# Drying Eucalyptus nitens: Screening for checking and collapse

**Authors:**

**Rosie Sargent, Doug Gaunt, Steve Riley, Toby Stovold, Mari Suontama, Grant Emms**

**Date:** June 2017

Publication No: SWP-T022

# TABLE OF CONTENTS

**Disclaimer**

This report has been prepared by Scion for Forest Growers Research Ltd (FGR) subject to the terms and conditions of a research services agreement dated 1 January 2016.

The opinions and information provided in this report have been provided in good faith and on the basis that every endeavour has been made to be accurate and not misleading and to exercise reasonable care, skill and judgement in providing such opinions and information.

Under the terms of the Services Agreement, Scion's liability to FGR in relation to the services provided to produce this report is limited to the value of those services. Neither Scion nor any of its employees, contractors, agents or other persons acting on its behalf or under its control accept any responsibility to any person or organisation in respect of any information or opinion provided in this report in excess of that amount.

# EXECUTIVE SUMMARY

Eucalyptus nitens frequently develops within-ring checks and collapse (washboarding) during drying, making the wood unsuitable for use as sawn timber. Numerous studies have tried altering drying conditions to reduce levels of checking and collapse, but this has not been completely successful, and low recovery due to drying defects remains a major barrier to its use for sawn timber.

Previous nitens drying research at Scion aimed to see if pre-treatments could be used prior to drying to reduce levels of checking and collapse in dried timber, but this work highlighted issues around log selection and drying technique, which may have led to low levels of and collapse

The current study aimed to ensure that boards used in drying studies had a wide range of checking behaviours, and that the effect of lab-scale drying methods on final levels of degrade could be understood. For this, 200 trees were screened using a variety of non-destructive measures, and these were compared to numbers of checks counted in discs cut from 100 of the trees. From this data the numbers of checks expected in the remaining 100 trees were predicted, and this was used to select 30 trees to be sawn into boards for a drying study. Discs cut from the 30 selected trees showed very little correlation between the number of checks predicted and the number actually counted. For discs cut at breast height the correlation was slightly stronger than that for discs cut 3m up the tree (at the height the logs were cut).

The sawn boards were dried using 8 different drying techniques, and following drying the boards were docked at once end and assessed for checking and collapse (grouped as ‘degrade’ for the purposes of this report).

Due to delays in shipping discs and logs to Rotorua, currently (30 May 2017) the drying study got underway later than planned. Six of the eight drying schedules are complete and the final two drying treatments are expected to be complete in late 2017 or early 2018.

Drying temperature had a significant effect on levels of degrade seen in the boards - boards dried at 50°C had significantly higher levels of degrade (53% of boards with degrade) compared to boards dried at 20 or 25°C (~15% of boards degraded). Boards that had been frozen showed no improvement in degrade compared to boards that had not been frozen. Boards dried with varying temperatures (air drying) had slightly higher degrade than boards dried at a constant temperature. In future, drying work should use drying conditions that change between day and night because this will better replicate drying done in industry. Despite the differences between drying methods, some logs produced boards that consistently had very low or very high levels of degrade, even in the very severe, or very mild drying methods.

To understand the relationship between the non-destructive screening measures and the check propensity of each log, the levels of degrade were averaged across all the boards cut from each log. This ‘log condition’ value was used to create a linear model linking to predict log condition from the non-destructive measurements. This model was reasonably effective at predicting the log condition ($R^2 = 0.44$). This suggests potential to screen standing trees to select those which are less likely to develop degrade during drying.

# INTRODUCTION

Collapse and within-ring checking are major issues encountered when processing *E. nitens* into solid wood products, and are one of the main reasons why nitens is not routinely used for sawn timber production. Collapse and within-ring checking are both caused by the same underlying mechanism – water tension forces arising early in the drying process, so in this report the two terms are used interchangeably, generally to indicate which of the two forms of degrade are most likely to occur in that situation – the same water tension forces will be seen as checks in a disc, but may be seen as collapse in a board.

Eucalyptus nitens drying research at Scion has found that levels of checking and collapse can vary significantly between experiments, making it hard to understand checking and collapse behaviour. In previous SWP drying research (Sargent, et al., 2016), only 20% of control boards had checking or collapse, which made it difficult to determine if the pre-treatments tested were having an impact on collapse. For the current work, two approaches were taken to avoid a repeat of this uncertain result. Firstly, trees were screened to make sure the logs selected for the drying trial have a representative range of checking and collapse propensity. Secondly, a wide range of drying schedules were chosen, to ensure that we are not seeing artificially low levels of collapse and checking due to the drying method to be used.

It is known that susceptibility to collapse is very variable between trees in *E nitens*, and that there is a strong heritable component to this. Checking susceptibility is generally measured via destructive, time-consuming methods such as drying discs and counting the resultant checks. Screening for checking and collapse has been studied extensively for Radiata pine, leading to some faster assessment methods, such as measuring collapse in a 10 or 12mm increment core. Development of a low-cost screening tool for checking and collapse propensity in nitens would make it easier to consistently select wood that has a range of checking behaviours, leading to more meaningful experimental results.

This tool could potentially also be used by forest owners to identify logs that are not check prone, so they could be used for sawn timber. This seems particularly pertinent to nitens where there is a ready market for non-saw logs and its utilisation as sawn timber is limited by its high collapse and check proneness.

There are a variety of non-destructive tools that could be used to screen for check propensity, such as acoustic stiffness, Resistograph (http://www.imlusa.com/html/iml_resistograph.html/) and shrinkage of increment cores. In order to evaluate the potential of these, they need to be systematically compared to existing practice (counting checks in discs) and compared to the final drying quality of boards cut from these logs.

To cover a wide range of drying techniques, the following drying schedules were chosen:

- Dry 20°C 65%RH
- Dry 20°C 65%RH + pre-freeze at -7°C
- Dry 25°C 65%RH
- Dry 25°C 65%RH + pre-freeze at -7°C
- Dry 50/40°C
- Dry in covered shed ('air drying')
- Dry in indoors (~20°C with natural humidity variation)
- Dry in freezer (-20°C, low humidity via compressed air).

The rationale for choosing these schedules is as follows. The recommended method of reducing degrade in *E. nitens* is to either air dry, or to dry at a low temperature and very high humidity until the wood is below 30%MC, after which the wood can be dried at a higher temperature (e.g. in a conventional kiln or solar kiln). Air drying depends heavily on the weather conditions and is not repeatable. In drying research, keeping conditions standard gives much more repeatable results, but may not give results that correspond to those seen in standard air drying. To test if there is any difference between drying at constant temperature and natural air drying, two air drying schedules (with no humidity control) were used - one indoors, with more severe drying conditions, and one outdoors. This was compared to two constant temperature schedules at 20° and 25°C to see if there was any difference between levels of degrade in the constant or variable drying conditions. Additionally, for the constant-temperature schedules any difference in drying behaviour between these two temperatures that would indicate a collapse threshold. It is believed that collapse prone species have a ‘collapse threshold temperature’ below which the wood is stiff enough to withstand water tension forces and avoid checking and collapse. This temperature is reported to be between 20 and 28°C for *E. regnans* (Innes, 1995). No data has been found for *E. nitens*.

Previous work on freezing wood prior to drying was inconclusive (Sargent, et al., 2016), so this has been repeated for two charges - followed by drying at 20°C or 25°C.

Two additional drying methods were also included in this study - kiln drying at 50°C/40°C, which is unusually harsh for drying nitens, but will identify any trees that are likely to have little degrade no matter how they are dried. The second technique is to dry the wood while it is frozen, by ice sublimating from the wood surface, which eliminates water tension forces. There is some evidence in the literature (Choong, et al., 1973; Harrison, 1998) that this may reduce checking and collapse, but it has never been tested for nitens in a systematic way.

# METHODS

## Screening of standing trees

We identified a stand of nitens that SouthWood Exports was ready to harvest. SouthWood selected and labelled 200 trees for screening. These trees were evenly spaced through the stand.

For each tree identified, we measured sonic velocity with a Hitman ST300, extracted a 10mm increment core and made two Resistograph measurements at breast height. Cores and Resistograph were both aiming to include the pith of the tree. Cores were covered in water and returned to Scion. The cores were assessed using the method outlined in WQI App 41 (Appendix 2) (Holden, et al., 2005). For each core, six growth rings were marked at evenly spaced intervals between the bark and the pith. The earlywood and latewood diameters were measured for each marked growth ring (measurements were made perpendicular to the wood grain). The volume of each core was determined by water displacement. Cores were then oven dried at 103°C for 48 hours, then weighed and the diameters of the earlywood and latewood bands measured again. From these measurements the following was calculated:

- Density (kg/m (kg/m$^3$)
- Differential shrinkage of earlywood relative to latewood (mm)

The sixth shrinkage measurement (the furthest from the bark) sometimes coincided with the pith, or was within one or two rings of the pith, especially for the smaller Keens trees (see below). Growth rings very close to the pith tend not to check or collapse and it was decided to leave this shrinkage measurement out of further analysis (e.g. calculation of the average shrinkage) as it was not comparable between trees.

The ST300 velocities were used as-is without any further analysis.

The raw Resistograph traces were truncated to remove the part of the trace corresponding to the bark, and the part of the trace beyond the pith. The bark edge was identified manually by clicking on the point on the trace where the bark ended. There is an abrupt change in torque at this point, so it was easy to identify. Locating the pith was more difficult, sometimes the trace will look symmetric around a point of low torque corresponding to the pith, but this was not common for the nitens traces. The pith location was estimated by finding the point at which the trace was most symmetrical (minimising the squared differences between the traces either side of the symmetry point).
It was not known how best to interpret the Resistograph traces, so these were analysed via a variety of methods (calculating means, slopes, identifying obvious peaks in the data, the maximum length of the trace itself etc.

Previous work by the Scion Genetics team had collected discs from 7-year old nitens trees from known families in a progeny trial (Keens block) in SouthWood’s forest. These discs had their checks counted, and this was used to rank the families from the most to the least check prone. A sister trial to the Keens block has 11 year old trees from the same families and it was decided to extend the non-destructive testing to include two families in this trial - the most check prone family and the least check prone family. The non-destructive measurements were made and assessed in the same was as that of the 200 trees in the main study.

## Disc assessment and tree selection

The first 100 trees were harvested, and a pair of discs cut from each tree – one at breast height, and one 3m up the log (at the height that a saw log would be cut). The discs were sent to Scion where they were photographed, dried at 40°C until almost dry, then oven dried at 103°C to ensure all the discs were at the same moisture content. The discs were cut in half (through the cross section) to expose a newly sawn face and this was sanded to expose the checks. The checks were counted by hand, and were recorded by growth ring.

Each variable calculated from the non-destructive testing was compared to the number of checks in either the breast height or log height discs for each tree, but no good regressions were seen, the best (maximum shrinkage value for each core) had an R2 value of 0.11.
To improve the predictions from the non-destructive tests, it was decided to use a Random Forest™ model (Breiman, et al.), a machine learning method for classification and regression. Specifics of the method can be found in (https://en.wikipedia.org/wiki/Random_forest). A model was created which used all the measurements available to predict either the breast-height or log-height checking. In order to validate the random forest model, two-thirds of the 100 trees were used to create the model, and the remaining one-third of the trees were used for validation (using the model to predict the number of checks expected, and comparing this to the number measured). Once the random forest models had been created (one for breast-height discs and one for log-height), they can be used to predict numbers of checks in other trees using their non-destructive measurement data.

Once the models were complete, they were used to predict levels of checking in the remaining 100 trees, using their non-destructive measurements. From these predictions 30 trees were chosen that had a wide range of checking behaviours, as well as a wide range of values for each of the main non-destructive measurements. Where several trees had similar measurements, preference was given to larger diameter trees to make sawing easier.

## Log assessment and drying trial

The 30 identified trees were harvested, and discs cut from breast height for each tree. 3-metre long 2nd logs were cut from each tree (starting 3m up the tree), and the logs and discs were sent to Rotorua.

The logs had a disc cut from their large end (corresponding to the log-height discs in the first 100 trees) and these discs were dried and assessed along with the breast height discs in the same manner as those from the original 100 trees.

To track the location of sawn boards within each log, the logs had sheets of barcodes glued to the freshly sawn surface of the large end of the log. These were coated with water-based clear polyurethane to protect against moisture damage.

The logs were sawn in the Toi Ohomai Institute of Technology’s sawmill in Waipa to be cut into 100x25mm boards The sawmill has a reciprocating carriage single saw (bandsaw), and a single resaw (bandsaw) meaning that it was not particularly well set up for quarter sawing of hardwoods. The diameter of the logs meant that the typical sawing pattern used for quarter sawing radiata pine was also not suitable. However, efforts were made to produce 2-3 quarter sawn boards per log, and this was sufficient for this study. The rest of the boards were predominantly flatsawn and these have been used in other drying studies, or are being air dried for future use. There were concerns about drying stress during sawing, and some boards distorted significantly during sawing (up to ~100mm bow in some boards). This made resawing difficult, and there was significant variation in board dimensions (green dimensions were 106x28mm +/- 7mm).
Where possible, boards with very variable thickness were discarded and not used for the drying study.

The sawn boards were returned to Scion and sorted to identify the quarter sawn boards. Boards were cut to 500mm lengths, avoiding major defects (wane, mechanical damage) but not specifically avoiding knots. Short (20mm) biscuits were cut from between each board, to determine moisture content and density of each board. The barcoded end was retained for each board, and these were used to record the position in the log of each board.

Boards were sorted into the following 8 charges, ensuring that each of the 30 logs had one board in each charge.

- Dry 20°C 65%RH
- Dry 20°C 65%RH + pre-freeze at -7°C
- Dry 25°C 65%RH
- Dry 25°C 65%RH + pre-freeze at -7°C
- Dry 50/40°C
- Dry in tilt shed (‘air drying’)
- Dry in DIC room (20°C with humidity cycling)
- Dry in freezer (-20°C, low humidity via compressed air (will use 200mm samples)).

Boards were end coated with a two-pot epoxy paint (Carboguard 635), then weighed prior to being dried. Board pre-frozen at -7°C were individually sealed in plastic prior to freezing and were removed from the plastic prior to thawing and drying.

For each of the drying conditions, boards were dried until all boards in the charge were estimated to be below 30% MC, then were kiln dried at 70/55°C to around 12%MC, then equilibrated at 20°C, 65%RH until their weights stabilised. The boards were then cut in half and visually assessed for checking and collapse using a four point scale to indicate the severity of each type of degrade.

The quantified levels of checking and collapse were compared to the non-destructive measurements for each tree (including the predicted number of checks from the random forest model).

# RESULTS

## Non-destructive measurements

### Core Shrinkage, Density and Acoustic velocity

The average values of the metrics calculated from the 10m cores and the ST300 are shown in Table 1. S1 to S6 are the individual shrinkage values for the 6 growth rings identified. The maximum and average shrinkage values only cover rings 1-5, since S6 sometimes coincided with the pith, so was not considered to be measuring the same thing in every core. Average levels of shrinkage are similar to those seen in radiata pine previously (ranging from 0.2mm near the bark to 0.8mm near the pith) (Appendix 2), but the maximum levels of shrinkage are much higher – values above 1mm of collapse was not seen in the radiata, but here most growth rings have maximums shrinkage levels of 2mm or greater

Average density is slightly lower than that seen in another study on NZ growth nitens - Lausberg, et al. (1995) found average core densities of 435 kg/m$^3$ for 15 year old trees grown in Kaingaroa with a range of densities of around 150kg/m$^3$, which is slightly larger than the 125kg/m$^3$ range seen here.

The acoustic velocity from the ST300 gives an indication of the wood stiffness (stiffness values can be calculated if the green wood density is known).

Table 1. Average core shrinkage measurements

| | Basic Density (kg/m$^3$) | S1 (mm) | S2 (mm) | S3 (mm) | S4 (mm) | S5 (mm) | S6 (mm) | Max shrinkage (mm) | Av shrinkage (mm) | Acoustic Velocity |
|---|---|---|---|---|---|---|---|---|---|---|
| Av | 418.1 | 0.21 | 0.42 | 0.59 | 0.58 | 0.67 | 0.66 | 1.07 | 0.49 | 3.9 |
| Stdev | 27.9 | -0.22 | -0.48 | -0.54 | -0.52 | -0.58 | -0.71 | -0.48 | -0.27 | 0.2 |
| Min | 369.8 | -0.46 | -0.33 | -0.64 | -1.36 | -0.68 | -0.62 | 0.09 | -0.42 | 4.8 |
| Max | 496.4 | 0.97 | 2.23 | 2.25 | 2.40 | 2.17 | 3.35 | 2.40 | 1.35 | 3.5 |
| Number of cores | 197 | 197 | 197 | 197 | 197 | 197 | 197 | 197 | 197 | 197 |

### Resistograph metrics

A typical Resi trace is shown in Figure 1. The part of the trace used for subsequent analysis (i.e. without bark and stopping at the pith) is shown in blue.

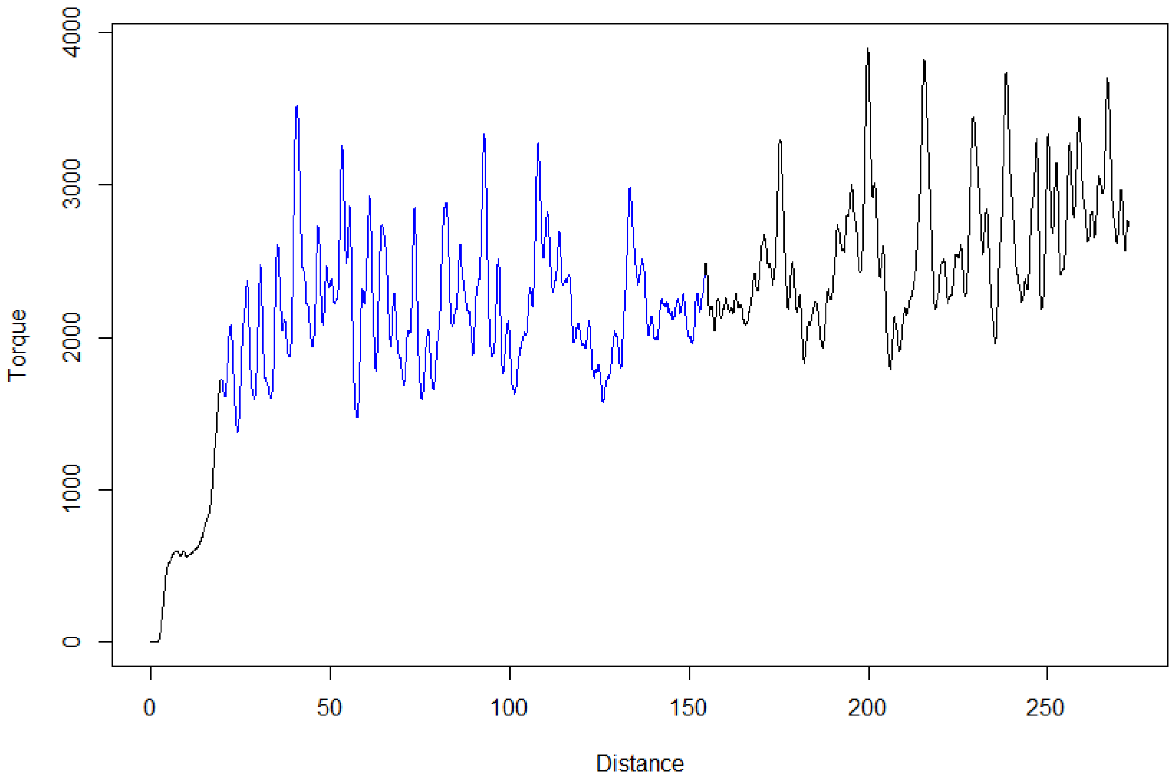


Figure 1. Resi trace showing section of trace used for analysis (in blue). This analysed section excludes bark and the section of trace beyond the pith.

Because it was not known how the Resistograph traces would correspond to check propensity a large number of metrics were calculated for each trace. These included:

- Average and standard deviation of the torque
- Maximum torque
- Length of the whole trace (including the part beyond the pith)
- Estimate of the tree diameter from the calculated pith location
- Slope and intercept of a linear fit through the trace
- Coefficients of a quadratic fit through the trace
- Periodigram of a Fourier transform of the trace
- A peak finding algorithm was used to identify obvious peaks in each trace and these were analysed for maxima and minima, as well as identifying nearby troughs to calculate the difference in maximum and minimum torque across a growth ring.

Some of these metrics were also calculated over different-sized subsets of the trace, to see if smaller scale variations in the trace shape influences checking behaviour.

## Assessment of discs and model predictions

The average number of checks in the breast height and log height discs are shown in Table 2. The log height discs have a slightly higher average number of checks, and a much higher standard deviation, indicating the number of checks is more variable. This is surprising, as check propensity is expected to decrease with increasing height up the tree (Shelbourne, et al., 2002). For both sets of discs there is a wide range of check numbers, from discs with no checks (or next to no checks) to more than 300 checks in a disc. Having a data set with such a wide range of checking behaviours increases the chances of making predictions that are valid for a large range of trees. Figure 2 shows the total number of checks by ring number for both the breast height and log height discs. While the heart-sap boundary was not formally assessed in these discs, it generally seems to appear between rings 10 and 13, suggesting that the highest incidence of checks occurred in the inner sapwood (rings 13 to 15).

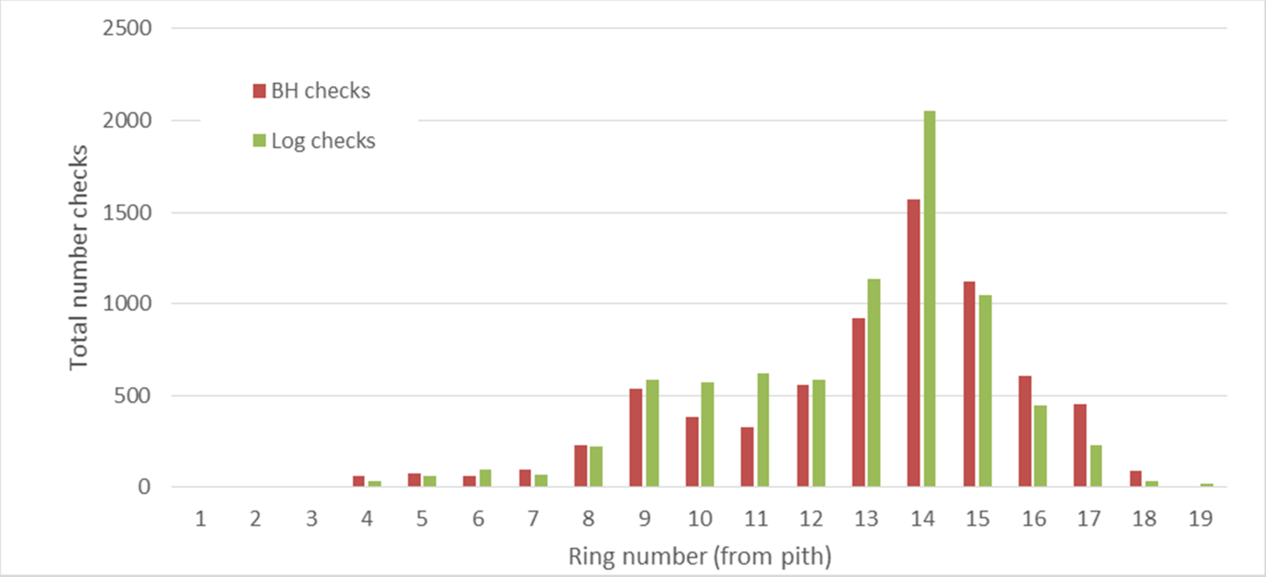


Figure 2. Total number of checks by ring number. Heart-sap boundary varies between trees, but is generally between rings 10 and 13

Table 2. Average numbers of checks, and disc diameters, at breast height and log height.

| | BH # checks | Log # checks | BH disc diameter (mm) | Log disc diameter (mm) |
|---|---|---|---|---|
| Av | 71 | 80 | 305 | 297 |
| Stdev | 56 | 80 | 45 | 40 |
| Max | 306 | 396 | 440 | 410 |
| Min | 1 | 0 | 170 | 170 |
| n | 102 | 102 | 102 | 102 |

The correlation between the number of breast height checks and the number of log height checks for each tree is shown in Figure 3. There is a weak positive correlation, with the number of log height checks generally being lower than the breast height discs, but there are also some notable outliers. Non-destructive measures of standing trees need to be taken at breast height, for practical reasons, but as butt logs generally have greater degrees of growth stresses, and more variable properties overall (Chafe, 1985), sawlogs are taken from higher up the tree as 2nd or 3rd logs. Wood properties vary with height, and predicting behaviour of 2nd and 3rd logs from the properties at breast height is always going to be a challenge.

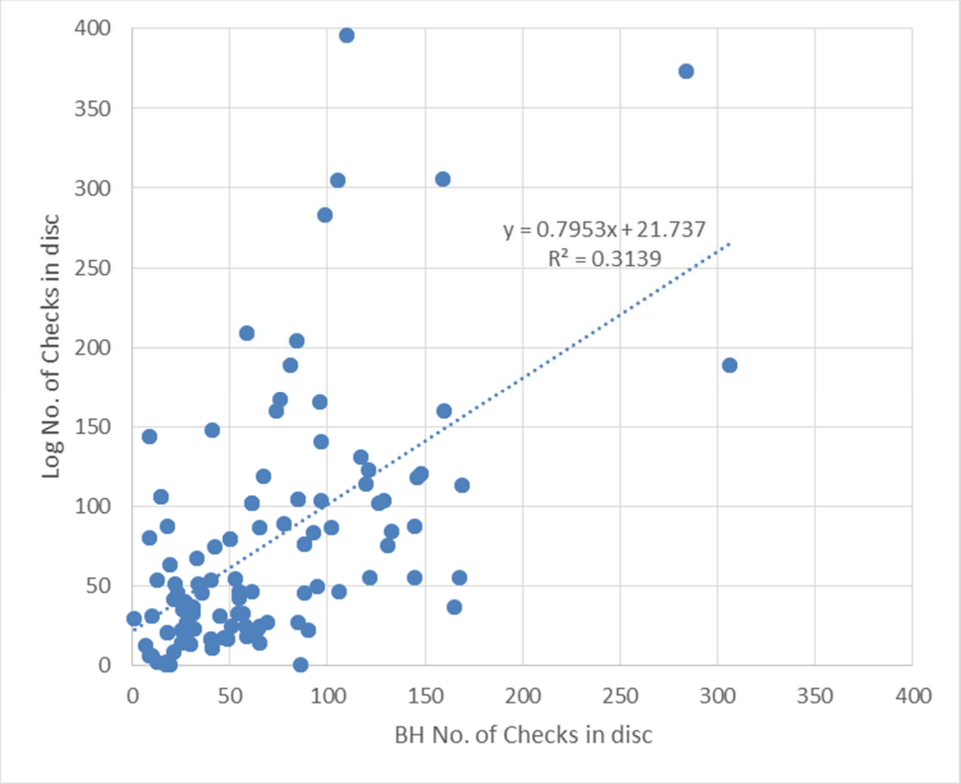


Figure 3. Correlation between the number of checks in a breast height disc compared to the corresponding log height disc.

## Basic correlations

To predict disc checking from the non-destructive measurements, an obvious starting point is to look at correlations between individual measurements and the number of checks at breast height or log height. Correlations were tried for all the measurements taken from the cores and ST300, and for selected Resistograph metrics. None of the individual metrics gave satisfactory correlations with the number of checks. The best correlation found was with the maximum shrinkage seen in the cores, and this is shown in Figure 4. Correlations with both breast-height and log height disc checking is shown. Not surprisingly the correlation is better with breast height checking, as this disc is much closer to the site where the core was taken.

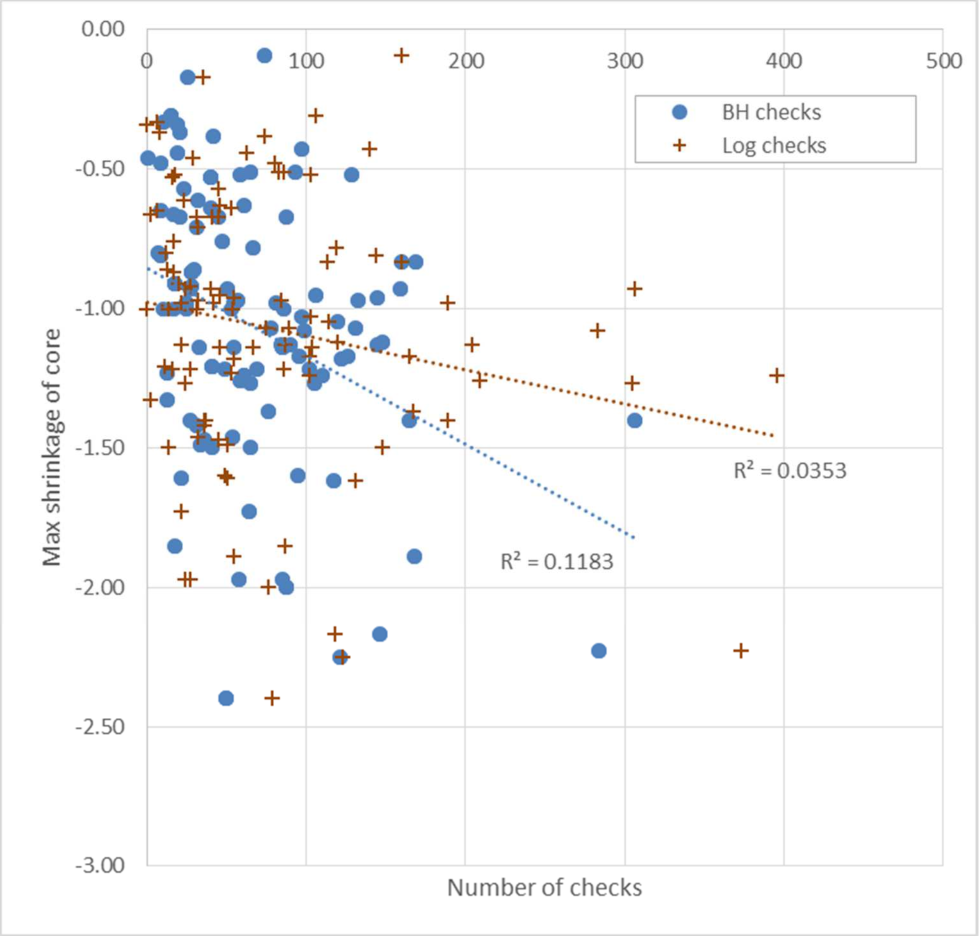


Figure 4. Correlation between number of checks and maximum core shrinkage

## Random forest modelling

Due to the poor results from basic correlations, and the likelihood of there being interactions between the different variables, a more comprehensive approach was needed to compare the relationship between the non-destructive measures and the number of checks in the discs. For this a Random Forest model was created.

Two separate models were created, one trained on (and used to predict) the breast height checking data, and one trained on the log height checking data. In order to determine the predictive power of each model, it is necessary to create the model using a subset of the data available, and use the remaining data to test the validity of the predictions (by comparing the number of checks predicted to the number of checks actually measured). For this the data from 66 of the 100 felled trees was used to create the model, and data from the remaining 29 trees were used to test the predictive power of the model. Of the 102 pairs of discs supplied to Scion, six tree numbers were duplicated in a second pair of discs, leading to the total number of trees being modelled being slightly less than 100.

Once the two models had been trained on the 66 trees, these models were used to predict the number of checks in the remaining 29 trees. The correlation between the number of checks predicted, and the number measured are shown in Figures 5 & 6. Neither correlation is especially good, but the breast height checking model has a better prediction than the log height model, probably due to the proximity of the breast height discs to the site where the non-destructive measurements were made.

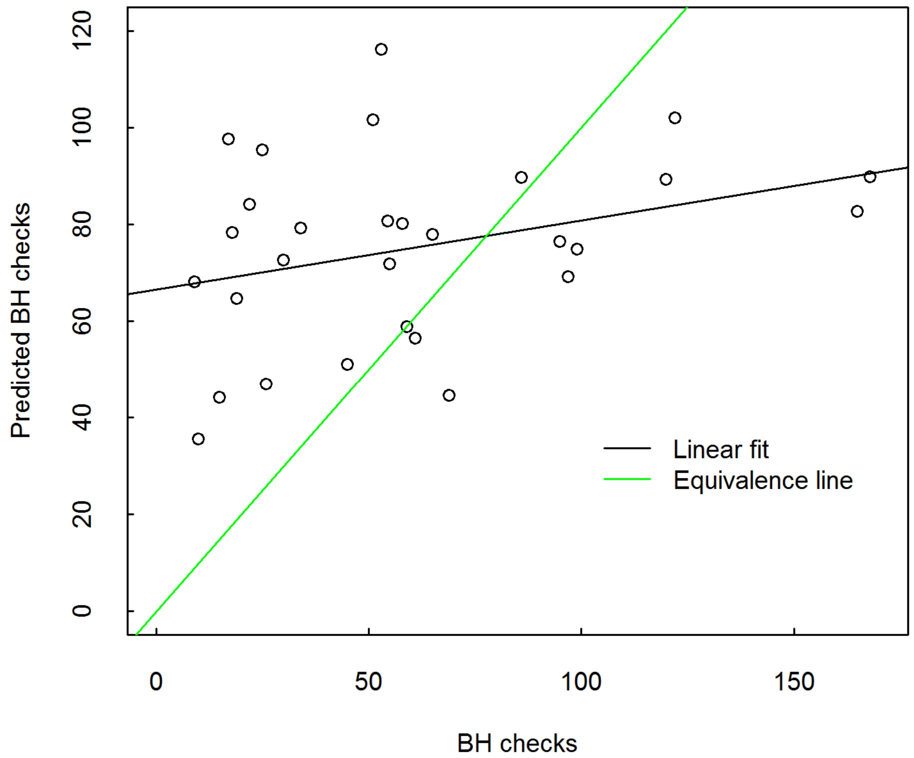


Figure 5. Prediction of number of breast height checks, and the actual number of checks measured

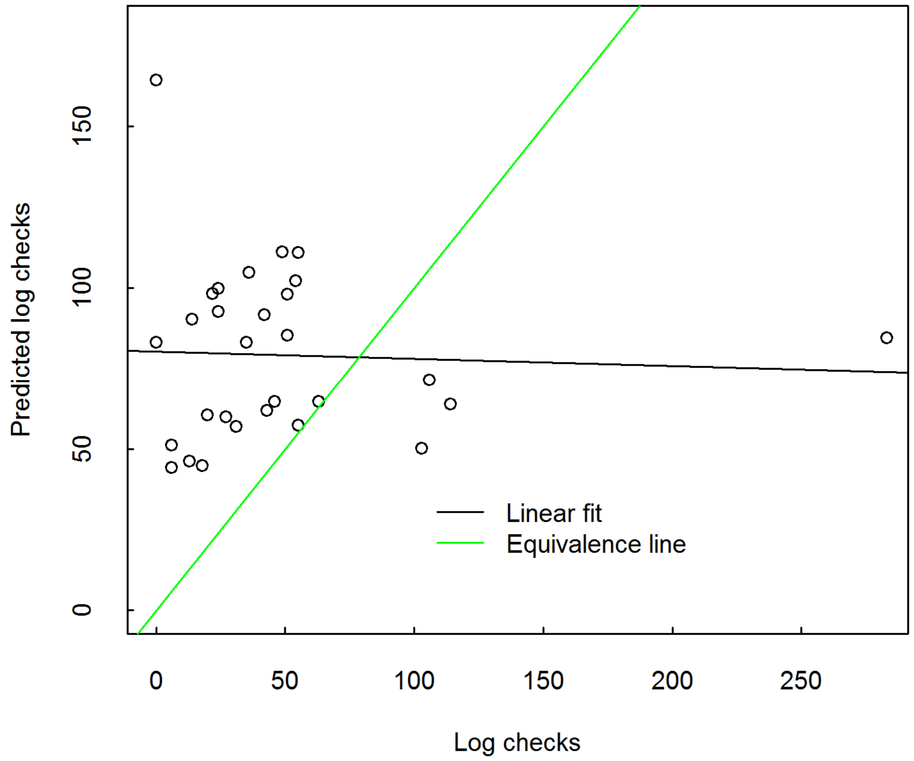


Figure 6. Prediction of number of log height checks, and the actual number of checks measured

## Prediction of checking in Keens trial trees

The random forest models described above were used to predict the number of checks we would expect to see in the Keens trial trees, given the non-destructive measurements taken on them. The number of predicted checks are given for each family in Figure 7. Both log height and breast height discs are overlaid on the same graph - log height discs are shown in grey. Since these trees are much younger than those used to generate the models, their non-destructive measurements are likely to be somewhat different, and discs cut from these trees would have a different cross section and different number of rings, meaning that the number of predicted checks given here is just a qualitative measure of the check propensity of the tree, not the actual number of checks we would expect to see in a disc cut from these trees.

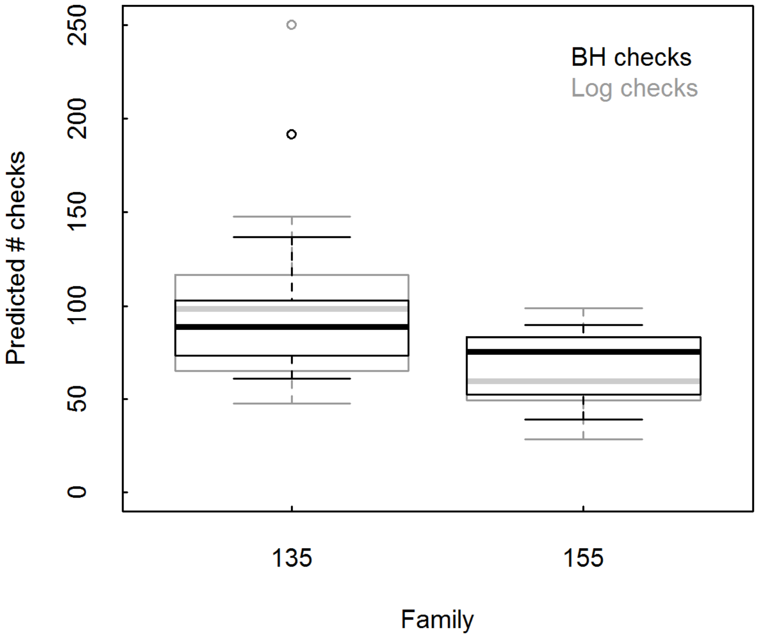


Figure 7. Checking in Keens trial families.

For both the breast height, and log height checks, family 135 had significantly higher numbers of predicted checks to family 155, although there is still a reasonable amount of overlap between the two families (the 135 family trees with the lowest numbers of checks have fewer checks than the 155 family trees with the highest number of checks). This result is not as clear-cut as we would like - in the 7 year old trees family 135 had an average of 42 checks and family 155 had an average of 12 checks - a more than 3-fold increase in checking between the two families.

## Drying study

### Log selection and sawing

Despite the poor correlations from the random forest models created above, the non-destructive measures from the remaining 100 trees were used to predict the number of breast height and log height checks that would be expected for each tree. The breast height checking predictions ranged from 7 to 284 checks in a disc, with an average of 69 checks per disc. From this, 30 trees were selected in the following way:

For each tree the following measurements were ranked by the quartile they fell into:

- BH checks
- Acoustic velocity
- Maximum shrinkage of the core
- Maximum height of identifiable peak in the Resistograph trace.

Trees were selected so each quartile of number of checks was represented, and within this, each quartile of the remaining measurements was also represented (where possible, not all combinations of measurements existed) where more than one tree had measurements within the same quartiles, the largest diameter tree was chosen. Based on the discs that had already been sent to Scion, tree diameter varied enormously (from 110 to 440mm), and it was important that the logs selected were large enough to be quarter-sawn. This selection method was intended to give trees with a wide range of properties, even if the predicted number of checks were inaccurate. From the resulting selection of trees, 30 trees were selected. From the original selection it was discovered that eight of the trees selected had already been felled, so additional trees were selected to replace these.

Second logs from the 30 selected trees were sent to Rotorua, along with breast height discs. Log height discs were cut from the logs once they had arrived in Rotorua. The discs were dried and assessed in the same way as the discs from the original 100 trees. The actual number of checks are compared to the predicted number in Figure 8. For both the log height and breast height discs, the correlation is very poor. Despite the poor predictions, both the breast height and log height discs have a wide spread of measured checks, some discs have no checks, some have over 200 checks. This means that the drying study should have boards with a wide range of checking behaviours, improving our chances of seeing differences between the different drying methods.

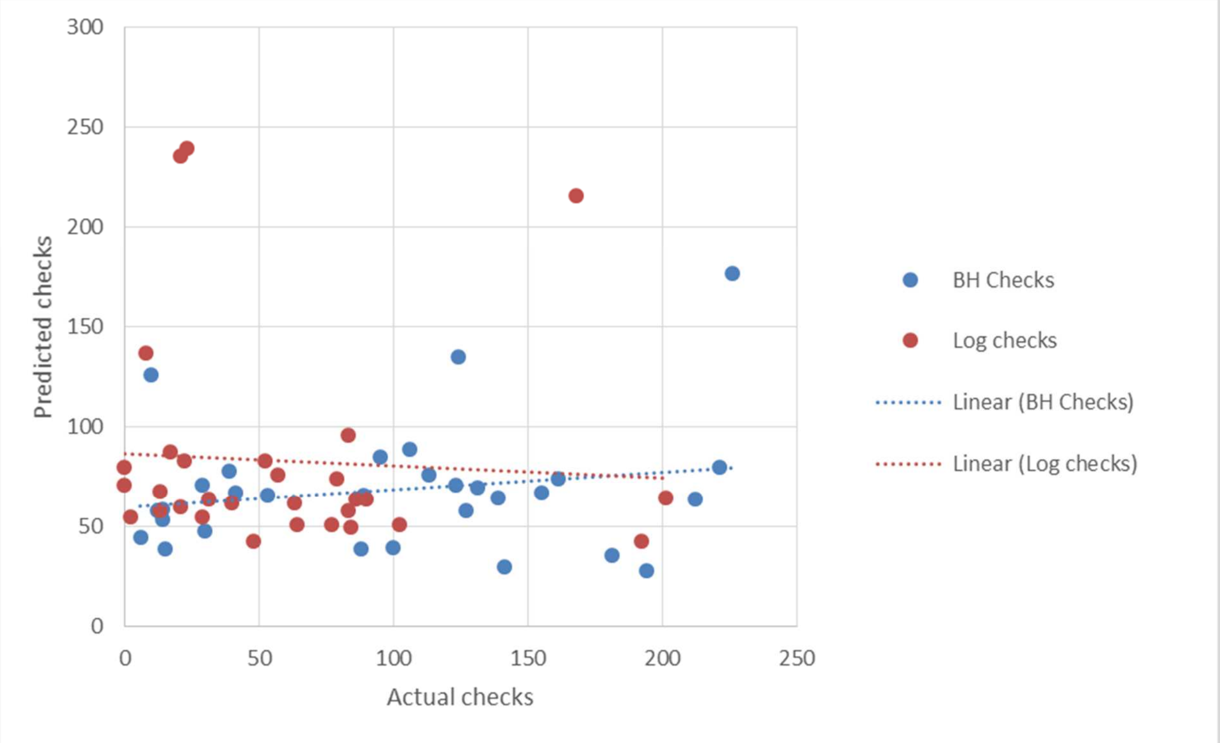


Figure 8. Comparison of predicted checks and actual checks for breast height and log height discs in the 30 selected trees.

After the log height discs had been cut from the large end of the logs, a sheet of barcodes was glued to the cut surface of the log. The barcodes remain attached to the boards during sawing, and allow easy identification of which log each board was cut from, and where in the log it was cut. The logs were then sawn into boards, aiming for 2-4 quarter-sawn boards per log. The remaining boards were either flat-sawn or intermediate-sawn and were retained to be used for other Scion processing work. From the 3m long quarter-sawn ‘parent’ boards, 500mm long sample boards were cut with 30mm blocks cut between each board for moisture content determination. These boards were then randomly assigned to eight charges, with each charge having one board from each log. The average density and initial moisture content of each charge is given in Table 3. The average values are all very similar, with similar standard deviations. Using the barcodes on each board, the location of each board within the log could be determined to the nearest 15mm. From this, the distance from the pith to the mid-point of each board could be determined, and the orientation of each board relative to the growth rings. The orientation was quantified as the angle relative to the growth rings, so 0° is parallel to the growth rings (flat sawn) and 90° is perpendicular to the growth rings (quarter sawn). Boards with a grain angle >80° were considered to be fully quarter sawn. The average distance from pith is fairly similar between the different modifications, and the standard deviation is quite small (~30-40mm, for a 15mm grid resolution). The grain angle is much lower than had been hoped (due to difficulties sawing small logs), but for almost all the charges at least half the boards were fully quarter sawn.

Table 3. Density and initial moisture content of each drying charge.

| Drying method | Density (kg/m$^3$) | | Initial MC (%) | | Av. grain angle | % fully Quarter sawn | Distance from pith (mm) | |
|---|---|---|---|---|---|---|---|---|
| | Av | stdev | Av | stdev | | | Av | stdev |
| Air dry in shed | 429 | 27 | 108 | 15 | 70 | 53 | 102 | 33 |
| Constant 20°C | 436 | 40 | 106 | 18 | 73 | 57 | 98 | 34 |
| Freeze then Constant 20°C | 439 | 33 | 107 | 15 | 71 | 50 | 97 | 33 |
| Constant 25°C | 434 | 35 | 108 | 18 | 73 | 57 | 105 | 37 |
| Freeze then Constant 25°C | 434 | 37 | 112 | 18 | 69 | 53 | 117 | 38 |
| Kiln dry 50/40°C | 425 | 32 | 116 | 19 | 67 | 57 | 114 | 36 |
| Air dry inside | 433 | 34 | 109 | 29 | 67 | 50 | 117 | 33 |
| Freeze Dry | 425 | 30 | 117 | 20 | 55 | 30 | 124 | 35 |

## Drying conditions

Traces of temperature conditions for each drying method are given in Appendix 1. In general each charge was dried as expected, with no major deviations from planned conditions. The charge dried indoors was initially intended to be dried at a minimum of 20°C, but a heater failure meant that temperatures frequently went below this level. In early May the room was getting quite cold overnight (16°C), so additional heating was found, and the room heated so it was at least 20°C overnight.

For each drying method, boards were weighed periodically, to estimate when they had reached 30% MC, then were kiln dried at 70/55°C to 12% MC (as recommended in Haslett (1988)). The boards were then stored at 20°C, 65%RH until their weight had stabilised.

Table 4. Drying times and moisture content variation for each

| Charge number | Drying method | Time to 30%MC (days) | Kiln Drying time (days) | Final MC (%) |
|---|---|---|---|---|
| 1 | Air dry in shed | | | |
| 2 | Constant 20°C | 41 | 6.7 | 12.2 |
| 3 | Freeze then Constant 20°C | 42* | 6.7 | 11.8 |
| 4 | Constant 25°C | 27 | 3.7 | 9.8 |
| 5 | Freeze then Constant 25°C | 28* | 3.7 | 9.5 |
| 6 | Kiln dry 50/40°C | 9.1 | 3.7 | 11.9 |
| 7 | Air dry inside (av 21°C) | 42 | 6.7 | 12.0 |
| 8 | Freeze Dry -20°C | | | |

* Includes 24h at -7°C prior to drying.
Remaining drying charges will be added as they complete drying

## Effect of charge on drying quality

For each drying technique, the proportion of boards with each level of degrade is shown in Figure 9. Darker colours indicate higher levels of degrade. Visually there are differences in the proportions of boards with each level of degrade between the treatments, and the overall proportions are significantly different between the boards dried at 20 or 25°C and the kiln dried boards (chi squared independence test). Kiln drying is not typical for E. nitens, so it is not surprising that it has higher levels of checking than the boards dried at 25°C. At both 20 and 25°C there was no significant difference between the boards that were pre-frozen and the boards that were not.

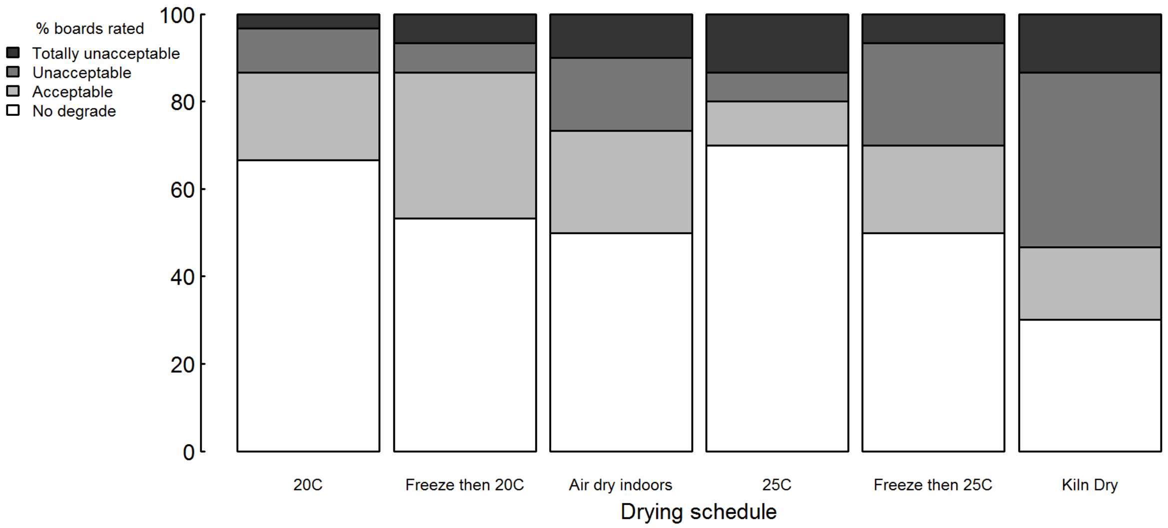


Figure 9. Levels of degrade for each drying method. Bars show the proportion of boards with each level of degrade, with darker bars indicating higher levels of degrade.

### Effect of log on drying quality

For each log, the level of degrade for all the boards dried to date are shown in Figure 10. Each rectangle represents a board cut from the log, and the boards are arranged according to the drying technique used. There are a wide range of degrade assessments between logs - some (e.g. 39) have no degrade after any of the three drying techniques, but one board (#176) has severe degrade for all the drying techniques. Most logs fall in between these extremes, with boards tending to have low levels of degrade (or no degrade) after 25°C drying, but higher levels of degrade after kiln drying

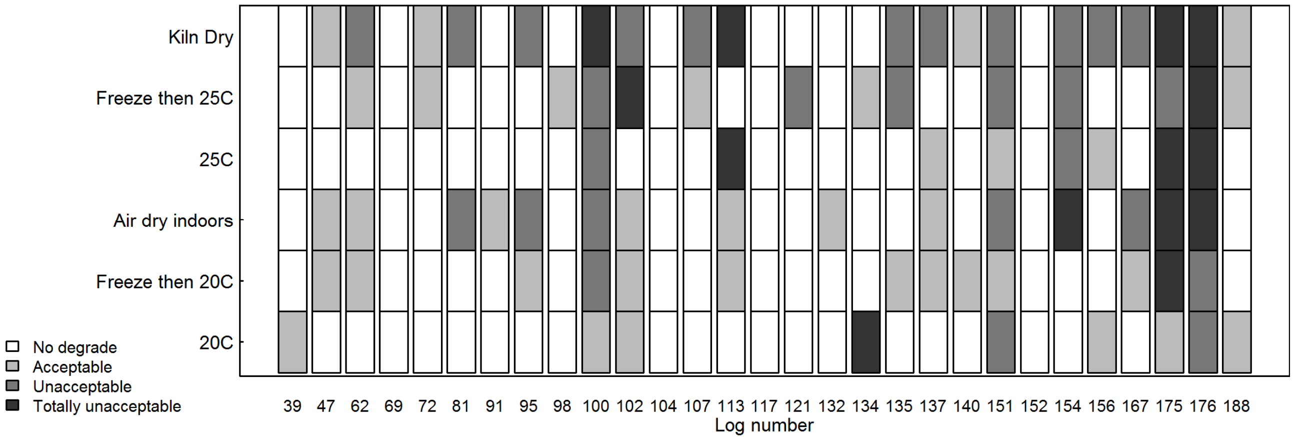


Figure 10. Assessment of degrade for boards cut from each log. One parent board was mislabelled during sample preparation, leading to one log (#93) not having any boards present in four of the charges shown here.

To investigate the link between overall log behaviour and the non-destructive screening measures, each log was assigned a “log condition” value - taken as the average of all the board condition values shown in Figure 10. A higher value of log condition indicates greater levels of degrade following drying. Two resi traces were taken for each tree, so each board has two sets of resi data associated with it, giving a total of 360 data points. Seventy percent of these data points (252 points) were used create a linear model to predict the log condition values from key non-destructive measures:

- Overall length of the resi trace (Max.resi)
- Maximum shrinkage of the 10mm core (Max.shrinkage..S1.to.S5)
- maximum height of a growth ring peak in the resi trace (maxdiff)
- Estimate of pith location on resi trace (Est.pith)
- Maximum torque of an identified peak in resi trace (max)

The model output is shown in Table 5.

Table 5. Model output for predicting overall log condition.

```
Call:
lm(formula = log_condition ~ Max.resi + Max.shrinkage..S1.to.S5. + 
    maxdiff + Est.pith + max)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.89904 -0.40420 -0.03476  0.30386  1.22977 

Coefficients:
                           Estimate Std. Error t value Pr(>|t|)    
(Intercept)              -3.7583940  0.7890132  -4.763 3.23e-06 ***
Max.resi                  0.0175994  0.0018947   9.289  < 2e-16 ***
Max.shrinkage..S1.to.S5. -0.2380815  0.0685169  -3.475 0.000603 ***
maxdiff                  -0.0011374  0.0001939  -5.865 1.42e-08 ***
Est.pith                 -0.0029803  0.0013212  -2.256 0.024950 *  
max                       0.0006675  0.0001361   4.906 1.68e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5001 on 250 degrees of freedom
Multiple R-squared:  0.5374,	Adjusted R-squared:  0.5281 
F-statistic: 58.08 on 5 and 250 DF,  p-value: < 2.2e-16
```

The remaining 108 data points were used to calculate a predicted log condition, to compare to the actual log condition from the board data. This is shown in Figure 11.

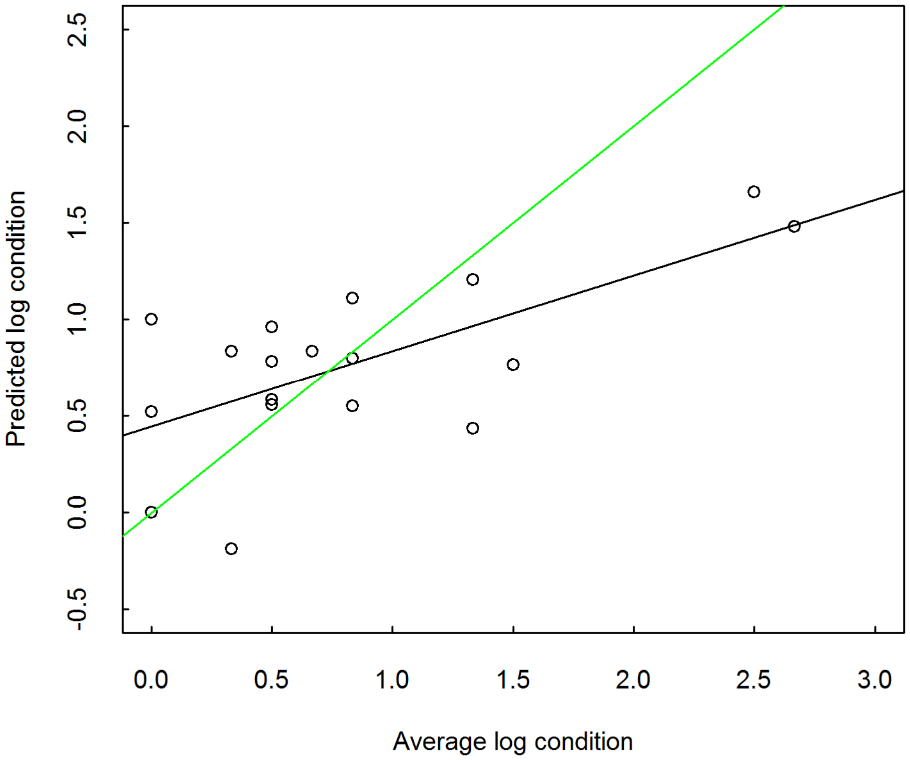


Figure 11. Actual log condition (average board condition for each log) vs. predicted log condition from the linear model in Table 5. R$^{2-}$value = 0.438

The fit from the linear model is not too bad, but only takes into account a small number of the resi metrics calculated, so a random forest model was used to find a relationship between the condition of each log using the same variables used to fit the disc checking model. This model was used to predict the log condition of the remaining data points. These are plotted against the actual log condition values in Figure 12. The fit from this model is no better than that of the linear model, suggesting that the simpler linear model should be used in future when estimating log properties from the non-destructive measurements.

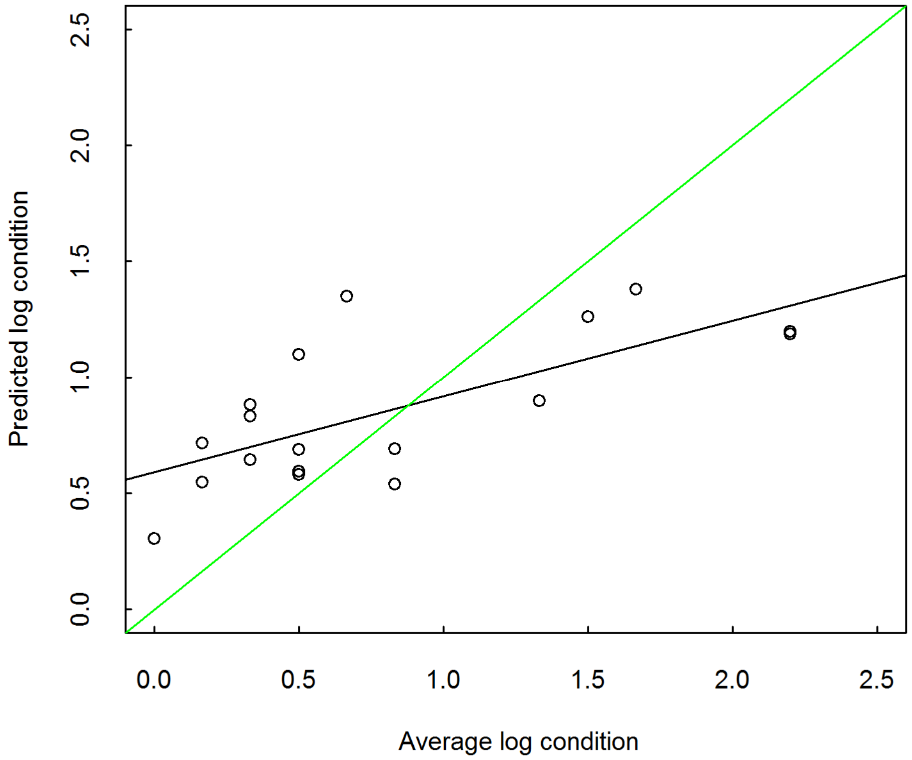


Figure 12 Actual log condition vs Predicted log condition from the random forest model. $R^2$ = 0.4867

**Predicted drying behaviour vs actual drying behaviour**

To determine if the degrade assessments of each board can be explained by the predicted log condition calculated above, a linear model was used. The following variables were included in the model:

- Predicted log condition (from the random forest model above)
- Whether the board had been frozen
- Drying temperature
- The growth ring orientation (i.e. quarter sawn or not)
- Whether the board had been dried under constant temperature and RH conditions

As with the previous models, 70% of the boards dried were randomly selected to create the model, leaving the remaining 30% to validate it. The output from this linear model is shown in Table 6. The effect of each variable is shown in the coefficients list, where the variable and its slope are listed, and on the far right a significance value is given. The predicted log condition is highly significant, as is the drying temperature. Both have a positive correlation - increased drying temperature increases levels of degrade, and increased (i.e. worse) log condition score increases levels of degrade. Variable drying conditions is also significant - drying under variable conditions increased levels of degrade. Both sawing orientation, and whether or not the boards have been frozen are not significant.

Table 6. Output of linear model to show the effects of predicted log condition and drying treatment on overall board rating.

```
lm(formula = board_condition ~ pred_log_condition + Freeze +
    Qsawn + Drying.temp + airdry)

Residuals:
     Min       1Q   Median       3Q      Max
-1.40492 -0.48132 -0.01684  0.39352  2.52795

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)        -0.681828   0.310358  -2.197   0.0300 *
pred_log_condition  1.070046   0.089242  11.990  < 2e-16 ***
FreezeTRUE          0.129370   0.152516   0.848   0.3980
Qsawn              -0.003645   0.002468  -1.477   0.1424
Drying.temp         0.029799   0.006464   4.610 1.02e-05 ***
airdryTRUE          0.396036   0.187301   2.114   0.0366 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6808 on 119 degrees of freedom
Multiple R-squared:  0.5843,   Adjusted R-squared:  0.5669
F-statistic: 33.46 on 5 and 119 DF,  p-value: < 2.2e-16
```

Using the coefficients from the model above, predicted levels of degrade were calculated for the remaining 30% of the boards. This is plotted against the actual levels of degrade in Figure 13. There is a relatively strong positive correlation between the actual and predicted levels of degrade (R2 = 0.6742), suggesting that the log conditions can help to predict final board degrade for a range of drying methods.

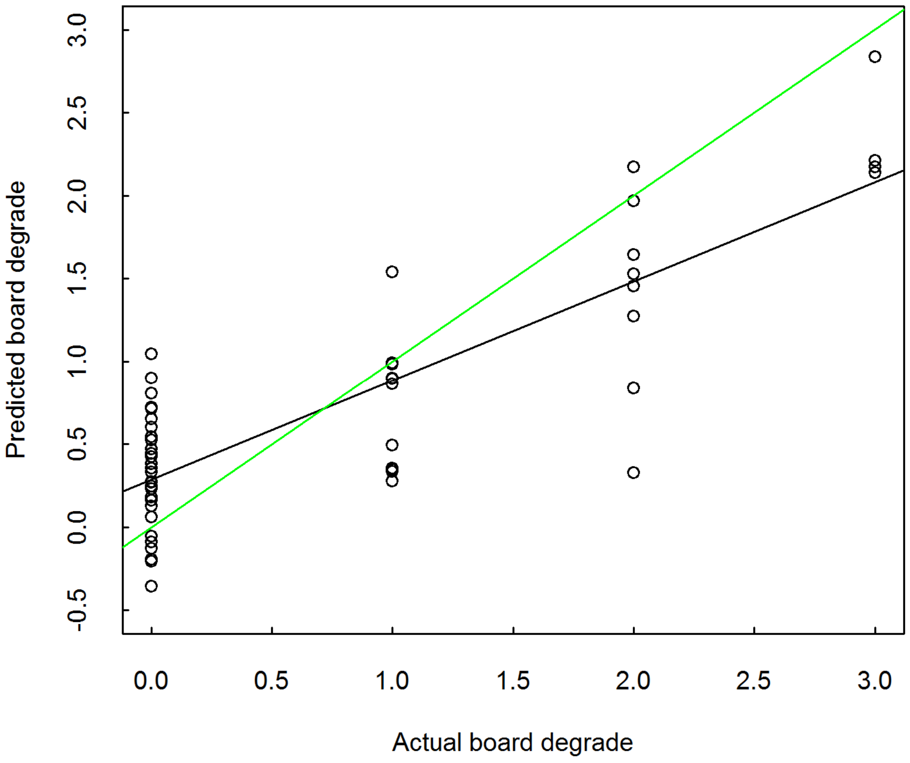


Figure 13. Predicted levels of board degrade vs Actual levels of degrade. The best fit line is shown in black ($R^2$ = 0.6742) and the equivalence line shown in green.

# CONCLUSION

The non-destructive measurements used here do not appear to give a good correlation with numbers of checks in discs cut from breast height and log height. Nonetheless, the 30 trees selected on the basis of the non-destructive measures had a wide range of checking behaviours - based on the number of checks in dried discs, and also in the levels of checking and collapse seen in dried boards.

Due to several delays during the course of this work two of the drying treatments are not yet dry, so have not been assessed for checking and collapse. These will be reported separately in a file note once they are complete (later in 2017). For the drying treatments that have been assessed, there was increased levels of degrade in boards dried at higher temperatures, but no significant difference in the boards that had been frozen. Air drying under variable conditions gave slightly higher degrade than boards dried under constant conditions. There was no significant difference between boards dried at 20°C and 25°C, despite suggestions in the literature of a collapse threshold between these temperatures where levels of degrade become much worse above the threshold temperature.

Good correlations were found between the non-destructive measurements and the average levels of degrade for each log. Log condition ratings calculated from these correlations showed good agreement with actual levels of degrade in the boards, suggesting potential for non-destructive screening to identity trees that can be dried without degrade.

Future drying studies that involve air drying timber will ensure that the temperature conditions vary between day and night, to give more representative levels of degrade comparing to industrial air drying practise. No further work will be done on pre-freezing.

Non-destructive screening shows promise for identifying trees that do not check or collapse, even when kiln dried, and this should be investigated further. Specifically measurements from the Resi and the 10mm cores gave good correlations with the levels of degrade in dried boards. As 10mm cores can be time consuming and problematic to collect, screening solely with the Resi measurements should be looked at further.

# ACKNOWLEDGEMENTS

This work required the assistance of a large number of people, both within Scion and other organisations.

Kane Fleet and Mark Millar did all the non-destructive measurements, assisted by SouthWood Exports.
Graeme Manley, Shaun Foster and John Rope at SouthWood Exports worked very hard to arrange the supply of trees, discs and logs for this work.
John Lee provided a lot of advice about assessing disc checking and assisted with preparing discs for check assessment. Bernie Dawson counted the checks in all the discs.
Jonathan Harrington gave a lot of advice about analysing the Resistograph traces and developing the disc checking predictions using Random Forests modelling. Jonathan also created the barcodes used to track the logs during sawing.
Toi-Ohomai Institute of Technology sawed the logs for us, and allowed us to prepare our logs in their log yard (cutting discs, attaching barcodes). John Lee, Greg Steward, Jamie Agnew, Kane Fleet, Bruce Davy and Steve Chapman (all Scion) assisted with log preparation. John’s experience in attaching barcodes was particularly helpful.
Bruce Davy, Jamie Agnew and Steve Chapman cut, labelled and painted the boards prior to drying and assisted with assessing degrade following drying. Bruce also set up and monitored several of the drying treatments. Maxine Smith assisted with moisture content and density measurement of the boards.

# REFERENCES

Breiman, L., Cutler, A., Liaw, A., & Wiener, W. randomForest: Breiman and Cutler's random forests for classification and regression (6 December 2009) by

Chafe, S. C. (1985). The distribution and interrelationship of collapse, volumetric shrinkage, moisture content and density in trees of Eucalyptus regnans F. Muell. *Wood Science and Technology, 19*(4), 329-345. doi:10.1007/BF00350810

Choong, E. T., Mackay, J. F. G., & Stewart, C. M. (1973). Collapse and moisture flow in kiln-drying and freeze-drying of woods. *Wood Science, 6*(2), 127-135.

Harrison, J. B. (1998). Method of drying lumber: Google Patents.

Haslett, A. N. (1988). FRI Bulletin No, 119: Properties and utilisation of exotic specialty timbers grown in New Zealand. Part V: Ash Eucalypts and *Eucalyptus nitens*. Scion, Rotorua.

Holden, G., Cown, D., & Kimberly, M. (2005). *Non-Destructive Testing for Intra-ring Checking in Radiata Pine. WQI report no. APP 41.*

IML Inc. *IML Resistograph*. Retrieved 06/06/2017, from http://www.imlusa.com/html/iml_resistograph.html

Innes, T. (1995). Collapse free pre-drying of Eucalyptus regnans F. Muell. *Holz als Roh-und Werkstoff, 53*(6), 403-406.

Lausberg, M. J. F., Gilchrist, K. F., & Skipwith, J. H. (1995). Wood Properties of *Eucalyptus nitens* Grown in New Zealand. *New Zealand Journal of Forestry Science, 25*(2), 147-163.

*Random Forest*. Retrieved 31/5/2017, from https://en.wikipedia.org/wiki/Random_forest

Sargent, R., Harrington, J. J., & Gaunt, D. (2016). *Improving drying quality of Eucalyptus Nitens Timber: Results to Date. SWP T-008.* Rotorua, New Zealand: Specialty Wood Processing Partnership.

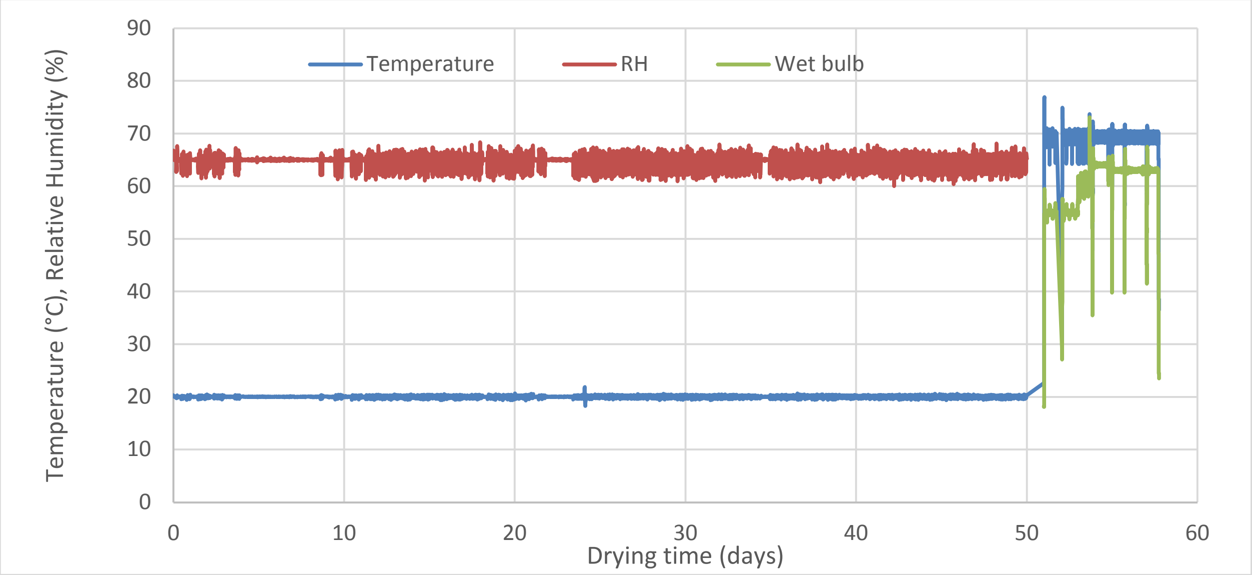
Shelbourne, C., Nicholas, I., McKinley, R., Low, C., McConnochie, R., & Lausberg, M. (2002). Wood density and internal checking of young Eucalyptus nitens in New Zealand as affected by site and height up the tree. *New Zealand Journal of Forestry Science, 32*(3), 357-385.

# APPENDICES

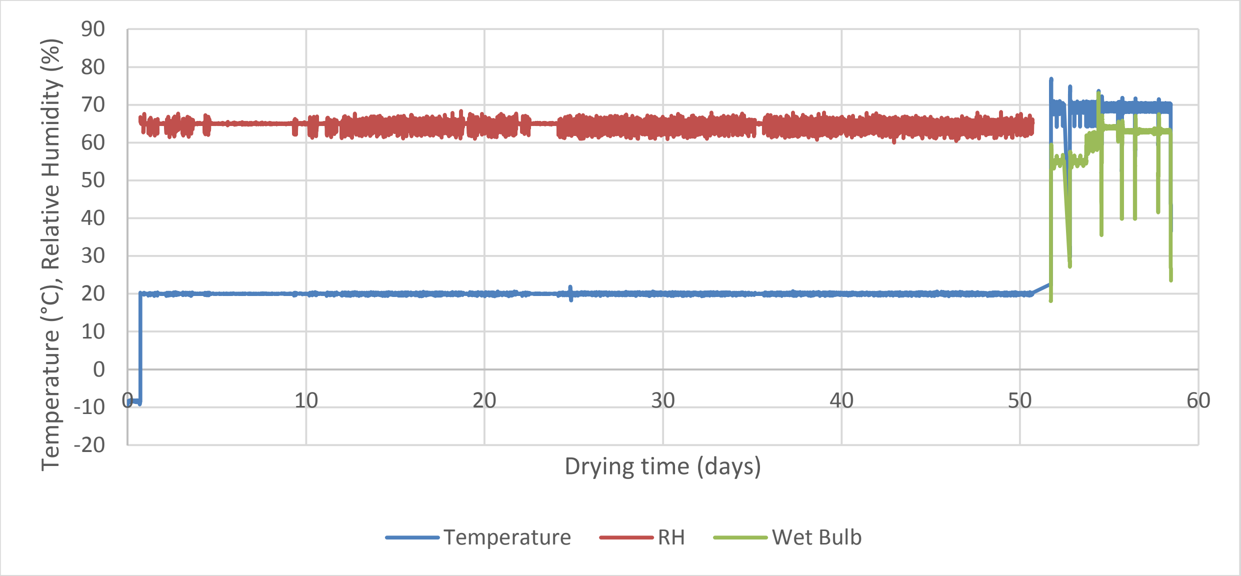
## Appendix 1: Drying conditions for each charge

Charge 1. Outdoor shed

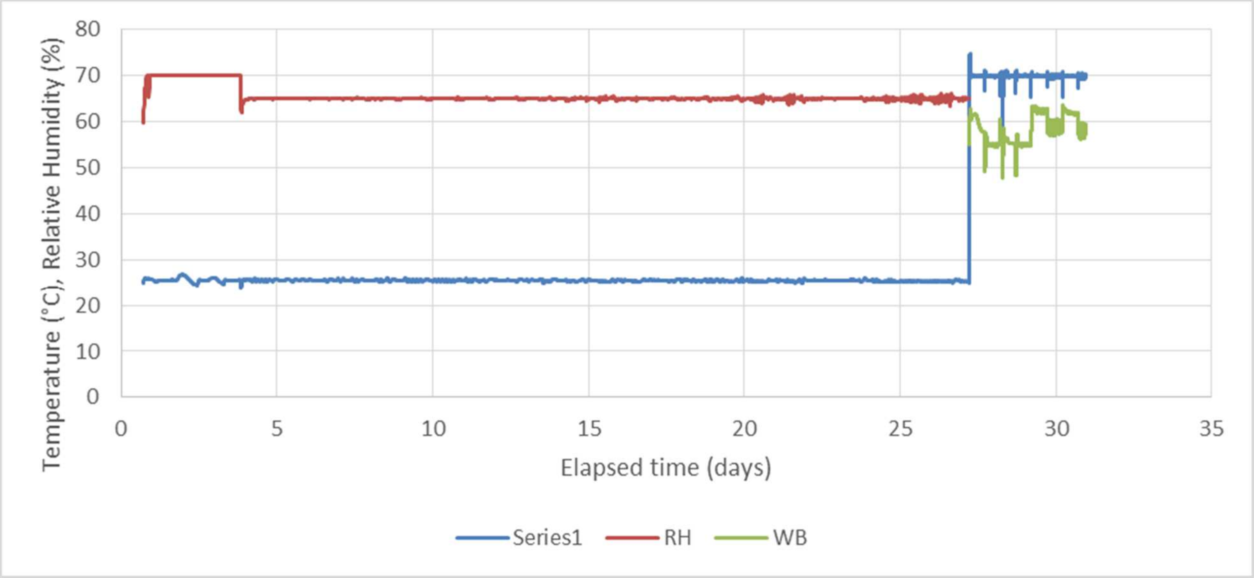
Charge 2. Constant 20°C



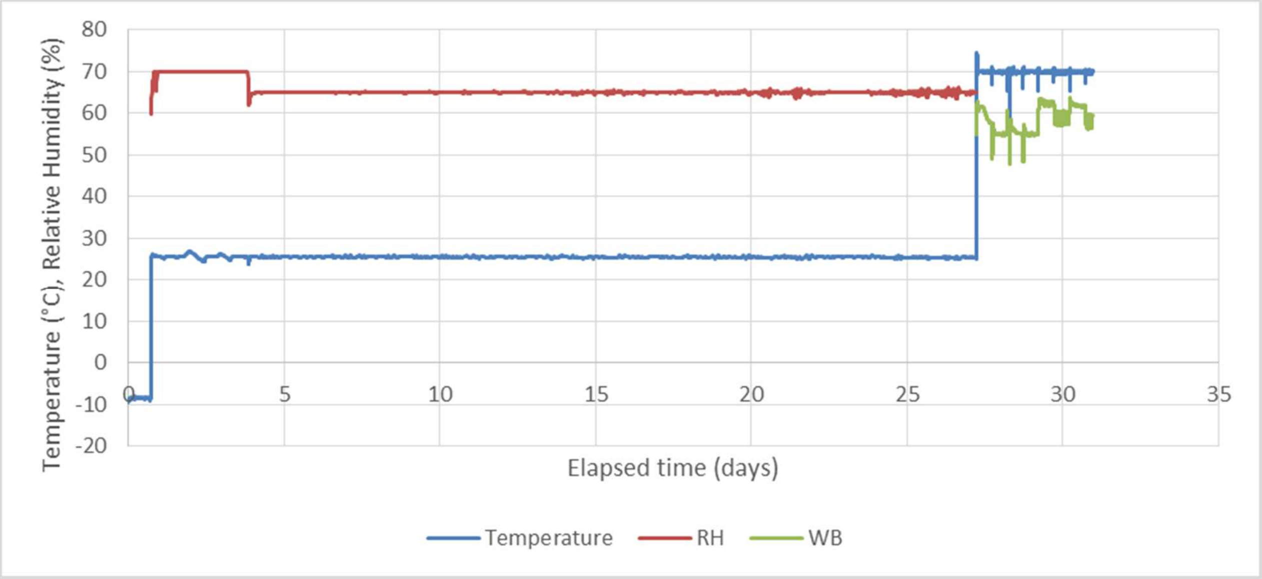
Charge 3. Freeze then Constant 20°C



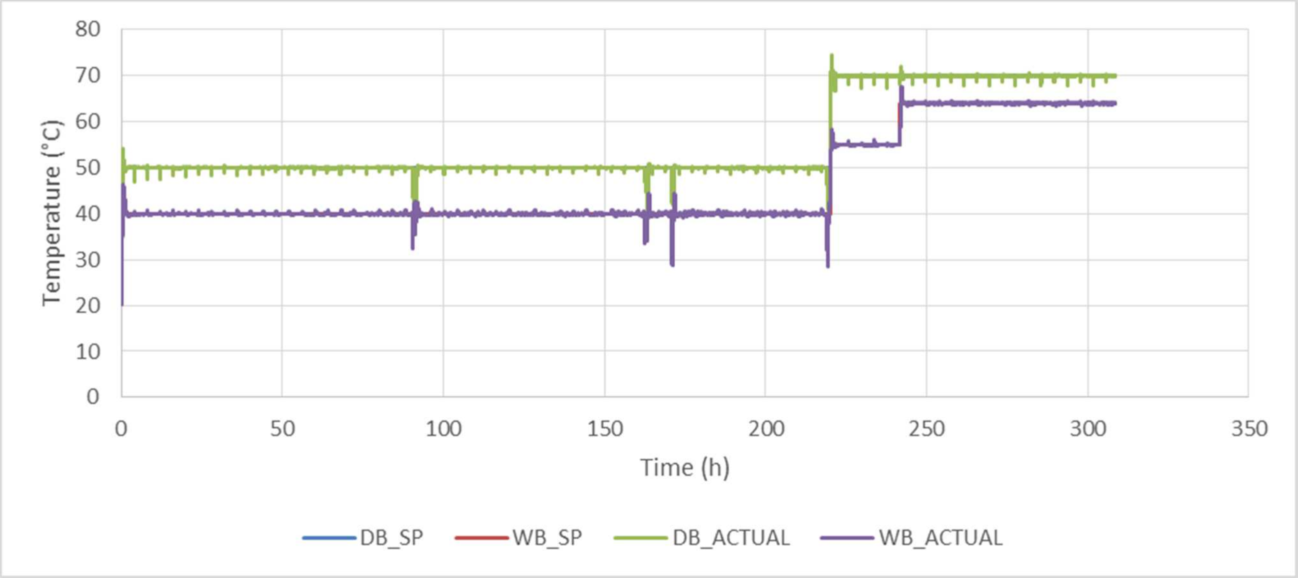
Charge 4. Constant 25°C



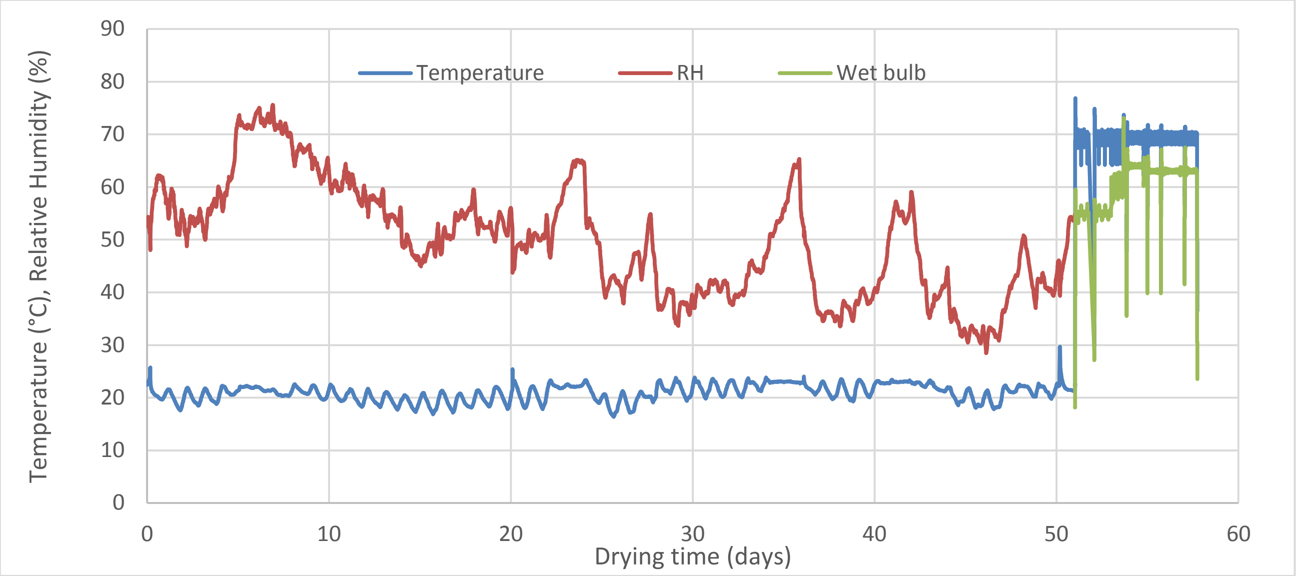
Charge 5. Freeze then Constant 25°C



Charge 6. Kiln dry at 50/40°C



Charge 7. Air dry inside



Charge 8. Freeze dry at -20°C

## Appendix 2: WQI report APP41

# NON-DESTRUCTIVE TESTING FOR INTRA-RING CHECKING IN RADIATA PINE
# - An Evaluation of the Core Method

**A Report for WQI Ltd**
**By**
**GRANT HOLDEN, DAVE COWN AND MARK KIMBERLY**
**REPORT NO. APP 41**
**DATE: FEBRUARY 2005**

Confidentiality: This is a report prepared for WQI Ltd. Information contained in this report is restricted to shareholders of WQI Ltd. This report may not be copied or distributed except amongst WQI Ltd shareholders.

## REPORT INFORMATION SHEET

| | | |
|---|---|---|
| ***REPORT TITLE*** | **Non-Destructive Testing for Intra-ring Checking in Radiata Pine - An Evaluation of the Core Method** | |
| ***AUTHOR*** | Grant Holden Forest Research<br>Dave Cown Forest Research<br>Mark Kimberly Forest Research | |
| ***REPORT NO.*** | 41 | |
| ***WQI OBJECTIVE*** | APP | Appearance |
| ***WQI PROJECT*** | 1 | Intra-ring checking |
| ***WQI TASK*** | 14 | Prediction of propensity of radiata pine to internal checking |
| ***WQI MILESTONE*** | 7 | An evaluation of the core method |
| ***SIGNED OFF BY*** | Graeme Young | |
| ***DATE*** | February 2005 | |
| ***CONFIDENTIALITY REQUIREMENT*** | This is a report prepared for WQI Ltd. Information contained in this report is restricted to shareholders of WQI Ltd. | |
| ***INTELLECTUAL PROPERTY*** | This report may not be copied or distributed except amongst WQI Ltd shareholders. | |

WQI LIMITED
New Knowledge in Wood Quality

forest research

# EXECUTIVE SUMMARY

## *NON-DESTRUCTIVE TESTING FOR INTRA-RING CHECKING IN RADIATA PINE*

### *-AN EVALUATION OF THE CORE METHOD*

*GRANT HOLDEN, DAVE COWN, MARK KIMBERLY*

*REPORT NO. APP 41 DATE: FEBRUARY 2005*

### Background

Intra-ring checking (IC) is widespread in the radiata pine resource, and WQI benchmarking studies are showing that it is present to some degree at all sites sampled. It is a major issue for appearance grade products, costing the industry at least $15 million a year.

The ability to predict the likelihood of IC from standing trees will result in greater efficiencies in resource allocation to appropriate end uses at the stump. Such a method could be applied both to stand evaluation and to breeding select genotypes with a lower likelihood of developing intra-ring checks; it would thus be a doubly valuable tool, with potential to project benefits both forward and back in the production cycle.

### WQI initiatives

Because intra-ring checking will be a feature of the plantation resource for the immediate future, a significant amount of WQI Ltd research is focused on the problem. Specifically, WQI has identified several lines of inquiry, and has initiated research to:

1. Investigate the fundamental causes of IC;
2. Investigate the effect of some management practices on the incidence of IC;
3. Develop and/or improve the accuracy of various methods of screening for and predicting IC.

### Project APP 41

This project is part of Item 3 above, one of several projects investigating potential prediction techniques.

The primary objective was to evaluate the relationship between checking in discs and collapse in core samples, with a view to developing a non-destructive core sampling technique for assessing a tree's potential for IC. Such a technique should ideally be suitable for use in both young and mature trees.

A pilot study showed a clear relationship between checking in oven-dried discs and collapse in 12mm cores, especially for discs with severe checking. However, that study was only carried out on relatively young trees (7-year-old) and it was decided to extend it to include both young and older stands. It was also important to investigate the effects of varying the time between core sampling and actual assessment of the cores on the results obtained.

Trees were selected from Puruki (7-year-old) and Kinleith (17-year-old) trials that had been previously assessed and known to contain both „”checking“ and non-checking „ families. Four families (2 „checking „and 2 „non-checking „) were sampled at each site, providing a total sample of 44 trees. Breast height discs and 12mm core samples were collected and dimensional measurements recorded before processing in the laboratory. Duplicate samples of both discs and cores were also stored for 19 days before oven-drying.

Discs and cores were then examined to determine whether there was a strong enough relationship between checks in discs and collapse in cores to mean that increment cores could provide a useful method for assessing propensity for intra-ring checking.

## Results

There were strong correlations between checking and core collapse for both fresh and stored cores at both sites. Spearman correlations of greater than **0.80** were obtained between checking count and both mean collapse across all sapwood rings and maximum collapse. As maximum collapse should be quicker to assess than mean collapse, it would appear to be the preferred variable to measure.
In a nutshell, 12mm increment cores can provide a useful non-destructive tool method for screening a resource for IC.

## Significance for WQI shareholders

These results further confirm the core based method as a potential substitute for the destructive disc analysis method.

To further improve confidence in this technique as a substitute for the disc-based oven-dried assessment (which requires tree felling) the method needs to be applied to a wider range of ages and sites.

Assessments of clear-fell aged trees would prove its applicability as a resource description tool and also its suitability in determining stand value. Proof of repeatability in young clonal stands will also indicate potential as a screening tool for breeding, but in all cases it is necessary to understand variability across sites to ensure uniformity in interpretation of intraring susceptibility.

## Implications for WQI

WQI has been seeking a cheaper and quicker method to predict intra ring checking. To assess a stand by the destructive disc method requires the felling of around 30 trees. Further investment in improving confidence in the core based method is warranted based on the outcomes of the work reported here.

## INTRODUCTION

Intra-ring checking is recognised as a major issue for appearance grade products, and a significant amount of WQI Ltd. research is focused on gaining a greater knowledge of factors contributing to the phenomenon (Jackson and Nair 2003; Kimberley and McConchie 2004; Ball *et al* 2004; Kumar *et al.* 2004). The WQI Benchmarking studies are showing that checking is present to some degree at all sites sampled, and concentrated in the butt log (Cown *et al.,* 2004). Given that it will be a feature of the plantation resource for the immediate future, refinements have also been made to improve laboratory methods for assessing the potential of material to express this defect during processing (McConchie *et al.* 2003; McConchie and Kimberley, 2003).

The ability to predict the likelihood of internal checking from standing trees will result in greater efficiencies in resource allocation to appropriate end uses at the stump. While the exact causes of internal checking still remain unknown (Cown *et al,* 2003), it is important to try to develop a non-destructive method that will indicate the propensity of trees to intra-ring check. The method could be applied to stand evaluation and in breeding to select genotypes with a lower likelihood of developing internal checks.

Very often, checked discs also show visible signs of collapse, and Pang (2001) noted differences in earlywood and latewood shrinkage and suggested they might be related to intraring checking. Thus, if increment core samples could be induced to shrink and/or collapse, this may give an indication of the propensity for checking during drying. This was looked at in a previous intensive study of young radiata pine clones from a check prone site using disc samples and SilviScan strips to investigate wood property and anatomical relationships to intra-ring checking (Ball *et al.,* 2004). Evidence indicated a relationship between checking propensity and low earlywood wood density, large tracheid diameter and thin cell walls (all factors associated with collapse _ Pang *et al* 1999). Nevertheless, square radial strips cut from these clones showed no propensity to collapse.

A pilot study comparing checking in oven-dried discs with collapse in 12mm cores showed a clear relationship, especially for discs with severe checking (Holden *et al,* 2004). However, this study was only carried out on relatively young trees (7-year-old) and it was recommended that the study be extended to include both young and older stands. It was also important to investigate whether delayed processing of cores may affect the relationship between disc checking and core collapse.

## OBJECTIVES

1) To evaluate the relationship between checking in discs and collapse in cores in an independent set of samples of different ages

2) To investigate the effect of core storage on subsequent collapse

## METHOD

Previous studies have identified check-prone and non check-prone families in several trials. Using this knowledge, two high checking families and two low checking families were sampled from trials in both Puruki Forest (planted 1997) and Kinleith Forest (887 female tester, planted 1987). In the Puruki trial, 6 trees per family were selected and in the Kinleith trial 5 trees per family were selected.

In early December 2004, the 24 unpruned trees in the Puruki Forest were pruned to 1.8 metres to provide access for core collection. One side of the tree was marked at around 1.4 metres, avoiding obvious defects and compression wood. Three 12mm bark-to-bark cores were extracted in the vertical plane, labelled and sealed in plastic bags. Each tree was felled and two 60mm breast height discs taken with the position of the cores marked on each disc. In mid December the same procedure was carried out on the 20 trees in the Kinleith trial. All samples were transported to Forest Research and stored in a cold room before processing.

The day after collection, one core from each tree was marked at each latewood boundary and intra-ring midpoint and tangential diameters measured at each point with a digital calliper. The radial length of the two halves of each core was also measured. Cores were randomly arranged in an oven and dried. A second core from each tree was stored in a cold room for 18 days before being processed as above and the remaining core sent to CSIRO for further testing. After drying, core diameters were remeasured at the marked locations and radial lengths recorded.

One disc from each tree was processed 2 days after collection and the remaining disc stored in the cold room for 18 days before processing. Bark was removed from each disc and the circumference measured. A cambium-to-pith slit was cut in each disc using a band saw and the discs oven dried. After drying the slit was remeasured at the periphery of the disc and the disc cut in half. Each half disc was then split, sanded and the checks recorded.

## RESULTS AND DISCUSSION

### Disc checking

The mean number of checks for each family for fresh and stored discs is shown in Fig. 1 and the number of rings affected shown in Fig. 2. An example of a checking disc versus a non-checking disc is shown in Appendix 1.

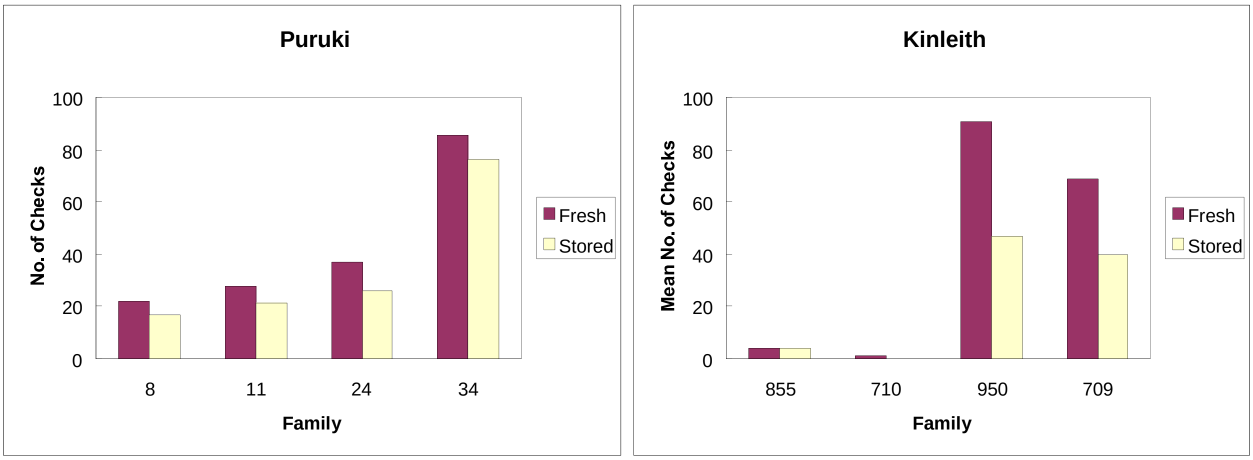


**Fig 1.** Mean number of checks per disc for Puruki and Kinleith

As expected, there was a similar level of checking in both the young stand (Puruki) and the older stand (Kinleith) since low and high checking families were selected at each site.

Previous studies showed that at Puruki, families 8 and 11 were likely to be low checkers and families 24 and 34 high checkers. However, data from this latest study indicated that all the young families had at least a moderate level of checking (> 20 checks / disc) and family 24 was at the lower end rather than the expected higher end of the scale. This implies a relatively high level of within family variation in checking, 7 years after planting, and if an estimate of family performance was required at this young age, then a higher sampling intensity than 6 trees per family would be needed. However, the objective of this study was to relate core collapse to disc checking, and the level of checking between discs was adequate for this purpose. After disc storage for 19 days, the overall level of checking had decreased by up to 30% in the moderate checking discs and around 10% in the high checking discs. Although a reduction in checking after storage was expected, the level of reduction was not as great as that found in earlier studies (McConchie *et al.* 2004). It should be noted that 5 of the discs (20%) had *increased* checking after storage, indicating how inconsistently discs can perform after storage.

In the Kinleith trial, checking generally followed the family pattern identified from earlier studies, with families 855 and 710 showing on average less than 5 checks per disc and families 950 and 709 greater than 60 checks per disc. After disc storage for 19 days there was very little change in the low checking families, but nearly a 50% reduction in total checks in the high checking families. These results align more closely with the results from earlier storage studies compared with the Puruki data.

The average number of rings affected by checks, for each family, ranged from 2 to 5 rings on the Puruki discs and the range after storage decreased to about 1 - 3.5 rings. In the older Kinleith discs, less than one ring on average was affected in the low checking families and up to 7 rings in the higher checking families. After storage, there was only a slight reduction in rings affected in the low checking families and a far greater reduction in rings affected for family 709. However, family 950 showed very little difference in rings affected between fresh and stored discs (Fig. 2).

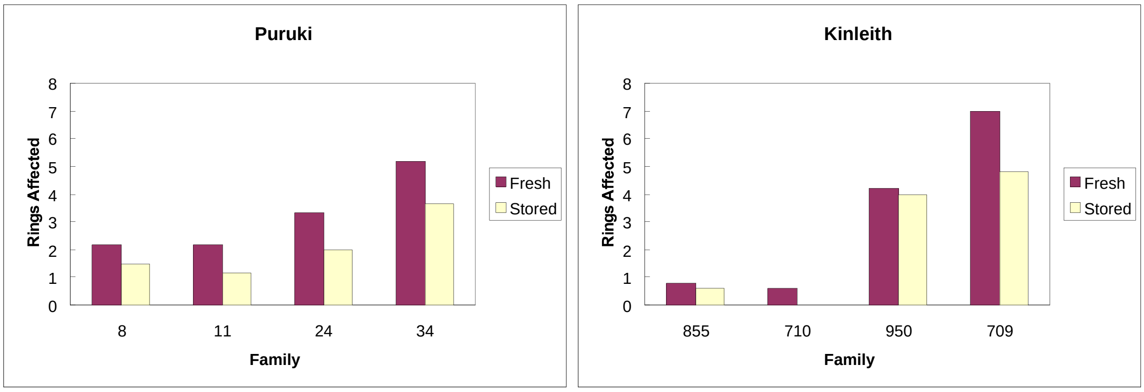


**Fig 2.** Mean number of rings affected per disc for Puruki and Kinleith

### Core Measurements

Measurement locations on the cores are shown in Fig. 3. Over 4500 diameter measurements were taken on the 88 cores. Measurements were not recorded in the heartwood region since generally no checking occurred in this area of the disc (Appendix 2).

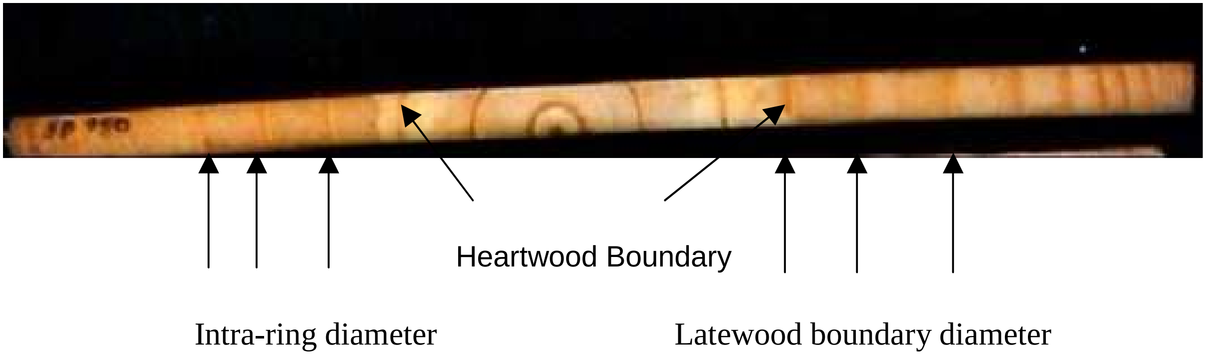


**Fig 3.** 12mm green core showing measurement locations

Tangential shrinkage was calculated from latewood boundary diameter and intra ring diameter from fresh and oven-dry cores and expressed as:

Latewood shrinkage = (A + B) / 2  (A1 + B1) / 2

Intra ring shrinkage = C  C1

Collapse = Latewood shrinkage  Intra ring shrinkage

where :

A = Latewood boundary A (fresh)

B = adjacent latewood boundary B (fresh)

A1 = Latewood boundary A (dry)

B1 = adjacent latewood boundary A (dry)

C = Intra ring (fresh)

C1 = Intra ring (dry)

An example of fresh versus dry cores is shown in Appendix 1.

Figs. 4 and 5 show the mean core collapse by ring number from bark for trees from the two sites.

There was little bark-to-pith trend for Puruki trees but collapse was generally higher in the fresh cores compared with the stored cores. Ring number from bark was only determined approximately for Kinleith trees due to some outer rings being difficult to identify. Nevertheless, a clear trend was evident for the Kinleith trees. Collapse increased steadily with distance in from the bark to the heartwood boundary and, as mentioned previously, no measurements were taken beyond this region. The lower level of collapse in the outer rings could, to some extent, be a reflection of the narrow rings in this unthinned stand. Collapse was slightly higher in fresh than stored cores for Kinleith trees.

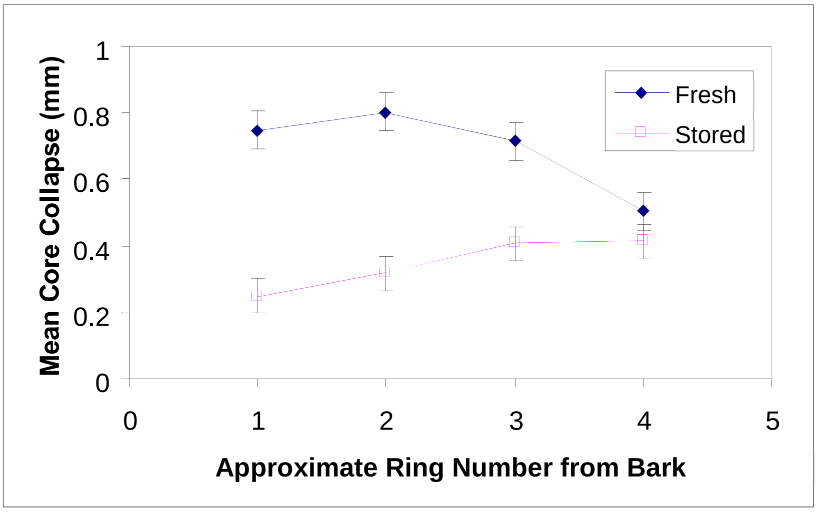


**Fig 4.** Mean core collapse by ring number from bark for the Puruki trees. Error bars show standard errors.

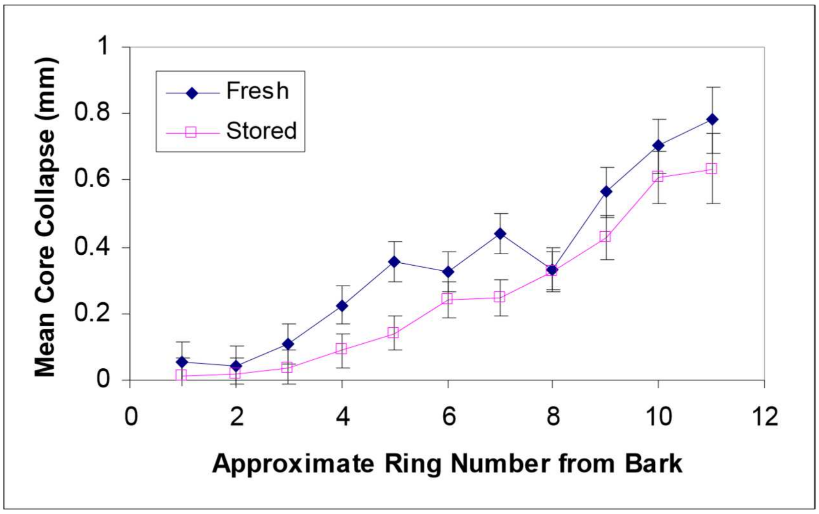


**Fig 5.** Mean core collapse by ring number from bark within the sapwood for Kinleith trees. Error bars show standard errors.

For each tree, checking count and rings affected by checking were averaged across the two half discs. The maximum core collapse (average of the maximum collapse from each of the two halves of the bark-to-bark cores), mean core collapse across all sapwood rings, and mean collapse in each ring from bark was obtained for each tree.

Spearman correlations were then calculated between checking and collapse variables. There were generally strong correlations between disc checking and core collapse. For both fresh and stored cores at both sites, correlations of greater than 0.80 were obtained for mean collapse across all rings and maximum collapse (Tables 1 and 2). As maximum collapse should be quicker to assess than mean collapse, it would appear to be the preferred variable to measure. It should be noted that outer ring collapse in the Kinleith trees was so small that the correlations between checking and collapse from these rings are generally spurious.

Table 1. Spearman correlation coefficients showing the relationship between core collapse (maximum, mean and collapse for each ring from bark), and disc checking (number of checks and number of rings affected) for Puruki trees.

| **Variable** | **Fresh** | | **Stored** | |
|---|---|---|---|---|
| | **Check count** | **Ring count** | **Check count** | **Ring count** |
| max. collapse | 0.85** | 0.90** | 0.74** | 0.78** |
| mean collapse | 0.84** | 0.91** | 0.72** | 0.76** |
| collapse, ring 1 | 0.73** | 0.67** | 0.46* | 0.46* |
| collapse, ring 2 | 0.79** | 0.88** | 0.67** | 0.66** |
| collapse, ring 3 | 0.73** | 0.83** | 0.56** | 0.63** |
| collapse, ring 4 | 0.72** | 0.79** | 0.59** | 0.64** |

* statistically significant at p=0.05

** statistically significant at p=0.01

Table 2. Spearman correlation coefficients showing the relationship between core collapse (maximum, mean and collapse for each ring from bark) and disc checking (number of checks and number of rings affected) for Kinleith trees.

| **Variable** | **Fresh** | | **Stored** | |
|---|---|---|---|---|
| | **Check count** | **Ring count** | **Check count** | **Ring count** |
| max. collapse | 0.86** | 0.84** | 0.83** | 0.81** |
| mean collapse | 0.83** | 0.81** | 0.85** | 0.83** |
| collapse, ring 1 | 0.45* | 0.47* | 0.68** | 0.71** |
| collapse, ring 2 | 0.33 | 0.30 | 0.02 | -0.02 |
| collapse, ring 3 | 0.59** | 0.57** | 0.48* | 0.53* |
| collapse, ring 4 | 0.77** | 0.76** | 0.66** | 0.65** |
| collapse, ring 5 | 0.63** | 0.63** | 0.58** | 0.54** |
| collapse, ring 6 | 0.57** | 0.55** | 0.67** | 0.65** |
| collapse, ring 7 | 0.57** | 0.60** | 0.68** | 0.69** |
| collapse, ring 8 | 0.62** | 0.62** | 0.71** | 0.71** |
| collapse, ring 9 | 0.60* | 0.59* | 0.39 | 0.41 |
| collapse, ring 10 | 0.71** | 0.70* | 0.60 | 0.61* |

* statistically significant at p=0.05

** statistically significant at p=0.01

Figs. 6 and 7 show the checking count plotted against maximum core collapse. For the younger Puruki trees, maximum collapse as low as 0.5 mm indicated low levels of checking and moderate levels of checking were evident with collapse of over 1 mm. For the older Kinleith trees, cores with maximum collapse less than 0.7 mm had virtually no checking. Mean checking counts for trees with maximum core collapse less than 0.5 mm, 0.5-1 mm, and greater than 1 mm are summarised in Table 3.

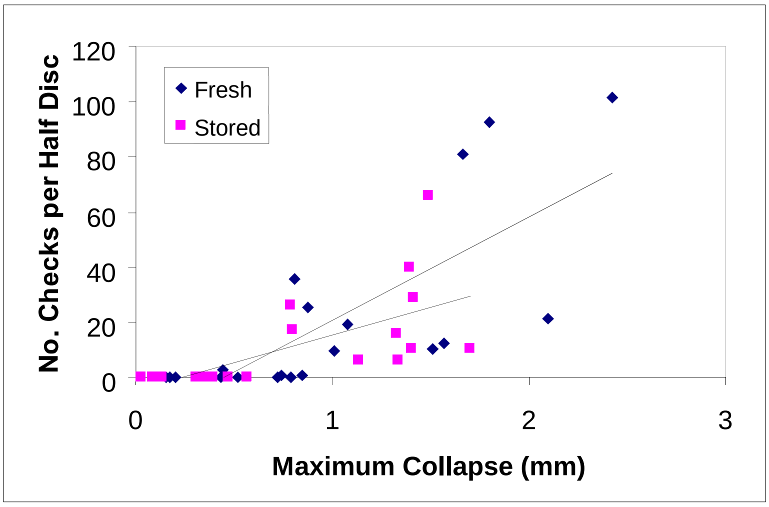


**Fig 6.** Checking count *vs*. maximum core collapse for the Puruki trees.

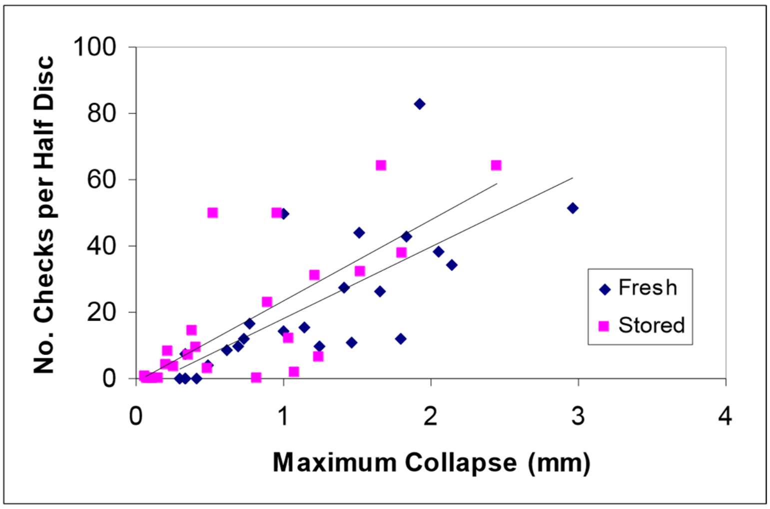


**Fig 7.** Checking count vs. maximum core collapse for the Kinleith trees.

Table 3. Mean check count and number of rings affected by checking, for trees classified on the basis of maximum core collapse.

| | | **Fresh** | | | **Stored** | | |
|---|---|---|---|---|---|---|---|
| **Site** | **Max. collapse** | **No. trees** | **Check count** | **Ring count** | **No. trees** | **Check count** | **Ring count** |
| Puruki | < 0.5 mm | 6 | 1.9 | 0.2 | 12 | 4.1 | 0.8 |
| | 0.5 - 1 mm | 6 | 18.5 | 2.4 | 4 | 30.5 | 2.4 |
| | > 1 mm | 12 | 33.0 | 4.1 | 8 | 31.1 | 3.2 |
| Kinleith | < 0.5 mm | 5 | 0.5 | 0.3 | 8 | 0.0 | 0.0 |
| | 0.5 - 1 mm | 7 | 8.9 | 1.4 | 4 | 10.8 | 2.0 |
| | > 1 mm | 8 | 43.4 | 4.6 | 8 | 23.0 | 3.8 |

## Core Radial Shrinkage

Core radial shrinkage expressed as a percentage of fresh core diameter is shown in Table 4. Spearman correlations were calculated between radial shrinkage and checking variables (Table 5).

Table 4. Mean Core Radial Shrinkage (% of diameter)

| **PURUKI FOREST** | | | **KINLEITH FOREST** | | |
|---|---|---|---|---|---|
| **Family** | **Fresh** | **Stored** | **Family** | **Fresh** | **Stored** |
| 8 | 3.39 | 2.60 | 855 | 2.64 | 2.33 |
| 11 | 3.22 | 1.98 | 710 | 2.78 | 2.42 |
| 24 | 3.15 | 2.02 | 950 | 3.02 | 2.59 |
| 34 | 3.97 | 2.38 | 709 | 3.46 | 2.45 |
| **Mean** | **3.36** | **2.22** | | **2.98** | **2.45** |

Table 5. Spearman correlation coefficients showing the relationship between radial shrinkage and disc checking (number of checks and number of rings affected) for both sites

| | **Fresh** | | **Stored** | |
|---|---|---|---|---|
| | **Check Count** | **Rings Affected** | **Check Count** | **Rings Affected** |
| **Puruki** | 0.19 | 0.29 | 0.10 | 0.28 |
| **Kinleith** | 0.71** | 0.72** | 0.25 | 0.28 |

** statistically significant at p=0.01

Mean shrinkage for the Puruki fresh cores ranged from 3.15% for family 24 up to 3.97% for family 34, with the lower checking families (8 & 11) placed somewhere between, indicating that there was no clear pattern of radial shrinkage relating to checking (Table 4). Mean shrinkage after storage was significantly less (2.22%) compared with the fresh cores (3.36%).

Kinleith cores showed slightly less shrinkage compared with the Puruki cores. The fresh cores showed a significant correlation between radial shrinkage and checking (Table 5), with family 855 the lowest (2.64%) and family 709 the highest (3.46%). However, this trend was not evident after storage with all families showing a similar level of shrinkage. As with the Puruki data, there was a reduction in shrinkage with storage (2.45%) compared with fresh cores (2.98%).

### Tangential-Radial Shrinkage Differential

The tangential-radial shrinkage differential was calculated as oven-dry slit width / green disc circumference. Mean values for each family are shown as a percentage of disc circumference in Table 6.

Table 6. Mean Tangential-Radial Shrinkage Differential (% of circumference)

| **PURUKI FOREST** | | | **KINLEITH FOREST** | | |
|---|---|---|---|---|---|
| **Family** | **Fresh** | **Stored** | **Family** | **Fresh** | **Stored** |
| 8 | 3.17 | 2.57 | 855 | 3.04 | 2.80 |
| 11 | 3.32 | 2.87 | 710 | 3.09 | 2.64 |
| 24 | 3.04 | 2.65 | 950 | 3.09 | 2.86 |
| 34 | 3.38 | 2.76 | 709 | 3.65 | 3.48 |
| **Mean** | **3.23** | **2.71** | | **3.22** | **2.94** |

At Puruki, shrinkage ranged from 3.04% (family 24) to 3.38% (family 34), both of these were at the higher end of checking in the discs and it was evident that there was no clear trend relating shrinkage differential to checking in the discs. The shrinkage differential was lower in the stored disks (2.71%) compared with the fresh discs (3.23%).

In the Kinleith trial, the shrinkage differential was highest in one of the high checking families (709), however there was little difference between the other 3 families. As in the Puruki trial, there was a reduced shrinkage differential for the stored discs (2.94%) compared with fresh discs (3.22%).

## CONCLUSIONS

- Increment cores (12mm) provide a useful NDT method for assessing propensity to intraring check.
- High correlations were obtained relating both mean core collapse across all rings and maximum collapse to intra-ring checking in discs.
- In the older stems, maximum collapse > 0.7mm was a strong signal for disc checking, while in the younger trees, > 0.5mm collapse was associated with checking.

Families previously selected for low and high levels of checking retained similar patterns, with significant within family variation in checking. This confirms the repeatability of the disc method.

- Discs and cores should be processed within a few days of collection. Storage of discs for 18 days between collection and oven-drying resulted in a decrease in checking of up to 30%.
- In older trees there was a consistent pattern of core collapse increasing from the bark to the heartwood boundary and generally no collapse occurred in the heartwood. This was evident in both discs and cores.
- The younger trees did not have a bark-to-pith pattern for collapse, presumably because heartwood formation had not begun (heartwood does not check), and ring widths were fairly uniform (narrow rings tend to show less collapse).
- No clear relationship was evident between radial shrinkage or tangential-radial shrinkage differential and intra-ring checking in discs.

## RECOMMENDATIONS

1. The Core Method has been shown to be a promising approach to NDT for propensity to intra-ring checking. It has only been applied in relatively small trials to date in the central North Island. It needs to be validated across a wider range of material.
2. Families have been shown to be quite variable in intra-ring checking _ requiring large numbers of samples for statistical validity. Clonal trials (requiring fewer samples for statistical validity) should be identified for further research on:
    a. **Age of expression of intra-ring checking**. Young material is more prone to collapse and checking, but it is uncertain how this relates to older stems with more heartwood. Select a trial where the same clones are replicated at different ages and compare the Core Method and Disc evaluations to evaluate the possibility of early selection for resistance to checking.

    b. **Effect of site**. Compare the same clones across different sites. Older clones would be preferable, if available.

    c. **Effect of physiological age**. Compare the same clone at physiological ages 1-3 years (on the same site?).

## ACKNOWLEDGEMENTS

Thanks are due to Kane Fleet, Mark Millar and Mike Rendall (Waimihia Thinners) for assistance with core and disc collection.

# REFERENCES

Ball, R.D., McConchie, M.S., Cown, D.J. 2004: Evidence for associations between SilviScan measured wood properties and intra-ring checking in a study of 29, 6-year-old *Pinus radiata* clones. Submitted to Canadian Journal of Forest Research.

Cown, D.J., McConchie, D.L. and McConchie, M.S. 2003: Intra-ring internal checking in radiata pine (*P. radiata* D. Don) in New Zealand. WQI Report App 1. 21pp.

Cown, D.J., McKinley, R., Jones, T., Downes, G. 2004: WQI Benchmarking Study. Summary of Sites 1-9 (Aupouri, Athenree, Ruatoria, Kaingaroa x 2, Mohaka, Lismore, Ngaumu, Southland). WQI Report Res 31.

Holden, D.G. and Cown, D.J 2004: Investigate methods of inducing collapse in cores. WQI Report App 22. 12pp.

Jackson, S. and Nair, H. 2003: Radial fibre collapse potential and cell wall lignin as indicators of intra-ring checking in radiata pine. WQI Report App 10. 24pp.

Kimberley, M., and McConchie, M.S. 2004: Effect of season and heartwood development on intra-ring checking. WQI Report App 15. 15pp.

Kumar, S., Jefferson, P., Carson, M. 2004: Variation in intra-ring checking within and among sites. WQI Report App 17. 21pp.

McConchie, M.S., Kimberley, M. Haque, N. 2003: Enhancement of the oven-drying method for predicting intra-ring checking. WQI Report App 11. 26pp.

McConchie, M.S. and Kimberley, M. 2003: Comparison of results of the improved ovendrying method for intra-ring checking, with existing techniques. WQI Report App 14 12pp.

McConchie, M.S. and Kimberley, M. 2004: Managing radiata pine intra-ring checking samples between collection and processing. WQI Report App 20. 10pp.

Pang, S.; Orchard, R.; McConchie, D.L. 1999:Tangential shrinkage of *Pinus radiata* earlywood and latewood, and its implication for intra-ring internal checking. New Zealand J. Forestry Science. 29(3): 484-491.

Pang, S. 2001: Anisotropic shrinkage, equilibrium moisture content and fibre saturation point of earlywood and latewood in radiata pine. *Proceedings* IUFRO International Wood Drying Conference, Tsukuba, Japan. 8pp.

# Appendix 1: Disc And Core Comparisons

Example of severely checked disc compared with a green and oven-dry core from the same tree

Example of a non-checked disc compared with a green and oven-dry core from the same tree

# Appendix 2: Effect Of Compression Wood On Checking And Core Collapse