VALIDATION OF A REDWOOD SEQUOIA SEMPERVIRENS (D. DON) ENDL BUTT LOG SAWING SIMULATOR

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By

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Redwood Buttlog Sawing Simulator: Validation

Abstract

Redwood (*Sequoia sempervirens* (D. Don) Endl.) has been identified as a species with considerable potential for plantation forestry in New Zealand. Investment decisions in high value alternate species must be based on accurate wood quality and value predictions. There is an opportunity to extend non-destructive evaluation tools available to redwood growers, and to present the outputs of the growth model by log products and sawn timber.

A redwood pruned buttlog sawing simulator has been developed however the simulator had not been tested with real data. Twelve redwood trees from Mangatu estate were selected for a sawing study; these logs were reconstructed and run through the sawing simulator. Computerised log processing was used to produce simulated pruned log sawing outturn from the redwood Buttlog Sawing Simulator, and results were compared to real results from a sawing study.

The objective of the study was therefore to determine how well the simulator matched volume and grade out-turn from twelve logs. This study found the many inconsistencies between simulated data and real data; particularly related to log size. While this study was unsuccessful in validation of the redwood sawing simulator, it provides initial insight into the simulators strengths and short comings.

Key words: redwood sequoia; simulated sawing; pruned logs; log reconstruction

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Introduction

Growing interest in alternative plantation species in New Zealand has led to the identification of redwood (*Sequoia sempervirens* (D. Don) Endl.) as a species with considerable potential. Unlike the dominant *Pinus radiata* D. Don, redwood timber is valued for its rich colour and natural durability due to the extractive content in its heartwood (Cornell, 2002). Historically redwoods have been grown in on a range of sites across New Zealand, however management of these potentially important stands has been lacking (Marshall & Silcock, 2009).

Pilot studies completed throughout New Zealand have found large variation in timber grade out turn across redwood stands. As alternative species plantations come with higher costs than traditional pine plantations, knowledge of volume and value recovery is essential for potential investors. Looking to the future, there is a major opportunity to provide redwood growers with equivalent investment analysis tools to that of the pine forest growers.

One such tool has been developed by Hamish Marshall of Interpine Forestry; a redwood buttlog sawing simulator. This simulator had not yet been validated against real sawn redwood data. The New Zealand Redwood Company, alongside Future Forests Research (FFR) had data from a sawing study performed on 13 redwood trees sourced from Mangatu Forest on the East Coast of New Zealand.

A butt log sawing simulator is an essential tool to assist in management decisions associated with pruning a forest resource, as the lowest 5 m of a tree typically contains 50% of the total value of the stem (FOA, 2012). The Redwood Co. and FFR are interested in the potential use of the sawing simulator to predict yields from the New Zealand redwood estate, of particularly volume out-turns, total timber board out-turn and timber grade return as determined by percentage heartwood content.

Objectives

The main objective of the study reported here was to carry out a validation of the buttlog sawing simulator using a real sawing study dataset.

A secondary objective, if necessary, was to propose adjustment factors to aid to the construction of a valuation tool for redwood growers in New Zealand.

Review of Literature

Redwoods and their history in New Zealand

New Zealand has yet to discover redwood (*Sequoia sempervirens* (D. Don) Endl. on a large scale. Redwood timber is naturally durable, has colour and character; good insulation and is extremely stable. Redwood heartwood is extremely durable and timber that contains heartwood is significantly more valuable than other timber (*Redwood File*, 1961). Early redwood planting dates back to approximately the 1870's across a wide range of New Zealand sites including South Canterbury, Hutt Valley, Wanganui and Auckland. By the early 1900's several redwood plantations were established throughout Canterbury, Otago, Waikato and the well-known Long Mile Grove in Rotorua (Cornell, 2002).

Sawing simulators and their applications in New Zealand forestry

Planning is the key to a successful redwood crop in New Zealand, however there are challenges associated with this potential new species (Rönnqvist, 2003). Emerging technologies that allow for better utilization of raw materials are the key to continuing development of New Zealand's forestry industry, keeping it competitive in the export market. Computerised sawing simulators such as the SEESAW (Park, 1989) and the AUTOSAW (Todoroki, 2003) have been developed to assist in forest management; below a review of several sawing simulation studies have been reviewed.

Several studies have been completed using sawing simulators to gain a better understanding of what factors influence value recovery in a sawmill. These studies are valuable for both buyers and sellers of pruned logs to realise potential grade outturn and value associated with the high quality clear timber from pruned logs. Simulators are of particular importance as the pruned butt log can contain up to 60% of total value of each tree (FOA, 2012). It is common practise to in New Zealand saw mills to maximise yields from logs. Mills have to sought to increase log conversion and timber extracted from each log in order to increase value recovery (Todoroki & Rönnqvist, 2002).

SEESAW is a computer simulator for sawing pruned logs, the simulator was 'built' using reconstructed radiata pine logs. SEESAW is a visual sawing simulator which uses data collected from real pruned logs (Park, 1989c); the log profiles were created using cross-sectional co-ordinates from a central point on each log (Todoroki, 1988).

Park (1989a) tried to create a standardised method for deriving sawing results, using 20 pruned radiata pine logs with log detail summarised by log. Log length ranged from 3.7m to 6.1m, small end diameter (SED) ranged from 416 – 520mm and defect cores from 267 – 363 mm. this study set certain benchmarks that the SEESAW had meet in comparison the actual data. Logs were rebuilt after sawing to replicate real results from the TITC mill; the SEESAW then ran the same sawing pattern to determine how well the SEESAW could replicate real out turn; particularly in relation to grade distribution.

A study to determine whether it is possible to extract maximum value from pruned logs with an imperfect knowledge of internal defects (Todoroki, 2003); found that knowledge of internal defects is especially crucial with pruned logs. Ten logs were used, seven of which had detailed data maps produced by cross sectional data collection; the other three were examined using a sawing study. Real sawn timber was assigned coordinates which allowed lumber to be mapped back onto the original log for comparison with simulation; benchmarks were also used to evaluate simulator performance. A good result for a real sawmill is to come within 5% of benchmarked levels, anything further than 15% is deemed poor (Park, 1989b). Statistical analysis was used to determine if the population means were equal using the two-sample *t*-test for total lumber per tree values.

Performance benchmarks were sets for both volume optimisation and value (Todoroki & Rönnqvist, 2002). Simulations were carried out using data collected from previous sawing studies. To track logs through sawing, the ends of each log was painted a different colour to allow identification of boards by tree after milling (Todoroki & Rönnqvist, 2002). Logs were reconstructed and measurements were taken of internal branch stubs and pitch recorded.

Other species' timbers have also been trialled through sawing simulators in New Zealand; *Cupressus macrocarpa* Hartweg and *Cupressus lusitanica* Miller have also been investigated for conversion recovery in clear timber grades (Park, 1989b). 12 small logs were measured and assessed for quality and potential logs, then the same (virtual) logs were processed using the AUTOSAW sawing simulation package and the resulting log descriptions were evaluated.

Reconstruction of logs was important to identify defect core dimensions (Park, 1989a). The are two steps in log breakdown at sawmills; primary cutting reduces logs to slabs after which the secondary cutting turns slabs into merchantable boards (Todoroki & Rönnqvist, 1999). The problem sawmills face is that defects in pruned logs are only exposed after the primary cut. Optimisation of primary and secondary processing was carried out using AUTOSAW. Simulations preformed with reconstructed models of radiata logs with knowledge of both internal and external characteristics. Simulations were run in order to meet three objectives:

- Volume maximisation with no knowledge of defects
- Value maximisation with full knowledge of defects
- Combination to maximize volume at primary cut and value at the secondary cut

The study found that increases in value recovery at the primary breakdown result in overall loss in recovered volume, however the gain in value was considerable.

Some trials have found simulators to provide a better estimations of timber potential than real sawing studies (Park, 1989a). A study completed in the central North Island of New Zealand using *Pinus radiata* D. Don, the SEESAW was found to maximise clear timber grade recovery compared to real lumber sawn at a timber industry training centre (TITC). Results from real mill sawing showed greater variation than simulation results, as results are heavily dependent on mill conversion (Park, 1989a). Sawing accuracy was deemed to be a key influence on lumber yield (Todoroki, 2003), however this did not necessarily flow on to an increase in value. The (Park, 1989a) study proposed that sawing simulation results were more accurate than actual results. The results showed the need for accurate, detailed information of logs and it is essential to have strict controls for mill sawing rules for results to be comparable.

Results from sawing simulators were based on two types of analyses; conversion analysis and total sawn produce per log (Park, 1989c). Analysing the specific practises of individual mills was ignored due to the large variation in individual mill outturn and practises. Due to the uniqueness of every log, care must be taken in assumptions regarding value gains (Todoroki & Rönnqvist, 1999).

Computer simulated sawing of logs was found to increase volume recovery by 10%; value recovery was not modelled. Todoroki (2003) found that some knowledge of the internal defects in lumber, even if it is imprecise, increase volume recovery compared to no knowledge of log internal defect (Todoroki, 2003). Using a cross sectional analysis system to obtain detailed log data, this method allows the unique shape of each log to be captured and better representation of elliptical logs, sweep and taper (Todoroki, 2003).

The aim of a study conducted by Park (1989b) was to identify differences between real and simulated sawing mainly in mean conversion rates and grade distributions. Sample size ranged from eight logs to 25 and resin pockets were ignored when cutting clear grades. Comparison of several different mills conversion rates to that of a sawing simulator identified large differences with conversion rates ranging from 55% to 73% (Park, 1989b).

The objectives of Park (1989c) were to simulate the sawing of a range of radiata pruned logs, this study specifically looked at:

- Total conversion to sawn lumber
- Conversion to clears grades
- Number of boards produced
- Length of clears grades

This study reconstructed logs once they had been sawn in the mill to then compare real data to different simulated sawing patterns in SEESAW.

The use of 25 mm thick boards was implemented to allow fair assessment between large and small trees. Results showed that small logs could produce large volumes of clear timber, however not in large dimensions.

80 pruned logs with known internal defects were measured, all chosen because they had similar dimensions but varying degrees of pruning quality, ‘sawn’ in AUTOSAW using a cant sawing pattern (Figure 1).

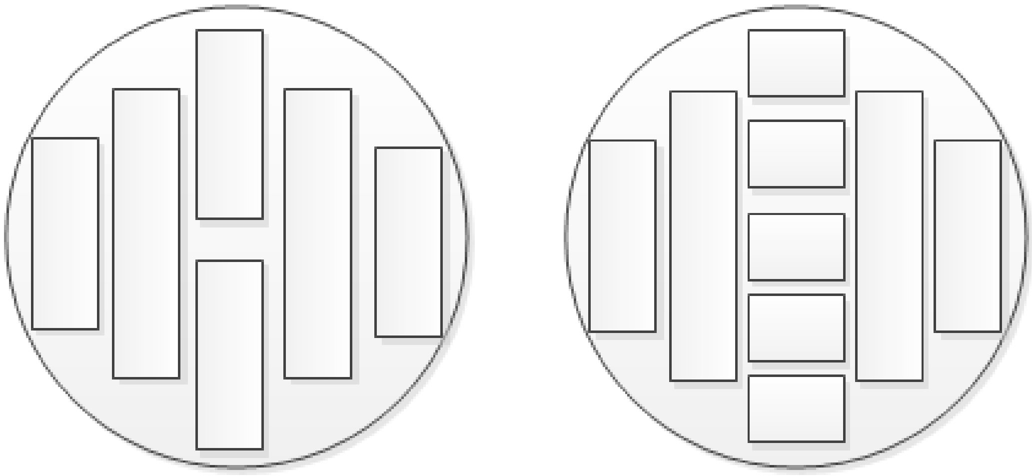

Figure 1 Live sawing pattern and Cant sawing Pattern

Different types of simulations were run; value and volume maximisation in AUTOSAW (Todoroki & Rönnqvist, 1999). effect of ovality on lumber yield was investigated using digitised western hemlock (*Tsuga heterophylla*) logs sawn in the AUTOSAW simulator (Todoroki, Monserud, & Parry, 2007). Logs were selected to represent a range of growth conditions and therefore ovality; stems were measured at cross sections at right angles to capture ellipticity. All board dimensions digitally sawn from each stem were recorded and tracked. Ovality was determined to be neither beneficial of detrimental to lumber value recovery, however value recovery was greatly influenced by sawing pattern (Todoroki et al., 2007).

Data analysis was conducted to derive relationships at a log level across a range of pruned quality (Park, 1989c); 40 theoretical logs were used that were reconstructions of real logs, using measurements. Several studies by Todoroki used a two-sample t-test to determine if simulated and real sawing out-turn population means were equal. In one such study a t-test statistic was used to test hypotheses if values differed by more than 2 mm increments (Todoroki, 2003).

The SEESAW simulator was found to predict higher yields than reality, this was anticipated given the simulator's inability to account for knots hidden beneath the woods surface. However further into the sawing process, knowledge of defect core dimensions gives little advantage in overall conversion (Park, 1989c). AUTOSAW consistently edges lumber to lower levels of wane than were found for the corresponding pieces actually sawn from logs (Barbour, Parry, Forsman, & Ross, 2003).

Key learning's from the literature are listed below and each point was considered during this study:

- The first opening cut into a log will influence the whole milling of the log (Park, 1989b).
- No mill can consistently perform to the same standard as a simulator, once optimized (Park, 1994).
- Problems matching logs arose from mill variation to eliminate this factor in the future more accurate log descriptions are necessary (Park, 1989a).
- Errors in simulated milling can be corrected; however actual saw milling does not have this option (Park, 1989b).
- Todoroki (1999) stated the importance, once again that to realise gains, a precise knowledge of stem characteristics is crucial.
- Todoroki (2002) states the need for volume optimized primary log breakdown followed by grade optimised secondary breakdown.
- Maximising the volume yield of high quality pruned logs is suited to New Zealand's pruned radiata estate (Todoroki & Rönnqvist, 2002).

Redwood buttlog sawing simulator

The successful development of digitized sawing simulators in New Zealand has led to the development of a simulator specifically developed for pruned redwood stems. The redwood buttlog sawing simulator was created by Hamish Marshal, and was completed in December 2012.

The butt log model is made up of the following:

- Log
- Knotcore
- Heartwood

The model can also deal with sweep (not used in this project) and variable taper in outer logs, log cores and heartwood. The sawing simulator can cut either a live or a cant sawing pattern (Figure 1).

The simulator was developed using theoretical sample logs. A spreadsheet developed by M.Kimberley (SCION) was used generate the log profiles. All logs were 6.1 metres long and were modelled with a range of characteristics:

- Diameter at breast height (DBH) ranged from 30 cm – 80 cm in 2.5 cm increments
- Diameter over stubs (DOS) ranged from 16 cm – 22 cm in 1 cm increments
- Sapwood diameter of 5 cm
- A stump height of 0.3 m was used

Other rules associated with this redwood sawing simulator can be found in the materials and methods section of this document.

Mangatu

Below is a brief background and overview of the Mangatu sawing study completed by Silcock and Marshall (2009).

This study was initially undertaken with the following objectives:

- Develop a data base of redwood log variable from New Zealand , including their actual timber grade outturn
- Determine wood quality and grade from a pruned stand
- Isolate the features that relate to log value recovery

The Mangatu redwood stand is 38 year old with a standing basal area of the stand was 108m3, more comprehensive description of Mangatu stand can be found in the materials and methods section.

Thirteen trees were selected across a range of diameters, pruned height, height to green crown and height; it was important to capture this variation due to the relatively small sample size. Trees were also categorized into having live, small or dead branches.

Next the 13 trees were then cut into 50 logs, analogous to the methods above, cross sectional measurements were taken both over and under bark at the butt of the log, breast height and then 3m intervals up the stem. Log section branch condition was also categorised as pruned, dead branches, green/ dead branches, green branches or epicormic shoots. Logs were then sawn at Waiariki sawmill in

Rotorua, each piece of timber was tracked through this process so it could be traced back to its original log.

Key findings of this study showed that no suitable relationship between any log characteristic and volume of heartwood lumber produced. The presence of large resin pockets and epicormic shoots also affected results as the stand was subject to poor tending. Rot and insect damage was also present in the logs.

The Next Step

The extensive use of the SEESAW and AUTOSAW in New Zealand shows there is value for the forestry industry in optimised sawing simulators to aid in management decisions. There is an obvious requirement for predictive models of the effect of silviculture on timber grade recovery, to provide for management decisions. The redwood buttlog sawing simulation does not contain any optimisation and the methodology of data collection and sawing methods of the Mangatu study match the previous successful sawing studies. This preliminary analysis of a pruned redwood resource provided the opportunity to use this data to validate the redwood sawing simulator.

Materials and Methods

Experimental overview

All data were collected as part of a value recovery exercise which was part of Future Forests Research's Diversified Species theme in association with Scion Research Ltd.

Study Site Description

Location

The study site was a small redwood stand in compartment 11 of Mangatu forest located on the East Coast of the North Island, New Zealand.

Stand variables and Silviculture

The stand was 1.4 ha in size, planted in 1979 with an initial stocking of 3086 stems/ha. The stand was pruned four times to a height of 6 metres with a final crop stocking of 398 stems/ha, the trees were felled at age 38 years (Marshall & Silcock, 2009). *For a full silvicultral history of the stand see appendix A.*

Genetics

As the national seed register did not begin until 1985, no genetic information is available for the seed used.

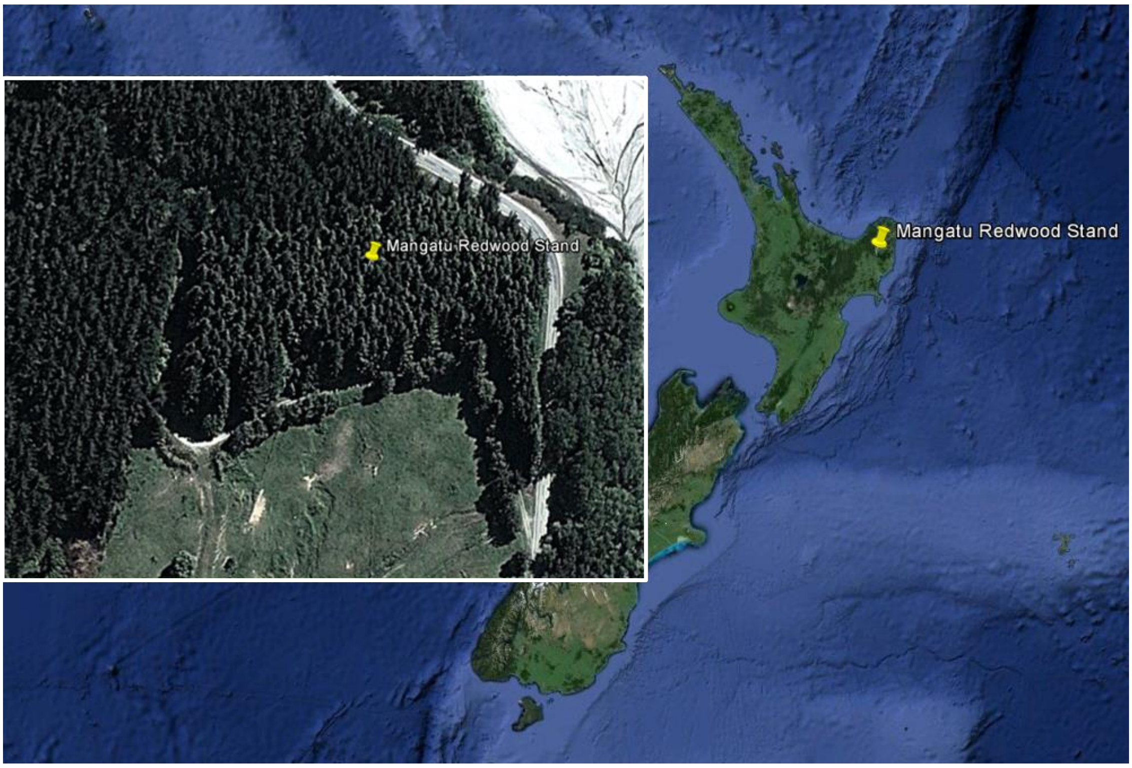

Figure 2 Location map of the Mangatu Forest redwood stand.

Mangatu Sawing Study

The Mangatu sawing study was initially undertaken to isolate features that relate to value recovery in redwoods. The study consisted of 12 trees deliberately selected to represent a range of diameters at breast height (DBH), pruned height, height to green crown and total stem height. *For a more detailed description of each tree see appendix B.*

All logs were sawn at the Waiariki sawmill in Rotorua, the mill was instructed to cut maximum board volume from the log heartwood. Sawing of the pruned butt logs followed the rule that 24 mm thick boards were sawn until first defects, and then 45 mm boards were sawn. Throughout the sawing process board outturn features were recorded for every board, features of interest for this study were:

- Length
- Four evenly distributed board thickness measurements
- Width
- Percentage heartwood

Lumber from Mangatu was graded according to the Standard Specification for Grades of California redwood Lumber defined by the redwood Inspection service (American Softwood Lumber Standard, 1999). Percentage heartwood and lack of other defects defined the grades assigned to the lumber. *A more detailed description of log grades can be found in appendix C.*

3D Log Reconstruction

All data from this study were stored in a relational database with Future Forest Research (FFR) which allows data to be traced back to parent trees.

Creating Log Profiles

The shape of each log was created using cross sectional characteristics recorded at several points along each log. The FFR data base contained measurements that were collected at a series of different intervals along each log consisting of:

a. Length
b. Diameter
c. Heart Diameter
d. Core Diameter
e. Diameter X direction
f. Diameter Y direction
g. Sweep Offset X
h. Sweep Offset Y
i. LED
j. SED

Extraction of these data allowed for creation of a log profile for each buttlog to re-construct lumber into logs. Individual profiles were created for each log. An example is shown in Figure 3.

To build 3D profiles of the reconstructed Mangatu logs required the follow input variables:

- Log ID- a variable representing the number of each of the thirteen logs
- Section ID- number assigned to each section of the log at point of measurement.
- Length- represents the length along the log that dimensions were measured
- X offset- this is a measure of the central offset of the log in the X direction as an offset from a central point marked on the large end of each log.
- Y offset- a measure of the central offset of the log in the Y direction an offset from a central point marked on the large end of each log.
- Diameter 1- representing half the diameter or the radius to the outside of the log in the Y direction
- Diameter 2- representing the other half of the diameter or the radius to the outside of the log in the opposite Y direction

Sweep

To create a measurement for sweep, offset was modelled using Pythagoras' theorem using measurements taken along each log. An average sweep was then determined for each log as a function of that log's total length.

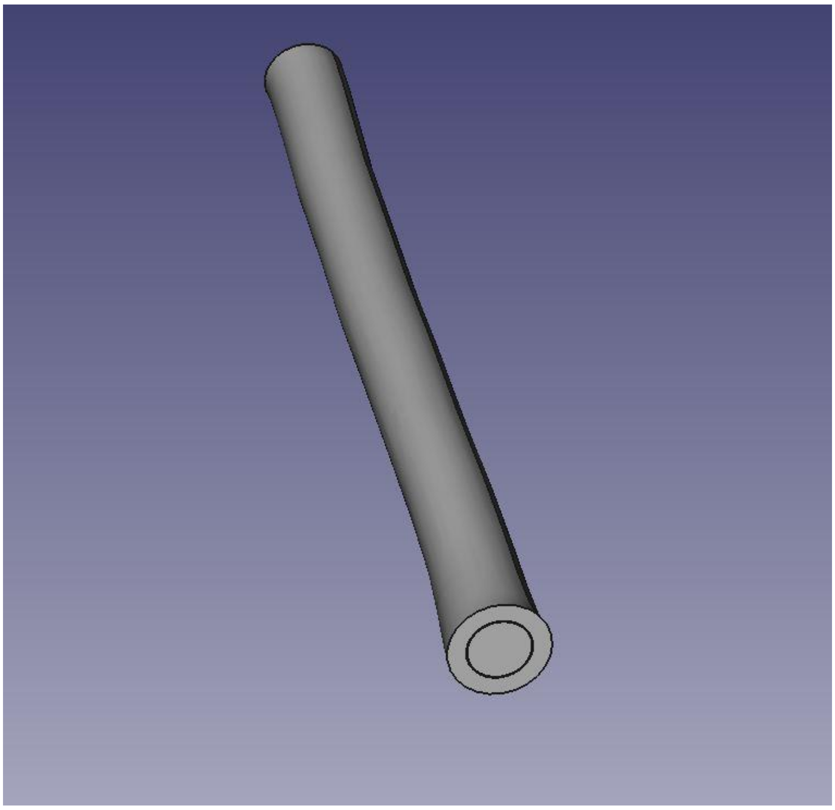

Figure 3 example of virtual log creation using Mangatu data

The Simulator

Once the log profiles were created they were run through the simulator.

The purpose of this simulator was to calculate a lumber volume by grade from differently sized, pruned redwood logs. The simulator model was developed in Python 2.6 using the FreeCAD 3-D modelling engine.

Simulator specifications

The simulator always cut the first board from the centre heartwood and maximised board length and width. The simulator viewed logs using three variables (Figure 3):

- Log – Log outside surface
- Knotwood – Knotcore dimensions
- Heartwood - Heartwood dimensions

Primary Breakdown

- The simulator cut 25 mm (Nominal) (23.81 mm actual) slabs until it hit the defect core, and the log was then rotated 180 degrees
- The simulator again cut 25 mm (Nominal) (23.81 mm actual) slabs until it hit the defect core, then the log was rotated 90 degrees
- The simulator again cut 25 mm (Nominal) (23.81 mm actual) slabs until it hit the defect core, then the log was rotated 180 degrees
- The simulator again cut 25 mm (Nominal) (23.81 mm actual) slabs until it hit the defect core.
- That left the centre cant, which was sawed into 50 mm (Nominal) (44.45 mm actual) slabs.

Secondary Breakdown

Each slab was cut into boards to maximise the volume of the board. The board length could vary between 6100 (or log length) to 1300 mm in 200 mm increment lengths

- The width of the board was selected from 100, 150, 200, 250, 300 mm (Nominal) (96, 147, 193, 245, 297 mm actual)
- The simulator could only cut up to 3 boards from each slab with the centre of the centre board aligned with the centre of the slab.

To get results close as possible to those sawn originally, the simulator was programmed to cut several different board dimensions. Table 1 below is the table of possible board dimensions; this also demonstrates the difference between nominal, green mill and invoice dimensions.

Table 1 Board dimensions cut by simulator (mm)

Nominal	Mill	Green Invoice
25*100	23.81*96	23*94
25*150	23.81*147	23*145
25*200	23.81*193	23*190
25*250	23.81*245	23*241
25*300	23.81*297	23*292
50*100	44.45*96	43*94
50*150	44.45*147	43*145

The simulator output files were in a similar format to the Mangatu data:

Simulator output

- DBH
- DOS
- Slab
- ID
- Position
- Length
- True board
- Volume
- Full board volume
- Width
- Thickness
- %heartwood
- %clearwood
- Wane

As the real-sawn boards and simulator-sawn boards could not be matched, all output data were summarised at a log level for analysis.

Full board Volume per tree

Full board volume per tree was defined as the product of width, length and thickness of all mill dimensions.

Heartwood content per tree

Heartwood content was defined as the percentage of total log volume which contains the durable, high value heartwood (Cornell, 2002).

Total board length per tree

Total board length was defined as the total length of board's cuts per log.

Grade mix

This was a variable created as a proxy to value; board grades were separated into three categories:

- 100% heartwood content
- 100 – 90% heartwood content
- < 90 % heartwood content

These grades represent the regulating factor in redwood grading rules, a simplified set of grading rules can be found *in appendix (C).*

Data Analysis

Conversion

A conversion comparison was used to indicate simulator performance (Park, 1989a).Conversion was used here as the total invoice volume of boards as a percentage of log volume.

Statistical Analysis

A two-sample *t*-test was used to determine if the population means were equal (Todoroki, 2003). In particular the *t*-test was used to test the hypothesis that the simulated lumber did not differ from the real-sawn lumber. The two sample *t*-test was performed for the following variables at a log level:

- Total board length
- Total full board volume
- Total heartwood content

Primary data analysis was conducted in Microsoft excel and all statistical analyses were conducted in the R statistical software(2.15.1). The main analytical procedures used were residual analysis at a log level to determine precision and bias.

Performance indicators

Performance indicators were used provide an initial sign of how the simulator outputs compared to real outputs. For each variable the predicted as a percentage of the actual was used to evaluate over or under prediction from the simulator for the data set overall.

$$(Predictided\ value\ \div Actual\ value\ ) \times 100$$

Residual analysis

Residuals were calculated using the formula below:

$$Residual = Total\ observed\ variable\ pre\ tree - total\ predicted\ variable\ per\ tree$$

Residual analysis was performed with real Mangatu data as the observed variable and sawing simulator outputs as the predicted variable for the following:

- Full board Volume per tree
- Heartwood content per tree
- Total board length per tree
- Over grade mix (%)

Simulator performance was also assessed with varying log size, for this reason bias was assessed as a function of:

- Small end diameter (SED)
- Log Volume

Results

Two-sample *t* tests showed that all simulated data populations (board out turn, full board volume and percentage clearwood) had significantly different means to their actual data equivalent (appendix D).

Conversion

Results showed that mill conversion was hardly influenced by SED at all (Figure 4), which is unusual. However the simulator yielded a correlation between conversion and SED.

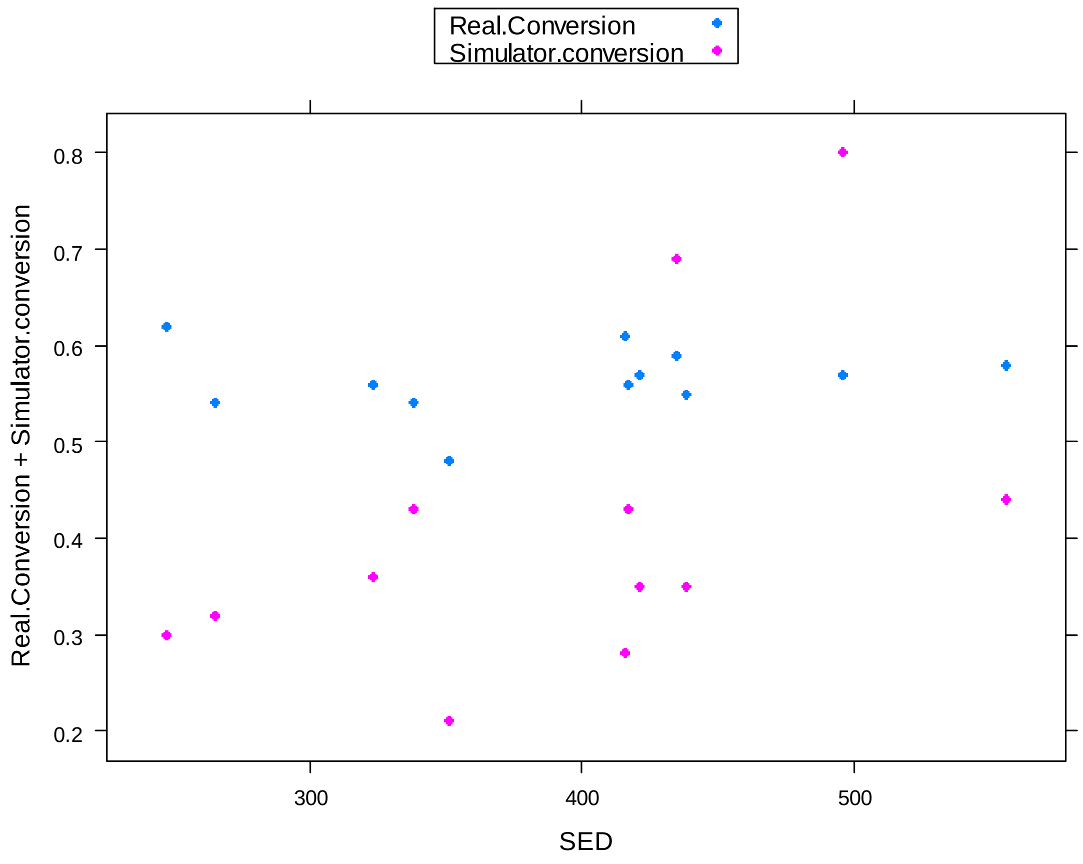

Figure 4 Conversion percentage per log for real and simulatred data against small end diameter

Board Length

The number of boards cut per tree is a simple representation of the disparity between real data and simulated data (Figure 5).

The plot of residual total board length (Figure 6) shows that simulator was under predicting the actual total length of boards cut per tree.

The simulator showed bias towards greater under prediction with increasing log size demonstrated by examining the effect of small end diameter size and log volume (Figure 7 Residual total length of boards cut per tree against small end diameterFigure 7 & Figure 8 respectively).

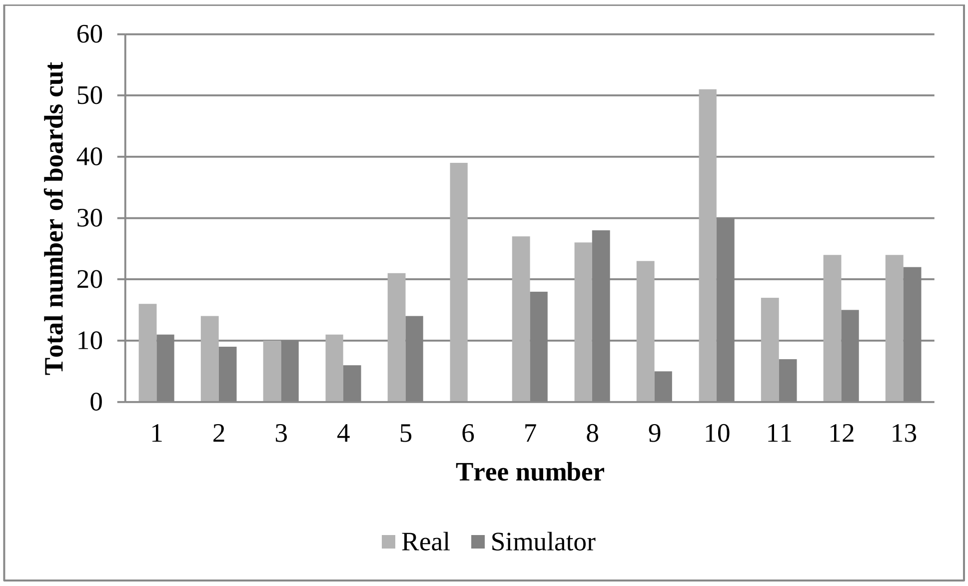

Figure 5 Total number of boards cut per log for real and simulated data

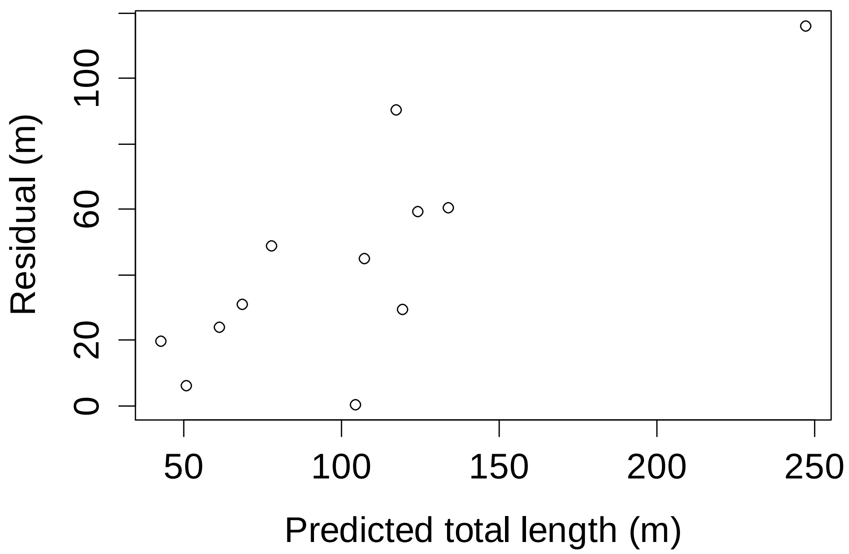

Figure 6 Residual plot of total length of boards cut per tree

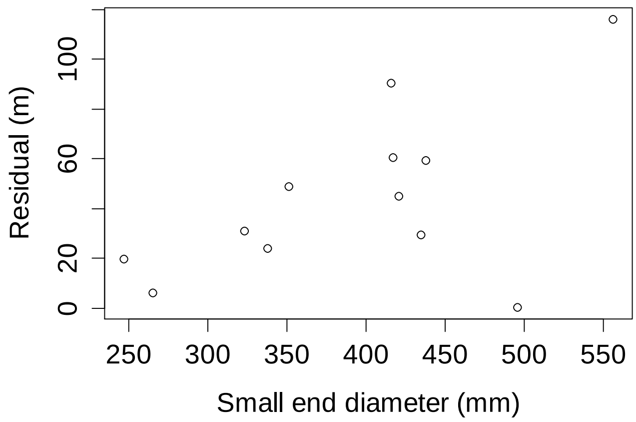

Figure 7 Residual total length of boards cut per tree against small end diameter

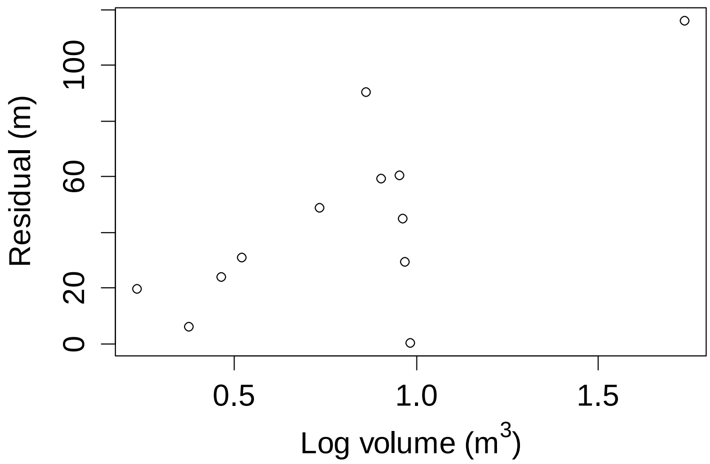

Figure 8 Residual total length of boards cut per tree against log volume

Full board volume

The performance indicator for full board volume showed that the simulator was under predicting full board volume per log for ten out of the 12 trees (Figure 9). Residuals support this result showing an under prediction for all but two trees (Figure 10).

The simulator under predicted full board volume per log, with bias increasing with log size (Figure 10 & Figure 11 respectively).

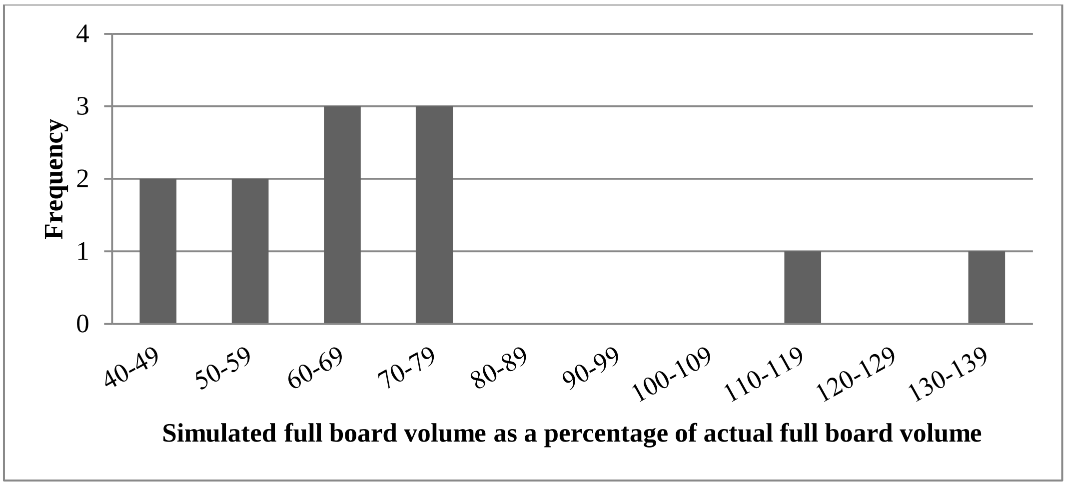

Figure 9 Simulator full board volume as a percentage of actual full board volume (m^3)

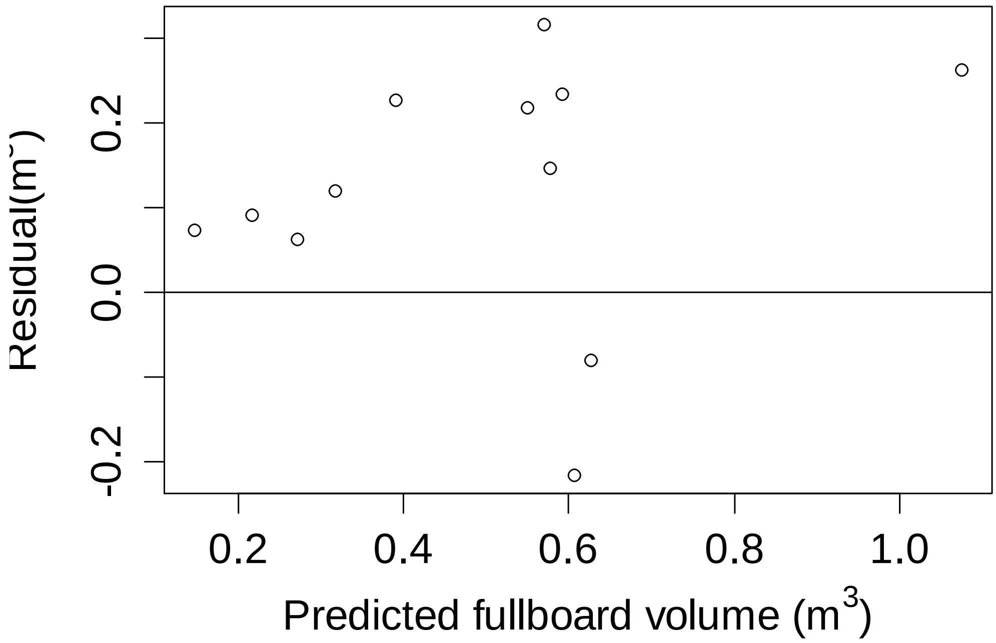

Figure 10 Residual plot of full board volume per tree

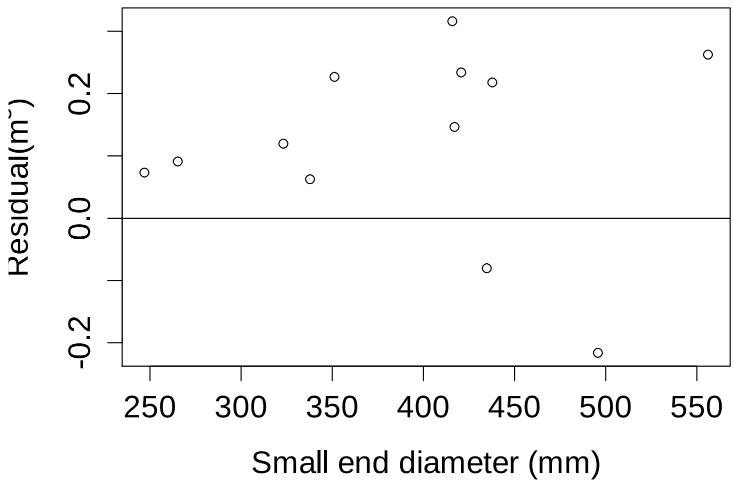

Figure 11 Residual full board volume per tree against small end diameter

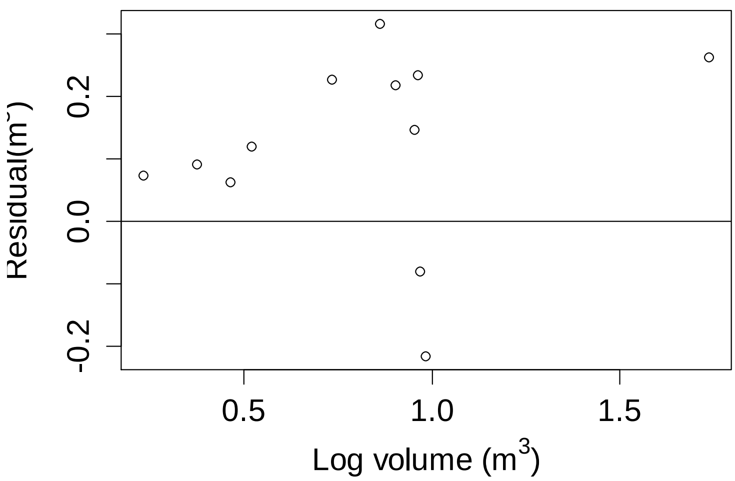

Figure 12 Residual full board volume per tree against log volume

Heartwood Content

Percentage heartwood content per tree was biased (Figure 13). Residual results showed a major trend; under prediction with lower amounts of observed heartwood to over prediction as heartwood content approached 100% (Figure 15).

The simulator tended to under predict heartwood content in small logs and over predict heartwood content in larger logs (Figure 15 & Figure 16 respectively).

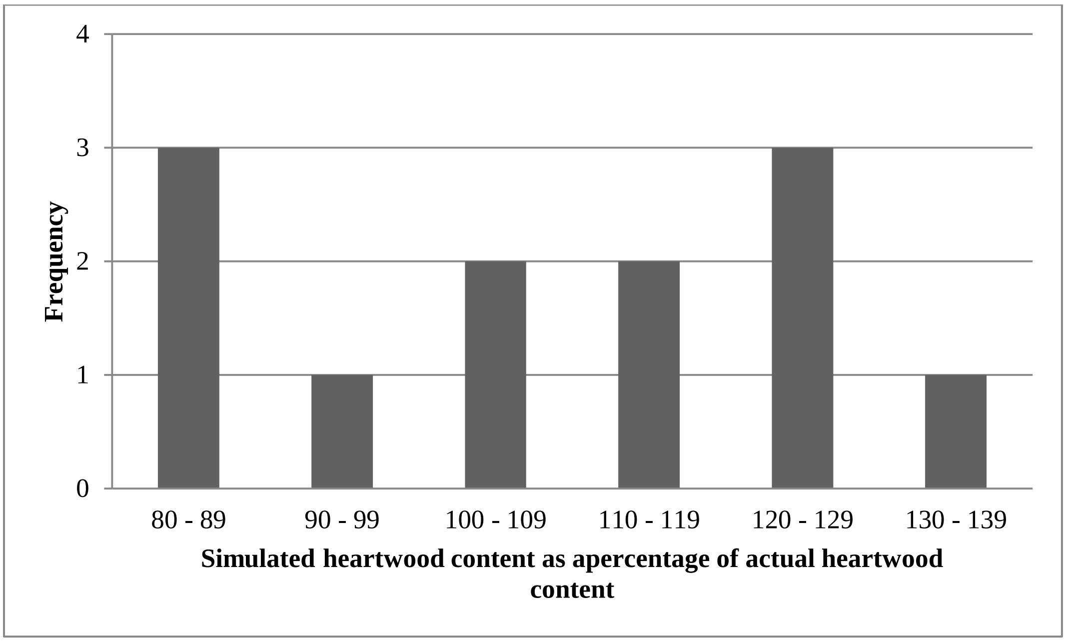

Figure 13 Simulator heartwood content as a percentage of actual

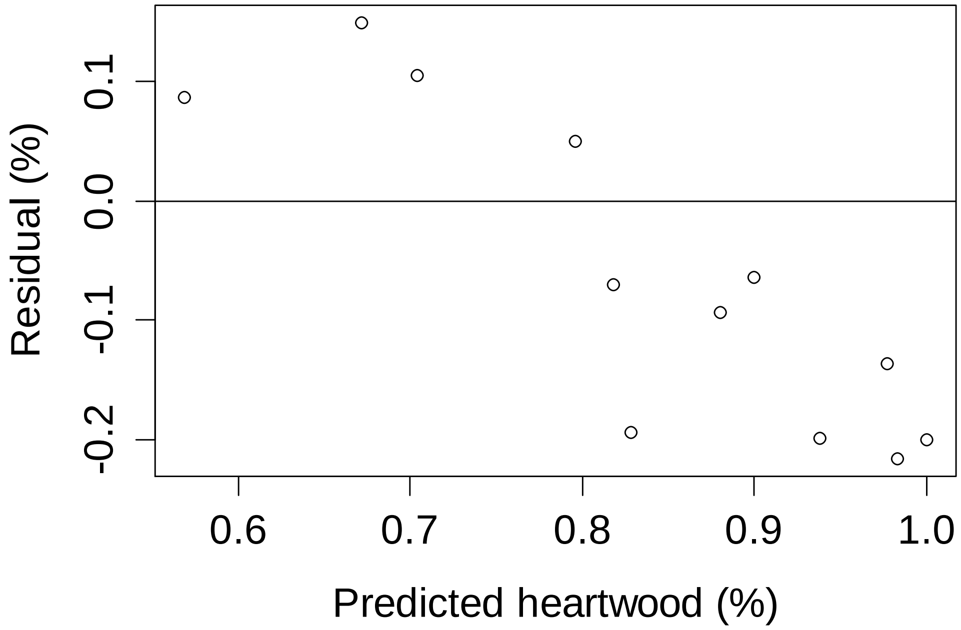

Figure 14 Residual plot of percentage heartwood content per tree

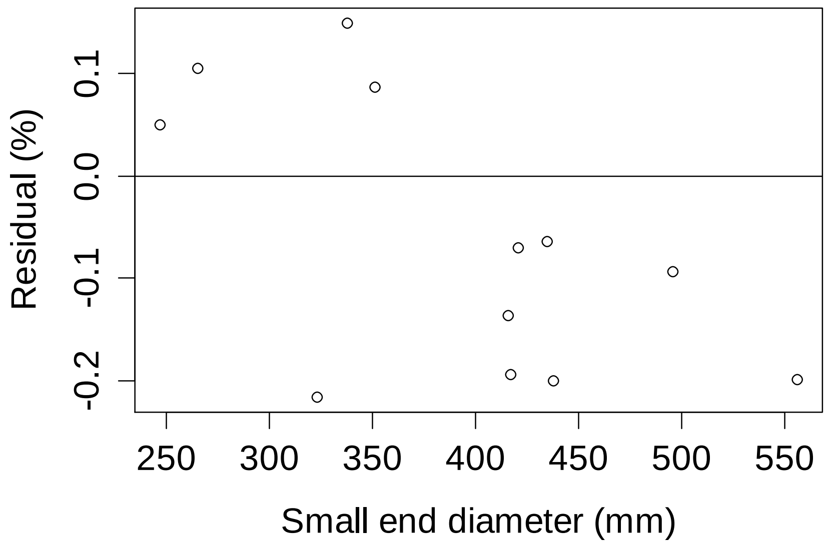

Figure 15 Residual percentage heartwood content per tree against small end diameter

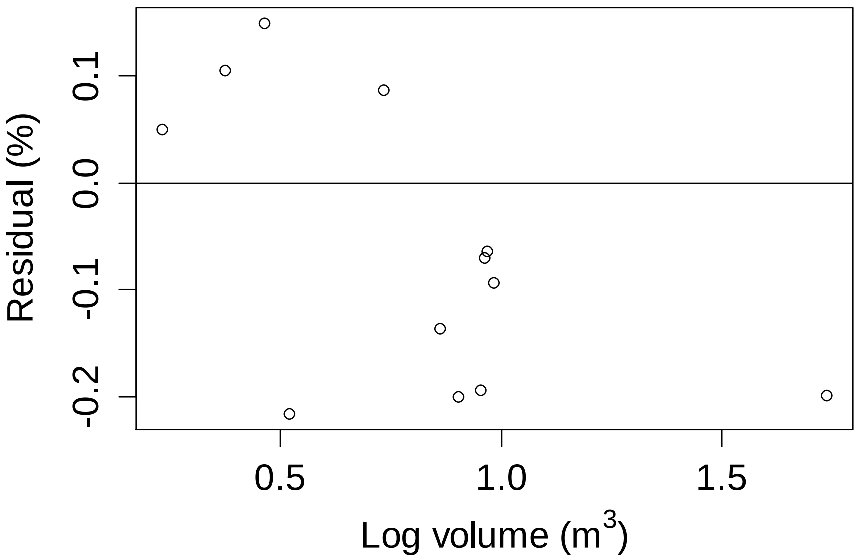

Figure 16 Residual percentage heartwood content per tree against log volume

Grade Composition

Results for grade composition showed that the simulator over predicted the proportion of boards that had 100% heartwood composition and under estimated boards that had below 90% heartwood (Figure 17).

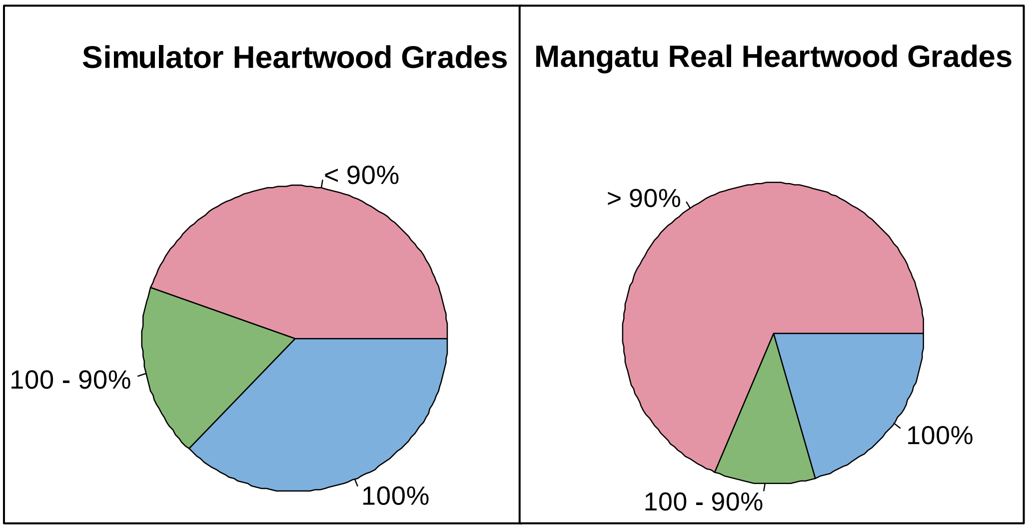

Figure 17 Heartwood grade composition for real and simulated data

Discussion

There is an opportunity to present the outputs from the redwood butt log sawing simulator to redwood growers to aid in management decisions; however the simulator must be valid before it can become useful to New Zealand redwood growers.

The purpose of this study was to validate a redwood sawing simulator; five variables were investigated as benchmarks to gauge simulator performance. Below results of this attempted validation are discussed.

Conversion

Results showed a large variation in conversion between real and simulated data. This result shows outright that the simulator is not performing in the same manner as the real data. Errors in simulated milling can be corrected, however actual saw milling does not have this option (Park, 1989c); this may attribute to inconsistencies in conversion.

The large amount of variation in conversion provides reason to examine the reasons for this difference for example look at the different board sizes being cut, however due to time constraints this factor was not analysed.

Total board length per tree

Results showed that the simulator is under predicting total board length per tree. However the dimensions of lumber being cut are not exactly the same and this may give rise to the discrepancy. This means that this difference may not necessarily mean the simulator is not incorrectly cutting boards just that it is cutting boards differently from those sawn at the Waiariki saw mill. Results from real mill sawing studies showed greater variation between several saw mills in board length than simulation results, outcomes are dependent heavily on mill conversion (Park, 1989a). This means that caution should be exercised when comparing only one saw mills data to the simulator, ideally a comparison with a greater number of saw mills using similar logs would provide a better indication of simulator performance. However this validation exercise still provides an initial indication of performance in the early stages of this simulator.

Full board volume per tree

It was found that the simulator under predicted full board volume at a log level for all apart from two trees. The result shows

Heartwood content per tree

The simulator was found to under predict heart wood content per tree with lower when lower amounts of heart wood were present in real data, and over predict when higher amounts of heart wood were present.

The results also showed a bias to under predict in smaller sized logs and over predict in larger logs. This may be due to the large variation in heart wood content present across all stems in real data, it was noted that not relationships could be derived between log size and heartwood content (Marshall & Silcock, 2009).

This result provides serious concern for the potential use of this simulator as redwood lumber value is derived from its heart wood content.

Over grade mix (%)

The simulator over predicted the quality of lumber produced. This grade mix percentage represents value as accurately as possible however with simulator out there was not enough data to grade timber properly. It is difficult to make results comparable with sawing in real data as saw mills are able to make decisions based on various features that cannot be replicated in data (Park, 1989b).

Limitations

Mangatu data

The Mangatu data set used to validate the simulator may be a source of inaccuracy is in this study; other studies have found that real data may be the problem (Park, 1994). The condition of trees was not able to be replicated; this is unfavourable as these defects are not able to be input into the simulator.

Sample Size

The sample size is a major limitation in this study; while similar sample sizes have been used in previous research it is difficult to draw definite conclusions from only 12 trees. However results still demonstrate how the simulator preforms over a range of different tree sizes and characteristics; these 12 trees here provide a base for the creation of a true, useful redwood sawing simulator.

The simulator

At this stage the model does not contain any optimisation and it cuts to maximum board volume. Sweep not being modelled in the simulator and it lacks input for other possible defects

The simulator was built was sample logs that Lacked of variability in heartwood diameter, the Mangatu data set had a large range of heart wood diameters.

Overall simulator performance

Results show that the sawing simulator was not correctly simulating sawing in a real mill. This study demonstrates how important it is to evaluate models and simulations with real data.

The objective of the study was to validate the simulator performance through analysis of how well the simulator matched volume and grade out-turn from 12 redwood logs given the information the redwood Co. could reasonably provide about trees in its estate. However evaluating the potential of a pruned resource relies on accurate data for use in sawing simulators (Park, 1989a). Knowledge of location and size of defects is crucial for sawing accuracy and to produce a simulator without input for these factors defects the purpose of volume and value recovery. The major impediment faced in computer based simulation is real saw mill operator can see the extent and position of imperfections and defect core in logs before making the first cut (Park, 1989c).

Several other factors were addressed in the literature that could not be modelled in this study which should be taken into consideration:

- Log orientation is a major factor and this was not recorded at Mangatu and cannot be input in to the simulator
- Sawing accuracy should not be overlooked as saw milling is a skilled operation which has many factors that influence decisions.

The long term objective for the redwood butt log sawing simulator should be match customer demands while satisfying mill turnover requirements. Latest versions of the AUTOSAW have been optimised with dynamic models for changing lumber prices and demand (Todoroki & Rönnqvist, 2002). The discussion above should be taken into consideration with future development of this tool.

Conclusions

1. The simulator is not producing the same conversion per tree as actual saw milling, this suggests that adjustments need to be made to the simulators cutting pattern for results to be successfully compared.
2. The simulator is under predicting total board length cut per tree, this is most likely due to the differences in board dimensions cut between the simulator and Waiariki sawmill.
3. Full board volume a main trend for under prediction, this result is expected considering results for conversion and total board length. Predicted full board volume was influenced by log size.
4. Prediction of heartwood by the simulator was majorly influence by log size with both over prediction and under prediction depending on log size.
5. Grade composition links in with heartwood predictions as this was used to grade logs; the simulator provided a more conservative set of grades compared to real data.

This validation study for the redwood butt log sawing simulator proved unsuccessful however the study still provides good insight into this relatively new tool. The major adjustment that should be taken from the results above is that the simulator needs to be adjusted to produce more accurate estimates with changing log sizes.

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Appendices

A. Table 2 Mangatu Silvicultral History

Activity	Age (Year)	Description
Pruning	9 (1979)	Fixed lift pruning to 2.2 metres
Thinning	9 (1979)	Thinned to waste down to 800 sph
Pruned	10(1980)	Fixed lift pruning to 4.0 metres
Pruned	12(1982)	Fixed lift pruning to 5.8 metres
Thinning	12(1982)	Thinned to waste down to 512 sph
Pruned	15(1985)	Variable lift pruning to 5.8 metres

B. Table 3 Basic log descriptions

Tree No	DBH (mm)	Height (m)	Pruned Height (m)	Crown Height (m)
2	511	29.4	5.2	5.2
4	400	35.2	6	24.7
5	380	31.4	6.5	6.5
6	385	31	6	24.5
7	583	31.8	6.6	25
9	602	40.4	6.8	25.8
10	365	27.4	4.6	3.4
11	603	38	6.5	22.3
12	810	35.5	7.1	
14	565	32.7	6.5	19.7
16	540	40	6.1	25
17	842			

C. **Table 4 redwood grading rules**

Grade	Percentage of Heartwood	Presence(Size)of Live Branches	Presence of Dead Branches	Presence of Rotten Branches	Presence of Rot
Clear All Heart	100%	Nil	Nil	Nil	Nil
Clear Common	< 100 %	Nil	Nil	Nil	Nil
Heart B	100%	Allow (50 mm)	Nil	Nil	Nil
B Common	< 100 %	Allow (50 mm)	Nil	Nil	Nil
Construction Heart	> 90 %	Allow	Allow	Nil	Nil
Construction Common	< 90 %	Allow	Allow	Nil	Nil
Merch Heart	>90 %	Allow	Allow	Allowed	Allowed
Merch Common	< 90 %	Allow	Allow	Allowed	Allowed

D. **Table 5 Two Sample t-test results**

			95% Confidence limits	
	t	P-value	upper	lower
Total Length	-4.53	0.001	-22715	-65735
Full board Volume	-2.77	0.018	-24862262	-218086030
Heartwood Content	1.7	0.117	0.149	-0.019

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