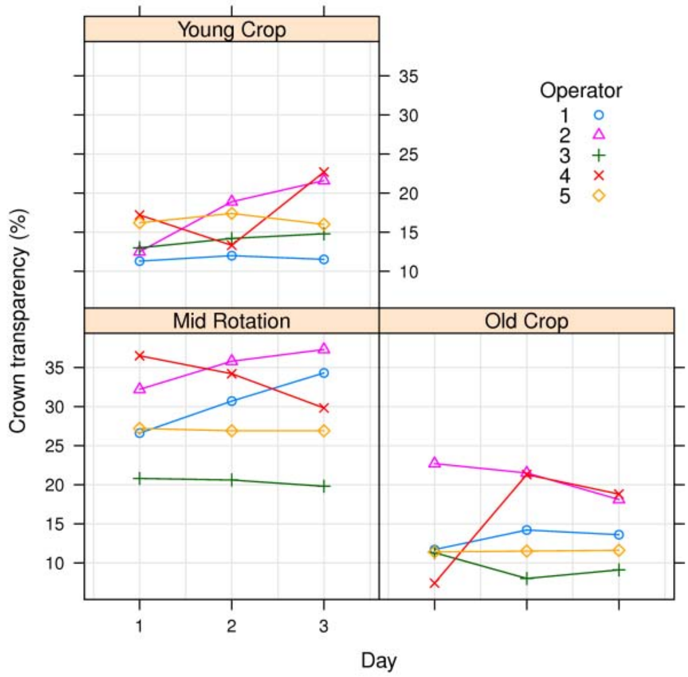


Figure 4. Crown-transparency assessment differences between operators

The difference between days was small and statistically not significant. There are obvious systematic differences between operators; for example operator 2 consistently provides values that are above-average. Total variation was partitioned between day, operator and site using a random-effects model.

[3] It is expected that the assessors involved in the national measurement regime would have more practical training than the assessors used in this survey.

Table 3. Sources of operator variation

| Source of variation | Variance (%$CT^2$) | Standard deviation (% CT) |
|---|---|---|
| Site | 69.5 | 8.3 |
| Operator | 13.5 | 3.7 |
| Day | 0.14 | 0.4 |
| Residual | 12.5 | 3.5 |

The difference between operators is high and needs to be mitigated by sampling design or procedure improvements (e.g. comprehensive training[4]). For example, if a single operator is used in one year and a different operator used in another year then (assuming a normal distribution), the data suggests there is a 33% probability[5] of observing a difference of more than 3.7% in crown transparency between years even if the trees themselves have not changed.

The extent to which the between-operator variation can be reduced by training remains to be seen though one would expect a reduction, the extent to which cannot be assumed in the absence of reliable data. It is important to note that the data in this analysis did not allow for the isolation of an operator by time interaction, "operator drift", from other sources of variation.

#### ***5.3.2 Variation Observed in CNI Plots Measured During 2002 and 2003***

Crown transparency data was collected from 39 plots in central North Island forests (mainly Kaingaroa) during 2002 and 2003. All plots were measured by the same operator, with plot size ranging from between nine and 60 trees and an age range of between one and 27 years after establishment. The plots used in the following analysis were selected from a larger data-set and included only those plots that had two measurements with at least 200 days apart. A mixed model was used to partition variation in crown transparency of the upper 50% of the crown. The model formula is as follows:

$$c_{ijk} = y_k + age_{ik} + age_{ik}^2 + p_i + t_{ij} + py_{ik} + \varepsilon_{ijk}$$

Where:
$i =$ plot number
$j =$ tree number within plot
$k =$ year (2002 or 2003)
$c_{ijk} =$ crown transparency of tree j in plot i in year k
$y_k =$ fixed effect of year k
$age_{ik}, age_{ik}^2 =$ fixed effects of the age in plot i in year k
$p_i =$ random effect of plot i and has variance $V_p$
$t_{ij} =$ random effect of tree j in plot i and has variance $V_t$
$py_{ik} =$ random effect of plot i in year k and has variance $V_{py}$
$\varepsilon_{ijk} =$ residual error with variance $V_e$

This model is equivalent to the model reported in Bulman and Kimberley (2005) with the addition of fixed age effects. Sources of variation are reported in Table 4.

[4] Bearing in mind that the data used in this analysis was based on novice operators with only brief training.
[5] Outside of one standard deviation from the sample mean.



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Table 4. Sources of plot measurement variation

| Source of variation | Code | Variance (%CT$^2$) | Standard deviation (% CT) |
|---|---|---|---|
| Tree | $V_t$ | 107.5 | 10.4 |
| Plot : Year | $V_{py}$ | 26.1 | 5.1 |
| Plot | $V_p$ | 14.4 | 3.8 |
| Residual | $V_e$ | 48.6 | 7.0 |

The between-plot variation is lower than reported by Bulman and Kimberley (2005). This is partly due to the absorption of some of this variation into an age effect. The variation in $V_p$ is additional to the variation explained by age. A model explaining the age effect was re-estimated independently using a slightly larger data set having a wider range of ages and including plots for which repeat measures were missing. Age and crown transparency were averaged across multiple measurements to provide one datum per plot. Crown transparency is predicted as:

$$ct = \frac{44.1\ age}{15.4 + age}$$

Predicted crown transparency is shown in Figure 5 with the plot data used to estimate parameter values.

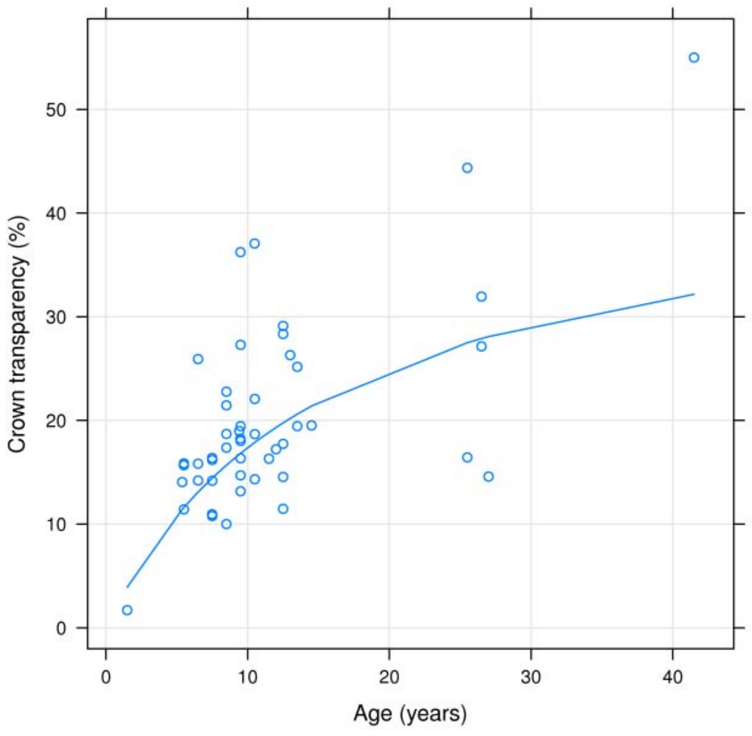


Figure 5. Effect of age on crown transparency. Each datum is one plot.

Figure 6 shows the national *P. Radiata* age class distribution up to age 30 from the 2009 National Exotic Forest Description (NEFD) (MAF, 2009). The expected result of the interaction between Figure 5 and Figure 6 is that the national average crown transparency will initially rise, before falling again, following the national average plantation age.

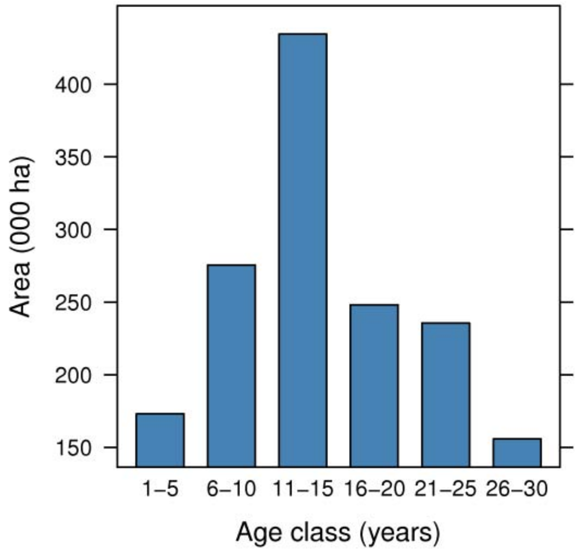


Figure 6. *P. radiata* age class distribution in NZ (as at 2009)

#### *5.3.3 Variation Observed in Monthly Measurements over an 18 Month Period*

The data given in Figure 1 of Bulman (2008) was used to estimate correlation between measurements of the same trees on a month-to-month basis. The data represents measurements of 25 tree plots. Four sites were assessed (with two plots at each site) on a monthly basis by the same operator (assessor). The raw data was not available and analysis was based on site-level averages at each measurement time, as shown in Figure 7. The dark line is the average of all plots.

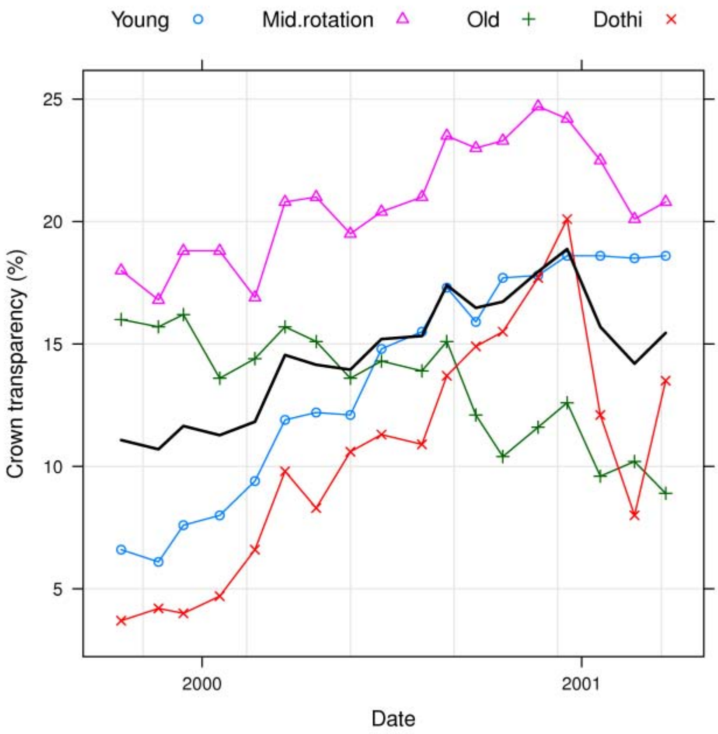


Figure 7. Successive monthly measurements over an 18 month period

The data set was analysed using site as a random effect and an auto-regressive correlation structure with common correlation coefficient (but independent time-series) at each site. The result was an estimated correlation between successive monthly measurements of 0.947 indicating a low variability between assessment made by the same assessor on a monthly basis. This translates to a correlation between annual measurements of ($0.947^{12}$) or 0.52.

There was insufficient data to extract an annual seasonal effect, however, Figure 7 suggests that the annual seasonal effect, if any, explains only a small proportion of the total variation; values in the same month in successive years are not strongly correlated. In the modelling that follows in this report, the seasonal effect is ignored and the correlation between measurements of the same plot one year apart is assumed to be 0.5 or 50%.

## 5.4 Recommendations and Rationale

### *5.4.1 Summary of Recommendations*

The following list summarises recommendations for a sampling strategy to monitor crown condition characteristics at a national level:

1. Assess 24 trees per plot for crown characteristics. It is desirable, but not essential, that the same number of trees are assessed in each plot;
2. Use approximately 100 plots established on a grid with random origin covering the target population;
3. Measure each plot annually. It is expected that at least 10 years of measurement would be required before long term trends became identifiable;
4. Use at least three measurement operators and record the operator against each measurement;

5. Repeat a minimum of 18 plot measurements using a blind re-measurement by the same or another operator; and
6. Re-measure for 3 years at this level of intensity and review the number of plots, operators and timing between measurements.

### *5.4.2 Rationale*

**Trees per plot**

Using the notation of Table 4, the variance of the year-to-year assessments in a single plot can be calculated as:

$$\left(V_{py} + \frac{V_e}{n}\right)$$

where n is the number of trees in each plot. As long as there are "enough" trees, the variance is dominated by $V_{py}$ and adding more trees does not reduce it further. From Table 4, 24 trees would be "enough" $(26.1 + \frac{48.6}{24} = 28.1 \approx 26.1)$. Adding more trees has a diminishing return e.g. with 50 trees the variance reduces to $(26.1 + \frac{48.6}{50} = 27.1)$, which has is not substantially less. On the other hand, with 10 trees the variance increases to 31.

The application of twenty four trees is thus viewed as an optimum plot size because:

a) It is in the right range of measurement techniques employed around the world;
b) It is consistent with ICP Forests methods; and
c) It assumes that the marginal cost of extra trees once the plot has been reached will not make a smaller number more desirable.

**Number of plots and years of measurement**

Part of the variation that results from year-to-year measurements can be controlled by establishing more plots. The other portion of annual variation cannot be controlled by increasing plot numbers, and is generally due to such factors as changing national weather patterns, changing population age and changing assessment behaviour. The second kind of variation must be understood by measuring for more years to gain an understanding the magnitude of these external influences. Once the second kind of variation (independent of plot numbers) dominates the total between-year variation then there is no point in measuring more plots.

From Table 4, a reasonable estimate can be determined of how much of the first kind of variation (plot-number dependent variation) can be expected. In this instance, this value ($V_{PY}$) is 26.1. On the other hand however, it is not possible to obtain a reasonable estimate of the plot number independent variation. As such, the approach adopted relies on an estimation of the effect that different levels of between-year variation would have on our ability to detect long-term trends; from this a judgement call on an appropriate number of plots (given the predetermined precision targets) can be made.

The ability to detect long-term trends can be simulated by generating time-series data with variance characteristics from Table 4, and then analysing that data for a long-term trend. Figure 8 shows the distribution of the magnitude of the long-term trend estimated from a number of simulations with different numbers of plots, from 40 to 320, and different years of measurement, from six to 24. For example, the bottom-left panel in Figure 8 shows the results from 200 simulations with 40 plots and six years of measurement. It shows a range of estimated long-term trend values from -1.0 to +0.5 % per year and a slight downward bias in the average trend. The distribution shows a standard error



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for the estimate of the long-term trend of 0.26% per year. About half of the simulations in this panel produce statistically significant trends ($\alpha = 0.05$). This outcome would be insufficiently precise if the target trend is 0.4% per year. Using 320 plots instead of 40 tightens the distribution (sd=0.083) but not as much as extending the length of the series to 24 years (sd=0.049).

There is no long-term trend in forest health in any of the simulations in Figure 8. The only things that are changing are the random variation within plots from year-to-year and the change in age of the plots. Plots were started with an initial age selected randomly from a distribution emulating the current *P. radiata* age class distribution (Figure 6), increased in age at one year per year and returned to age 0 upon reaching 30. The crown transparency increased with age using the curve shown in Figure 5. The New Zealand age-class distribution is not normal which means that the average age increases initially then drops. The average crown transparency does the same and the interaction between age and time is imperfectly separated during analysis resulting in an apparent trend, after adjusting for age, when no trend exists, particularly for short time series. This happens even though age is included as a covariate in the analysis and is part of the reason that a long time series is beneficial.

The method of analysis was to use a linear mixed model with time, age and age as fixed covariates, plot as a random level and an auto-regressive correlation structure within plot.

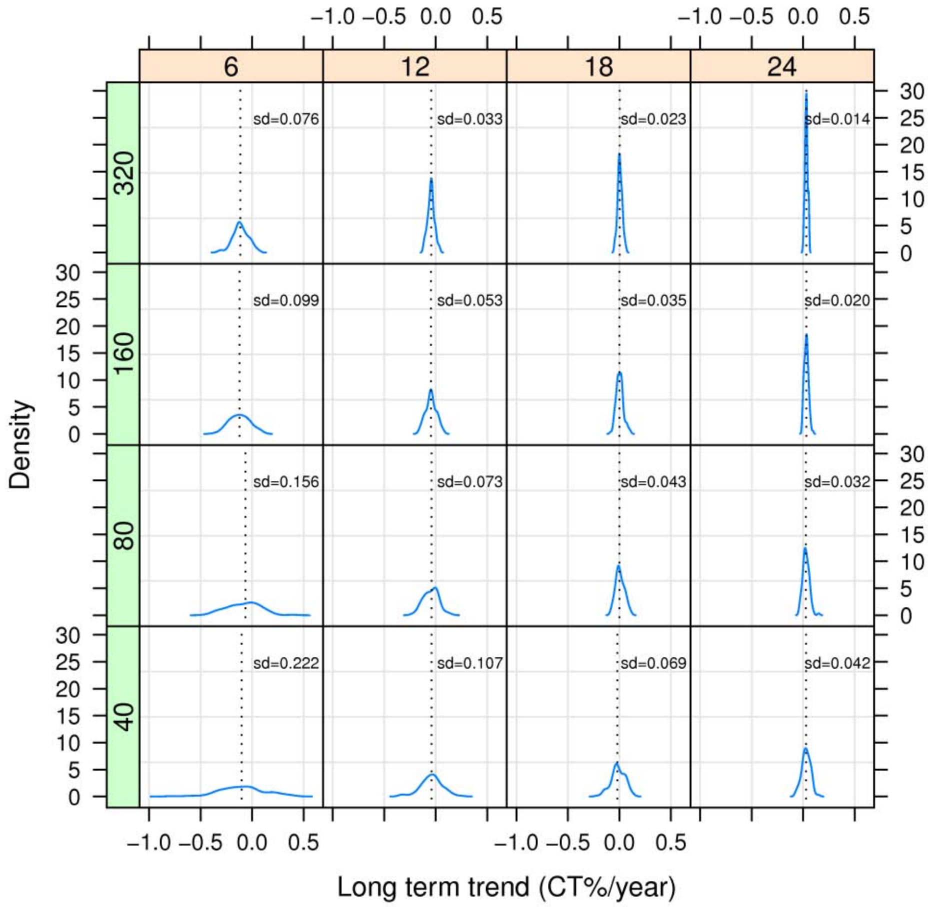


Figure 8. Effect of measurement length and plot count on estimated long-term trends : Vy = 0

Figure 8 optimistically shows what happens if there is no source of “uncontrollable” between-year variation other than changing age. The variance in the national average crown transparency from year-to-year ($V_y$) is zero.

Figure 9 shows what happens if $V_y$ is increased to 1.0 with between-year correlation of 0.5. This is equivalent to the national average varying from year-to-year with a standard deviation of 1% in crown transparency terms; this is 20% ± 1%, not 20% ± 0.2%. This modest increase in variation largely removes the benefit of having extra plots but not the benefit of having extra years of measurement.

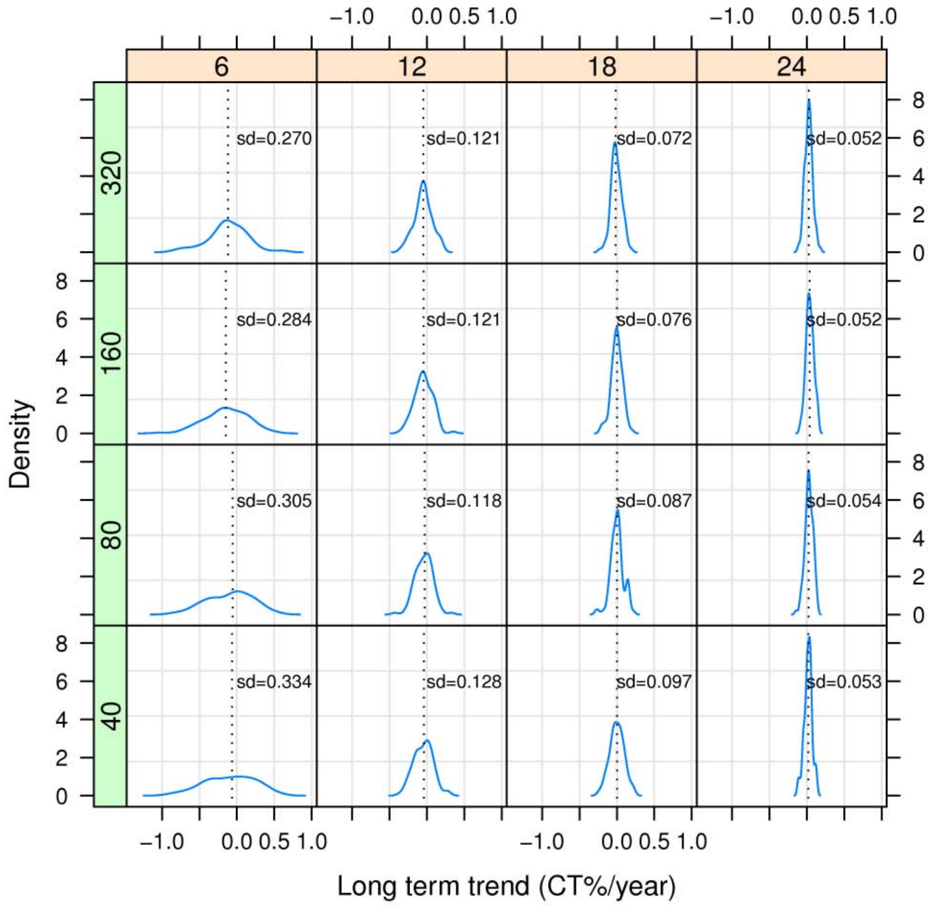


Figure 9. Effect of measurement length and plot count on estimated long-term trends : Vy = 1

In Figure 10 the year-to-year variation has been increased to 3% with the benefits of years over plots highlighted further.

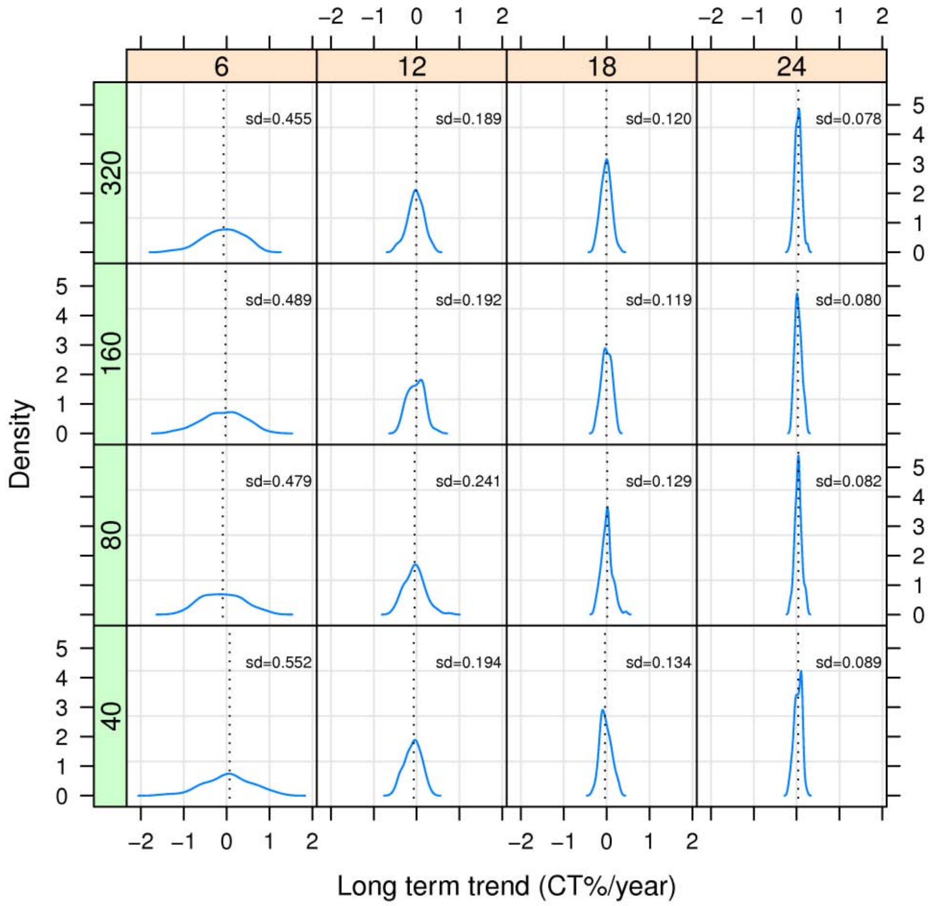


Figure 10. Effect of measurement length and plot count on estimated long-term trends : Vy = 3

What are the chances of experiencing year-to-year variance of 1.0 from sources that can't be controlled by adding more plots? By way of example, if 5 operators are used to measure all the plots in a year and the operators are replaced every year then the operator contribution to between-year variance is $\frac{13.5}{5} = 2.7$ (see Table 3). This can be reduced by training, experience and reducing turnover but not eliminated.

The between-year variation in the data used to provide Table 4 was 0.3 when expressed as a variance. This is based on a very small sample of 2 years and a small number of plots and was not significantly different to 0.0 but it does indicate that the between-year variation should not be completely ignored.

Thus, the rationale for recommending 100 plots was:

- First and foremost, keeping the annual cost down increases the likelihood that the monitoring system will last enough years to be useful (> 10 years);
- it is far more important to reduce between-year operator variation and between-operator variation, or at least to understand them by repeat measurements, than to measure more plots;

- A number lower than 100 was considered risk given that the estimate of $V_{py}$ in Table 4 is a regional estimate based on limited data and could be larger at a national level;

The number of plots can be reviewed and changed with the benefit of hindsight after three years of measurement. With three years measurement, a better understanding of the variance may be obtained which is likely to lead to a more precise plot number target given the target levels of measurement precision.

### *5.4.3 Number of operators and repeat measurements*

Between-operator variation (from year-to-year) and between-year variation for the same operator are likely to be significant contributors to total between-year variation. Using more operators reduces the total variation. Re-measuring the same plots more than once with different operators helps to quantify this variation. The recommendation of 18 repeated measurements is based on three operators and six plots, or three replicates of six pairs of operators. Finalisation of this aspect of the survey must include consideration of logistics. Repeating measurements of the same plot has the added benefit of identifying those measures that are more or less objective, reproducible and hence desirable. Recording the operator against each plot assessment in a formal way is necessary for inclusion of the operator effect during analysis.

## 5.5 Soil Plots

Duffill Watts Consulting Group (2005) calculated that 120 soil plots should be installed and measured three times in a rotation. In their report, there was only a limited description of the method used to calculate the plot numbers, and as such, these numbers could not be verified by Interpine. It was recommended that the soil samples be taken at three to four years post planting, at 13 to 15 years or before pre commercial thin and just before harvesting.

Using the New Zealand planted forest area age class distribution over the course of the next 25 years, the percentage of soils plots that would need to be measured each year ranges from 8% to 14%. This calculation assumes:

- Soil samples are taken at ages 4, 15 and 28 years; and
- No new afforestation or deforestation in the New Zealand forest estate.

## 5.6 Timing of Assessment

FCM measurement is normally carried out during the summer months. To produce high quality assessment of forest condition it is recommended that in New Zealand it is also performed in summer months, as discussed in the following:

- Crown transparency is more difficult to assess in poor weather conditions such as rain and fog. The ideal conditions for assessment are clear blue sky with bright sun light – days of this nature are more likely to occur in summer months;
- The symptoms of a number of diseases such as *Dothistroma* and *Cylaneusma* are only apparent during the spring and summer months; and
- Resin bleeding is very difficult to assess in wet conditions.

As the qualitative visual assessment of crown transparency requires the assessor to assess the transparency of the crown against the sky, it is important that that sky has similar characteristic for each assessment through time. To reduce seasonal variability between annual measurements it would be beneficial for each tree to be measured at the same time of the year, at the same time of day and under similar weather conditions.

Although summer measurement for FCM measurements is desirable, this would conflict with the standard re-measurement of New Zealand's forest growth monitoring plots which is normally undertaken during the dormant growth season (winter). The fast growth of New Zealand plantation species limits the growth plot measurement season to the months between May and August. At this time the assessment of growth is the key of objective of permanent plot re-measurement and it is highly unlikely that the current measurement programme would be moved to summer to better facilitate condition monitoring.

If forest growth and condition are to be measured on the same plot it would clearly be more cost effective to do both assessment at the same time, and thus, growth measurements take precedent in terms of timing. When measuring crown transparency in winter however, it is important that field measurement takes place on either side of annual needle cast (when the oldest needles are naturally discarded), and that this chosen period is maintained throughout time.

## 5.7 Potential Plot Networks

The major goal of implementing an FCM programme in New Zealand would be to monitor forest condition (health) over time. To achieve the goal of a cost-effective inventory that is both statistically significant and representative of an individual stand of trees to national forest resources assessment, the sampling method of choice is usually some type of randomly allocated grid based systematic sample.

In accordance with sound sampling practice, plots should be sited within the target population in such a way that any point in the population has a known and equal probability of being sampled. Either random locations or a grid with random origin would be suitable. There should be no objection to using an existing set of plots provided that they represent an equal-probability selection from the target population and have been suitably randomised. In accordance with this sampling strategy, the LUCAS plot grid might be suitable.

### *5.7.1 LUCAS Plot Network*

The New Zealand Government, under the Land Use and Carbon Analysis System (LUCAS) program (managed by the Ministry for the Environment), has set up a national grid-based network of plots to provide an unbiased estimate of carbon stored in New Zealand's planted forests. As part of the LUCAS program, a comprehensive set of up-to-date maps of New Zealand's plantation forest estate and recent aerial photography have been used to determine whether sample points on the LUCAS grid that fall on an area of planted forest. Currently, the LUCAS planted forest is divided into pre-1990 forests and post-1989 forests with the plots being located on an eight and four kilometre grids respectively. Figure 11 shows the grid design of the LUCAS network.



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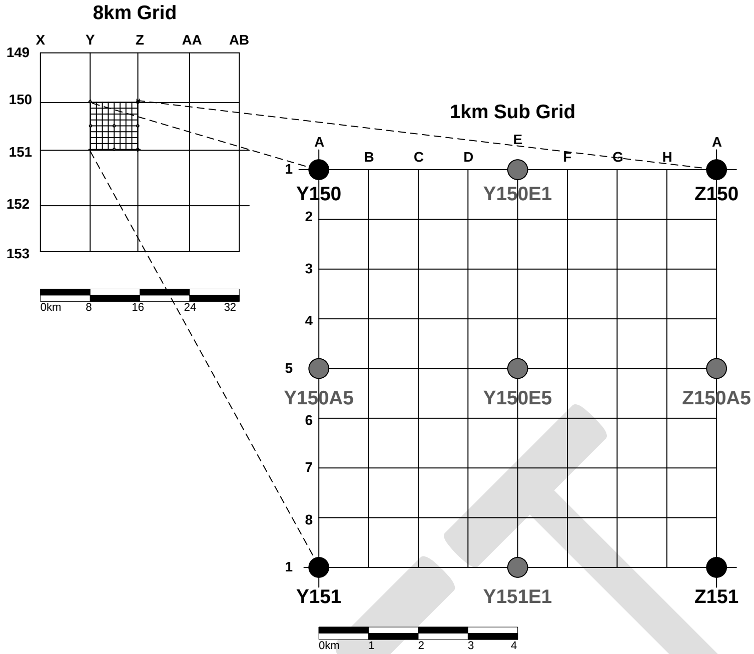


Figure 11. An extract from the LUCAS grid network showing potential pre-1990 forest 8km points (Y150, Z150, Y151), potential post-1989 forest 4 km points (Y150, Y150E1, Z150A5) and the 1 km sub-grid.

The bottom left hand corner of the LUCAS grid was randomly located off the southwest coast of New Zealand. The original sampling design for the LUCAS program was adapted from the United States National Forest Inventory design (Betchold et al 2005) which is used to monitor the condition forests in the US (Betchold et al 2005).

The plot size of each LUCAS plot is 0.06 hectares (not considering the effects of ground slope). The only evidence of the plot location is a steel rod hammered into the ground marked at a precise location as determined by high-grade GPS coordinates. Figure 12 shows the location of all the LUCAS planted forest plots that will have been measured at least once by the end of 2010.

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Figure 12. The planted forests plots on the LUCAS grid plots network

Nearly all of these plots would be available for a nation FCM programme in New Zealand. In total there will be 523 LUCAS planted forest plots installed by the end of the 2010 measurement season, of which 302 plots will be located on the eight kilometre grid (both pre-1990 and post-1989 forests) and a further 221 of the plots of specifically post-1989 forests located on the four kilometre grid[6]. If the plots on the LUCAS 16 km grid are used, the number of plots is 59. To identify an appropriate LUCAS network for FCM measurement, Interpine has develop Table 5 which gives the number of the established LUCAS planted forest plots on the LUCAS 8 km, 16 km, 8 by 16 km and 16 by 8 km grid (by region).

Table 5. Number of the 8 km Grid Plot by Region (based on the New Zealand regional council boundaries)

| Region | Number of Plots (8 km grid) | Number of Plots (16 km grid) | Number of Plots (16 * 8 km grid) | Number of Plots (8 * 16 km grid) |
|---|---|---|---|---|
| Northland | 22 | 6 | 12 | 9 |
| Auckland | 8 | 2 | 5 | 3 |
| Waikato | 57 | 13 | 29 | 28 |
| Bay of Plenty | 50 | 1 | 2 | 30 |
| Gisborne | 26 | 0 | 0 | 17 |
| Hawke's Bay | 21 | 0 | 0 | 11 |
| Taranaki | 5 | 1 | 2 | 3 |
| Manawatu-Wanganui | 19 | 8 | 10 | 15 |
| Wellington | 16 | 7 | 11 | 10 |
| Marlborough | 11 | 5 | 6 | 6 |
| Tasman | 19 | 4 | 8 | 8 |
| Nelson | 1 | 0 | 0 | 0 |
| Canterbury | 15 | 6 | 8 | 7 |
| West Coast | 7 | 2 | 4 | 3 |
| Otago | 16 | 3 | 5 | 7 |
| Southland | 9 | 1 | 4 | 4 |
| Total | 302 | 59 | 106 | 161 |

[6] A higher intensity sample was applied to the Post-1989 forest due to the UNFCCC reporting requirements of change in carbon inventory from 01 January 1990 onwards.

Overall the LUCAS plot network is ideal for a national FCM programme as it can be used to give an unbiased estimate of the change in forest condition at a national level, so long as the eight kilometre grid network is used. Inclusion of the 221 post-1989 plots across the four kilometre network will result in a bias toward recently established (post-1989) forest. Table 6 outlines the pros and cons of using the LUCAS plot for a national forest condition monitoring program.

Table 6. Pros and Cons of using the LUCAS Plot Network for a Nation New Zealand FCM Programme

| **Advantages of using LUCAS Plots** |
|---|
| The plots have been located in accordance to a statistically robust sampling design which allows national level estimates to be obtained. |
| The New Zealand Government, through the LUCAS program, is committed to installing the LUCAS plot network throughout New Zealand and carrying out at least two field measurements. |
| Each LUCAS plot has the following data associated with it:<br>- High resolution aerial photos<br>- High intensity airborne LiDAR |
| There are well tested and established measurement methodologies which, to-date, have been consistently followed. |
| The physical location of every plot in the network has been determined using high grade GPS to 0.5 meters of its theoretical position. |
| A large amount of plot meta data, tree (both crop and non crop) and soil data is collected on each on the plots. This data includes detailed instructions on the location of the plots, bearing and distance to each crop tree, standard PSP tree measurements and carbon and nitrogen values from the top five cm of the soil profile. |
| **Disadvantages of using LUCAS Plots** |
| The first of these plots were measured in the winter of 2008. This means there is very limited historical growth and health information on the plots. Although the collection of historical forest management information is part of the current LUCAS data collection, this data is only as good as the knowledge of the land manager. |
| The LUCAS plots are installed as unmarked plots making it difficult to find them without precise GPS coordinates. |
| Plot measurement techniques are non-destructive in that they try to preserve as much of the woody biomass as possible – including non crop biomass. In some instances, the lower canopy may need to crushed down to obtain an unhindered view of the upper crown. |
| There is a higher intensity sample of the post-1989 forest meaning that only the eight kilometer grid plots should be used. |
| Post-1989 and pre-1990 forests are measured in alternate years |
| The Government funded LUCAS measurement must occur during the dormant growth periods which is not the ideal measurement period for FCM. |

### *5.7.2 Permanent Sample Plot (PSP) Network*

In 2005 there were 13,255 plots stored in the SCION PSP database which were considered to be active. A further 14,012 plots have been either abandoned or harvested. Of the 13,255 active plots, approximately 55% are contained within some form of experimental trial and are therefore not representative of the surrounding stand.

PSPs tend to have a minimum area of 0.04 hectares; the size of plot is designed to include a minimum of 20-25 trees for the life of the plot. Without exception, all PSPs must be measured during the dormant growing months. For most of the country this period usually occurs between May and August, however in regions where the dormant growth period is short (e.g. Northland region), plot measurement should be scheduled for the same month of the year. In general, re-measurement for stands aged 0-10 years occurs annually, for stands aged 11-16 it is every two years, and every three years for stands older than 16 years.

Table 7 shows the distribution of the PSPs around New Zealand. It is clear that the distribution throughout the country is not representative of the forest area, for example the Gisborne and Southland region have only 59 PSP and 100 PSP respectively compared to Canterbury which has 229 plots.

Table 7. Distribution of validation plots by region and land use prior to establishment. Only PSPs in stands planted from 1960 are included.

| Region | Total | Farm | Forest | Sand |
|---|---|---|---|---|
| Northland | 566 | 183 | 124 | 259 |
| Auckland | 238 | 12 | 74 | 152 |
| Waikato | 492 | 144 | 304 | 44 |
| Bay of Plenty | 1851 | 184 | 1667 | 0 |
| Gisborne | 59 | 56 | 3 | 0 |
| Hawkes Bay | 417 | 426 | 131 | 2 |
| Taranaki | 7 | 6 | 0 | 1 |
| Wanganui/Manawatu | 219 | 31 | 17 | 171 |
| Wellington | 60 | 6 | 54 | 0 |
| Nelson | 326 | 10 | 316 | 0 |
| Marlborough | 185 | 66 | 119 | 0 |
| West Coast | 91 | 1 | 96 | 0 |
| Canterbury | 229 | 40 | 189 | 0 |
| Otago | 243 | 135 | 108 | 0 |
| Southland | 100 | 57 | 43 | 0 |
| Total | 5089 | 1217 | 3245 | 629 |

Table 8 outlines the pros and cons of using the PSP plot network for a national FCM programme. Although PSPs could be measured for growth and forest condition, the PSP plot network is not considered suitable for a national or regional FCM programme in the context of NZFOA's objectives. The risk of giving a biased estimate of the forest condition is high due to the lack of statistical robust methodology for the location plots within the PSP network.

Table 8. Pros and Cons of using PSP Plot Network for the Forest Condition Monitoring Programme

| **Advantages of using PSP Plots** |
|---|
| There are over 13,000 PSPs regularly measured in New Zealand. |
| New Zealand has a long history of PSP measurement. |
| The PSP are largely maintained by the New Zealand forest owners. |
| **Disadvantages of using PSP Plots** |
| In most cases there has been no statistical robust sampling strategy employed to locate the plots. |
| PSPs are generally used to monitor growth and build growth models. As such, they are located using the following rules:<br>a) Plot edge must be at least 15 meters from the stand edge or an open area.<br>b) Avoid old skid sites or internal logging tracks<br>c) Avoid gaps and wind-thrown areas.<br>d) Avoid exposed ridges and places where height measurement is difficult.<br>This means that collectively they cannot be used to report on a forest parameter at a national or regional level. |
| They are often included in some sort of the silvicultural trial |
| The ongoing measurement programme of many of these plots is largely dependent on the research program of SCION. |
| The PSP plots tend to be clustered in forestry estates owned / managed by companies with a more rigorous PSP measurement approach. |

The use of existing permanent sample plots for a national monitoring system is strongly discouraged because, in general, they fail to meet the criteria of equal probability and randomisation across New Zealand's estate. The problem with failure to randomly select plots with equal probability from a known population is that any trend in forest health that might ultimately be observed in 10-20 years time will only be attributable to the plots that were actually observed and not the wider population. This would be a highly undesirable outcome. Nonetheless, if the population being measured was bound to a specific estate (say, a large forestry company), and the manager of the estate had implemented a representative randomly allocated network of PSP plots, then (depending of the specifics of the plot allocation) theoretically PSP plots could be useful for FCM monitoring.

### *5.7.3 New Plot Network*

Setting up an entirely new plot network solely for a forest condition monitoring programme is a viable option. This would allow flexibility on the exact design of the plot layout and implementation. Internationally it appears that the majority of FCM programmes are installed on some type of systematic grid network, and overwhelmingly, on one, four, eight and 16 km grid networks.

Because of the sampling design required and the high cost of crew measurement activity, there is a significant cost for setting up a new plot network particularly if its sole objective is to provide information for an FCM programme. Consequently, it is highly advisable that any FCM programme be set up alongside another measurement programme where funding can be shared; the LUCAS plot network already established by the New Zealand Government provides an excellent framework for sampling.

## 5.8 Plot Design

There are a numerous plot layouts used around the world for FCM plots. In many European plot networks, four clusters of six trees are measured for each plot. These clusters are located 25m away from a survey plot centre along four cardinal points (Figure 13 a). The area of each tree cluster is known as the bearing and distance to the most remote tree in each cluster is recorded allowing per-hectare stand level statistics. The LUCAS measurement grid would allow four plot clusters to be based around the central point of the LUCAS main plot. This is a crucial consideration given LUCAS plot trees cannot be marked with paint or by other means, yet tree marking is a necessary part of FCM monitoring especially for auditing and understanding between-observer variation. Clustering trees away from the LUCAS plots would also allow for the removal of non-crop species so that a clear view of a plot tree may be obtained[7].

Tree condition is also measured in circular fixed boundary plots such as the four fixed area circular plots shown in Figure 13 (b). In New Zealand there is a desire to link FCM data to growth data and so it may be beneficial if both measures are recorded for the same trees. This would be possible with the bounded circular plots that are widely implemented in New Zealand's inventory programmes.

The LUCAS system uses bounded circular plots currently consisting of a 0.06ha central plot with three 0.04ha satellite plots. It is likely however that the satellite plots will be discontinued in future measurements. Assessment of all trees in the central plot is intended to provide around 30 crop trees in most cases, which will provide sufficient data for FCM analysis (see recommendations 5.4.1). However, the use of the bounded LUCAS plots also has disadvantages (discussed previously)

A consideration of the advantages and disadvantages of each approach is given in Table 9.

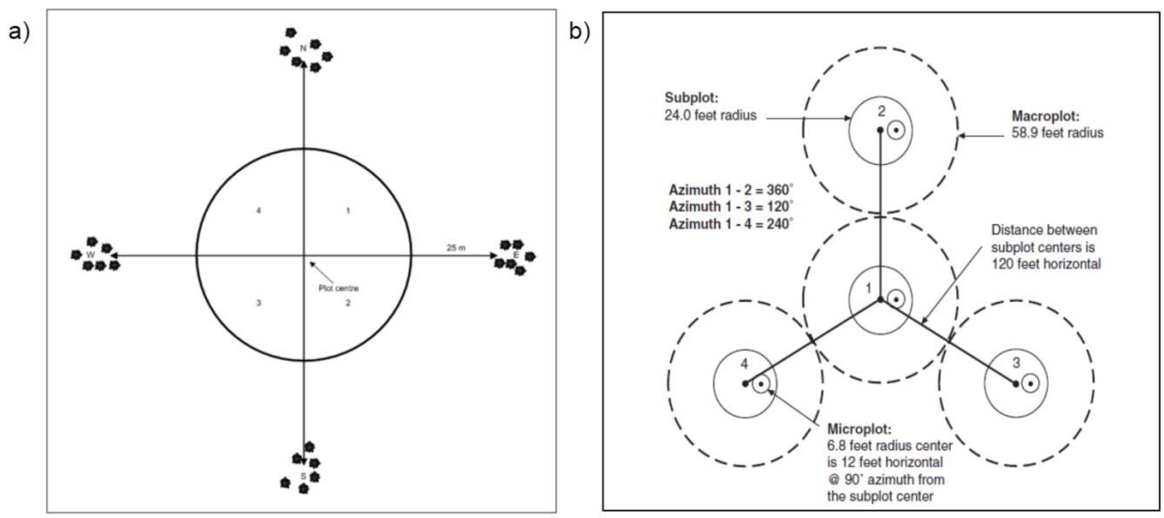


Figure 13. Examples of the cluster (a) and fixed boundary (b) FCM survey plots

[7] Because of the woody biomass measurement objective of LUCAS plots (for the purposes of carbon accounting), the integrity of all live woody material is preserved.

Table 9. The advantages and disadvantages of using fixed boundary versus and point cluster plots.

| Fixed Boundary | | Cluster | |
|---|---|---|---|
| ***Advantages*** | ***Disadvantages*** | ***Advantages*** | ***Disadvantages*** |
| Plot type already in place in LUCAS plots | Higher measurement error | Less measurement error | Significant changes to data capture and database |
| Methodology familiar to crews | Different number of trees each time | Same number of trees in each plot should lead to simpler analysis | Growth not measured on the same trees as condition assessment |
| Growth and condition can be measured on the same trees | Trees cannot be marked in the LUCAS plots | Outside of LUCAS so can be marked | |
| Data management will be easier | Vegetation must not be altered | Vegetation can be cleared if necessary | |
| | | Concurrent with many ICP forest protocol | |

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Provided that the trees at a plot location are sampled with equal (or known) probability, then plot shape and layout becomes largely a matter of practicality and data use. For example, if there is an intention to collect growth information in the same plot then the plots should be bounded because the use of unbounded plots to collect growth data creates issues with interpretation of the growth data.

## 5.9 Quality Assurance

Data quality is of enormous importance and should compliment a comprehensive training in any FCM program. In the early years of the British FCM survey, poor training led to biased or misleading data (Innes et al. 1986). Despite improvements in data collection techniques which eliminated bias in subsequent studies, the early errors have made it extremely difficult to recognise trends in the dataset even after an extended period of data collection (Hendry et. al 2004). This emphasises the importance of ensuring that proper training and data quality control are in place from the start of the survey period.

To prevent data quality problems it is vital that clear standardised definitions and field manuals are produced along with extensive training of field crews. Field audits are an extension of training and should be conducted by trained assessors soon after measurement commencement and extend throughout the measurement period. A short report should be produced by the auditor detailing any problems found with methodological feedback and improvement suggestions.

Audits should be complimented by blind re-measurement. Re-measurement should be made without access to the original data and without knowledge of which plots will be re-measured. Production and audit datasets can then be compared to produce a measure of precision and to check compliance with data quality objectives. Section 3.4.3 contains information on the appropriate amount of blind re-measurement necessary.

Data validation should ensure that all datasets are complete and that recorded data is within the accepted ranges and logically consistent. All data validation should be carried out in the electronic data capture system used during measurement.

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# 6 COSTING ANALYSIS[8]

To run a measurement programme such as the one discussed in this report the following cost components need to be considered when developing a budget:

- Training;
- Plot Measurement (including plot establishment);
- Third Party Auditing;
- Data Management and Hosting;
- Reporting; and
- Project Management.

Please note that the estimated productivity rates and measurement costs discussed in this paper, although based on Interpine's extensive experience in forestry inventory, are indicative only and for the purpose of high level budgeting.

## 6.1 TRAINING

Annual training and calibration of field assessors is widely regarded as an extremely important exercise for reducing "between-assessor" variability. Consequently, at least one week of training is recommended for each assessor(Bulman L. S., 2008). Interpine estimates that a programme of 106 plots would need at least three to five crews to be able to measure plots in a timely manner. Based on a crew training day rate of $900 (per crew) and a daily charge out rate of $1,500 for each trainer, a five day course would cost approximately $37,500[9].

## 6.2 TREE MEASUREMENT COST (INCLUDING PLOT ESTABLISHMENT)

Productivity figures published by Bulman (2008) state that on average it takes 9.8 minutes per plot to assess and record all variables for one plot of 25 young trees. Mid rotation stands take 11.3 minutes per plot and final-crop stands only took 9.2 minutes per plot. This time study was carried out on only one assessor but over a period of two years of monthly measurements. In Bulman (2008) all variables include: crown transparency, shoot dieback, general health, colour, stem visibility, resin bleeding, *Dothistroma*, *Cyclaneusma*, yellowing and crown depth. This compares to 8.0 minutes per tree taken in the British FCM systems to assess 28 different forest condition variables.

The plot measurement productivity estimates given in Table 10 are based on Interpine's extensive experience in forest inventory. These plot-per-day estimates are for standard growth plots where, on average, about 20 trees are measured for diameters with a subset of 12 trees being measured for height and quality.

Based on numbers published by Bulman (2008), the inclusion of FCM measurement is unlikely to substantially impact the average daily productivity figures estimated presented in Table 10. For planning purposes however it would be wise to assume that the plot rate would reduce by between 0.5-1 plot per day. If FCM measurements were the only variables being measured at each plot, these averages would like increase by 1-2 plots per day.

[8] All costs and figures presented in New Zealand dollars.
[9] These figures are estimated from average rates charged at the time of writing this report.

Table 10. Plot Measurement Productivity Estimates

| Measurement Type | Description | Mean Productivity | Likely Range of Productivity |
|---|---|---|---|
| Establishment and first measurement | Establishment:<br>Locate, permanently mark centre point (wooden peg, and buried metal rod), identify and tag trees within the plot, record GPS position.<br><br>Data collection:<br>All diameters (average 20 trees/plot), 12 heights of live trees with intact tops (or all trees if less than 12), heights of all trees with broken tops, and designation of standing trees as live or dead. Date and details of thinning or harvesting operations since the last inventory date, and details of any planned thinning or harvesting operations between the inventory date and the end of the current compliance period. Thinning and harvest details to include the tag numbers of trees removed for past thinnings/harvest. For anticipated future thinning or harvest, the date, thinning type, and post-thinning stocking anticipated.<br><br>Data may be collected either on paper, or on a handheld computer. | 2 plots per day[1]<br><br>3 plots per day[2]<br><br>5 plots per day[3] | 1-3 plots per day[1]<br><br>2-4 plots per day[2]<br><br>4-6 plots per day[3] |
| Subsequent measurements | Check and replace tags as required.<br>As for data collection at establishment. | 3 plots per day[1]<br><br>6 Plots per day[2]<br><br>7 Plots per day[3] | 2-4 Plots per day[1]<br><br>4-7 Plots per day[2]<br><br>6-9 Plots per day[3] |
| Assumptions | [1] *based assumption of vehicle travel required between plots, e.g. growth and health LUCAS plots on the 8 km grid*<br>[2] *based assumption of vehicle travel required between plots, e.g. growth and health PSP's geographically spread throughout an estate*<br>[3] *based on plots within walking distance e.g. trial / study zone PSP's* | | |

The day rate for inventory crews depends on a number of factors including the location of the plot, amount of auxiliary information collected and the skill level required. At the time of writing, the day rate for data collection ranges between $800 and $1,400. These rates include two crew members, a 4WD vehicle, handheld data capture computer, and GPS unit. A limited amount of project management and internal audit is also included in these rates. The measurement costs given in Table 11 and Table 12 assume that both growth and forest condition are measured on each plot.

Table 11. The cost to measure 302 plots (based on the LUCAS 8 km grid).

| Cost/day | 2 plots/day | 3 plots/day | 4 plots/day | 5 plots/day | 6 plots/day |
|---|---|---|---|---|---|
| $800 | $ 120,800 | $ 80,533 | $ 60,400 | $ 48,320 | $ 40,267 |
| $1000 | $ 151,000 | $ 100,667 | $ 75,500 | $ 60,400 | $ 50,333 |
| $1200 | $ 181,200 | $ 120,800 | $ 90,600 | $ 72,480 | $ 60,400 |
| $1400 | $ 211,400 | $ 140,933 | $ 105,700 | $ 84,560 | $ 70,467 |

Table 12. The cost to measure 106 plots (based on the LUCAS 16*8 km grid).

| Cost/day | 2 plots/day | 3 plots/day | 4 plots/day | 5 plots/day | 6 plots/day |
|---|---|---|---|---|---|
| $800 | $ 64,400 | $ 42,933 | $ 32,200 | $ 25,760 | $ 21,467 |
| $1000 | $ 80,500 | $ 53,667 | $ 40,250 | $ 32,200 | $ 26,833 |
| $1200 | $ 96,600 | $ 64,400 | $ 48,300 | $ 38,640 | $ 32,200 |
| $1400 | $ 112,700 | $ 75,133 | $ 56,350 | $ 45,080 | $ 37,567 |

## 6.3 Soil Sampling Costs

Duffill Watts Consulting Group (2005) estimated that it would take between ½ to full days for crews to gather soil samples for a single plot. Their research indicated that it would cost $384-$856 per plot to analyse the soil samples. The estimated cost per plot which included travel, sampling, shipping of sample to a laboratory for analysis, and a small charge for equipment hire or usage depreciation was between $2,000 and $3,000.

It was recommend for monitoring plots the indicators that Total C, Total N, C:N ratio and bulk density are collected. This soil data is already collected as part of the LUCAS planted forest inventory programme. As the above soil indicators only require soil samples to be collected in the field, it is feasible for this work to be carried by the field measurement team. This could reduce the cost per soil plot substantially.

## 6.4 Plot Re-measurement Costs

As noted in Section 5.9, the independent re-measurement of a plot subset is important to the success of any FCM programme being undertaken. This re-measurement work would need to be undertaken by a crew that is different from the one that carried out the primary assessment. In Section 4.4.3 it was advised that at least 18 plots of a national system should be “blindly” re-measured. If the same productivity and daily costs are assumed for re-measurement, then the cost of the repeat measurement programme would be 20% of the costs in Table 11 and 12.

## 6.5 Data Management and Hosting

A long term monitoring programme such as that proposed in this report would require a database for data warehousing. This database would need to be hosted in manner that would allow users to access and analyse the data. Although calculating the exact cost of data management and hosting for a FCM database is outside the scope of this report, Interpine estimates (based on its experience of hosting similar databases for several clients), that the cost would likely be around $1,500 to $2,000 per month. This would include hiring and hosting of server space for a Microsoft SQL database and 10-15 hours data management per month.

## 6.6 Reporting

Specifying the exact reporting requirements for an FCM programme is beyond the scope of this report. However for completeness of this costing analysis it has been estimated that NZFOA should budget around $10,000 per year for an annual report on the findings of the program. It is important for the long term success of this program that results are communicated to all shareholders annually. NZFOA may also want to publish results internationally.

## 6.7 Project Management

A measurement programme would require some degree of the project management; this cost would be in the order of the 10-15% of the annual cost.

## 6.8 Total Cost of Investment

Table 13 provides a summary of the total annual cost to undertake a FCM programme in New Zealand where approximately 106 plots are measured on the 16km by 8km LUCAS grid network.

Table 13. Summary of the annual costs.

| Item | Low | High | Comment |
|---|---|---|---|
| Training | $37,500 | $37,500 | (Based on training 5 crews) |
| Plot Measurement Cost | $35,333 | $74,200 | |
| Soils Analysis Cost | $5,699 | $12,703 | $ 384 (Low) - $856 (High)/plot |
| Re measurement | $6,000 | $12,600 | 18 plot re-measured |
| Data Management and Hosting | $24,000 | $24,000 | Based on $2,000 per month |
| Reporting | $5,000 | $10,000 | |
| **Total Cost** (excluding Project Management) | $113,532 | $171,003 | |
| Project Management | $18,864 | $36,034 | 15% of Total Cost |
| **Total Annual Cost** | **$124,885** | **$196,653** | |

It is estimated that the total annual cost of measuring the 106 plots would range from $125,000 and $200,000. There difference in price depends largely on the expense associated with the assessors contracted to carry out the measurement programme. If the 302 plots (plots on the LUCAS 8 km grid) were measured each year the total cost would increase by over $ 70,000 for the low estimate and $160,000 for the high estimate.



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# 7 RECOMMENDATIONS

The recommendations provided in this section have been based around the implementation of a New Zealand national FCM program using ground based plots. This monitoring system is designed to solely monitor change in forest condition and provide reporting at a national level.

- It is recommended that a total of 106 plots are measured annually. This number of plots is based on the 16km by 8 km LUCAS grid. The analysis presented in this report indicates that with the current level of knowledge around the sources of variability, additional plots would not vastly improve the ability to detect change. This intensity of measurement should be implemented for three years and then reviewed. The review should look at the observed variability in measurements to-date, number of plots, operators and timing between measurements.

- The same plots should be measured annually and re-established after harvesting in the same location for continuing measurement.

- Assessments should target approximately 24 trees per plot for crown characteristics. It is desirable, but not essential, that the same numbers of trees are assessed in each plot.

- Monitoring forest condition is a long term commitment. International experience indicates that it takes at least 10 years of annual measurement before meaningful results can be realised. It is recommended that the New Zealand industry requires at least 25 years of annual measurements before long-term trends can be adequately identified (if any).

- At least three measurement operators (crews) should be used. The operator identity needs to be recorded against each measurement. At a minimum, 18 plot measurements should be re-measured (six plots for each crew).

- The LUCAS planted plot network is well suited to becoming the basis of a national forest condition monitoring programme. Interpine encourages the NZFOA and its members to start open dialog with the New Zealand Government and its Ministry's (Ministry of Environment and Ministry of Agriculture and Forestry) on the long term continuation of the LUCAS plot network.

- The use of the New Zealand PSP network as part of a nation FCM program is not recommended. Generally these plots fail to meet the criteria of equal probability in selection and randomisation across the nation population of exotic forest. It is highly likely that any result calculated from the PSP would be biased. PSPs allocated on an estate level may be useful if they are allocated in accordance with the principles of systematic random sampling, as discussed in Section 5.7.

- Based on the calculations carried in this analysis, the NZFOA and their members should be budgeting between $125,000 and $200,000 per year to carry out a national level FCM programme. If the NZFOA was to successfully in work with the New Zealand Government and the LUCAS plot measurements, there is a possibility that the cost to NZFOA could be reduced.

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- As one of NZFOA member's secondary objective was to investigate the correlation between growth and forest condition, it is recommended that tree growth parameters and forest condition are measured on the same trees.

- Interpine also recommends the NZFOA investigates the potential use of low cost satellite imagery and LiDAR to detect change in forest condition. This has the potential to deliver similar results as the programme outlined in this report potentially at a reduced cost.

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