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Review of Wood Quality Algorithms

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EXECUTIVE SUMMARY

In this report, the major wood properties related to product value are discussed in terms of their impact on value and their inclusion in Atlas Forecaster. Forecaster currently includes algorithms for predicting wood density, acoustic velocity and heartwood content. It is concluded that the main properties of operational importance for structural regimes are catered for to a greater and lesser extent, but that clearwood regimes are not so well covered.

ATLAS FORECASTER

The current Forecaster approach seems to depend on actual stem data, but this is not using current knowledge to full effect. For instance, there is currently no overview for forest managers to guide them on topics for which there may be relevant information at the site or regional stand level – e.g. density (stiffness) and resin blemish zones. Simple maps could alert users to these high level issues and reduce the need for detailed predictions. The Density Zones and resin zones have been known and accepted since the 1970s, and could be presented in a User Guide. Similarly, properties like resin blemishes, microfibril angle, fibre length, spiral grain and intra-ring checking can be important for some uses, but do not lend themselves to single stem modelling. Foresters probably want only stand level or breed information on these anyway.

Suggested improvement:
A major initiative to assist Forecaster users in dealing with wood quality issues would be the inclusion of an Information Tab where current knowledge is summarised – along with maps of regional trends in specific wood properties, such as wood density, sound velocity and resin blemishes. This would allow users to decide whether they need to consider including them in predictions. The wood properties of primary interest, and their suggested improvements, follow.

WOOD DENSITY

There are currently two wood density models, created from different datasets. While they both seem to work reasonably well in predicting log density through time, the situation is confusing for the user.

Suggested improvements:
- Density is such an important variable for both product value and carbon sequestration that a single database and model is desirable.
- Using the most extensive data, create density maps to indicate regional effects, using modern mapping tools.
- Combine density and biomass models.
- Create a model to allow density input from age 8 years to allow capture of RPBC data.
- Allow for breeds by using genetic modifiers from RPBC data.

ACOUSTIC STIFFNESS

Acoustic tools are rapidly gaining in popularity because of their ease of use. However, questions still remain about their accuracy in predicting actual timber stiffness.

Suggested improvements:
- Improve the velocity/timber stiffness predictions by undertaking well-planned sawing studies (including standing tree assessments of density, heartwood content and velocity). Investigate the basis for the velocity “hook” observed with acoustic tools, by undertaking targeted sawing studies so that a more accurate prediction of actual timber stiffness can be obtained.
- Using the best database, create velocity maps, accounting for climatic and environmental variables. The inclusion of soil properties has the potential to improve predictions. Allow for breeds by using RPBC data.

MICROFIBRIL ANGLE

- Microfibril angle is recognised as a critical property for stiffness, particularly in the juvenile wood, but requires costly laboratory equipment to collect measurements. It is not yet feasible to consider routine measurements.

Recommendation:

- Do not implement an MFA algorithm at present, but collect more data in routine wood quality studies. The initial objectives should be to quantify the effect of growth rate in relation to site and thinning.

HEARTWOOD AND GREEN DENSITY

Heartwood and green density predictions are important for a) adjusting log sonic velocity values, and b) assessing when heartwood exceeds the defect core. While the timing of average heartwood development is fairly constant both in terms of initiation (around 10 years of age) and development (about 0.5 of a ring/year, the percentage of the stem occupied by heartwood can be affected by both silviculture and genetics.

Suggested Improvements:

- Ensure that heartwood (both diameter and ring numbers) and moisture content data are collected in all destructive sampling, along with acoustic measures to enhance the limited database and improve the predictive algorithm. Because heartwood development is very closely related to stem age at any level, a ring-based model may be more useful for assigning heartwood % and green density between stems.

SPIRAL GRAIN

This property is strongly implicated in timber twist, but is poorly understood. It also requires costly laboratory equipment to asses it where it has the greatest impact – in the juvenile wood.

Recommendation:

- Do not attempt to incorporate generic spiral grain patterns into Forecaster. There is not enough information to permit allocation of values to sites or stems with any degree of confidence.

INTRA-RING CHECKING

While the incidence has been found to be high on some sites, extensive studies have uncovered no links to site, silviculture or climatic factors.

Recommendation:

- It is not yet practical to consider the prediction of intra-ring checking in modelling systems.

RESIN BLEMISHES

Resin blemishes can significantly affect the value of pruned logs in some regions. External resin bleeding is a coarse indicator of internal resin blemishes but is not accurate enough for modelling. Consider resin issues at the stand level. There is some indication that the average level of resin defects may be related to site factors (exposure) and stocking levels, but this is not well quantified.

Recommendation:

- Prepare “resin maps” for inclusion in a Forecaster Information page, using all available data (including topography).
- Incorporate any information on silviculture (from Scion and WQI studies) and breeds available from RPBC.

COMPRESSION WOOD

Compression wood is widespread in radiata pine, but the trait is notoriously difficult to quantify in terms of predictable effects on timber products and value. Present knowledge is insufficient for modelling purposes.

Recommendation:

- Maintain observations of compression wood in destructive studies in order to better understand impacts of site, silviculture and genetics.

INTRA-RING CHECKING

Intra-ring checking is a sporadic problem for pruned logs in some areas, but despite intensive research, no links to site or silviculture have been uncovered.

Recommendation:

- It is not yet practical to consider the prediction of intra-ring checking in modelling systems.

INTRODUCTION

The forestry community has only a rudimentary understanding of the relationship between tree crown dynamics and wood formation, but the average stem profiles of a range of properties are now well known, and usually related to growth ring patterns. In radiata pine, branch characteristics and basic wood properties have a strong influence on product value, and hence there is a need to include predictions of quality in forest models. While an ideal approach may be to simulate stem growth and wood properties simultaneously, the data collection would be daunting and span many years – and still the models would be inaccurate because of a continually changing genetic base. At present we can only predict wood properties separately from GF Plus ratings and growth patterns.

Forest managers must consider the potential value of crops into the future, so predictive tools such as growth models are popular for predicting log volumes and distributions between log classes. One of the complicating factors in predicting stand value is the variability in key quality traits such as wood density, stiffness, stability and clearwood value. Knowledge of the causes of this variability is still fragmentary due to the interaction of site, silviculture and genetic effects (Drummond, 2004). There are clear trends to include more information on wood quality – as evidenced by the increasing use of acoustic tools for stand assessment and log segregation (Dickson *et al.,* 2004; Treloar, 2005; Amishev and Murphy, 2009). For instance there is now a trend for structural mills to incorporate acoustic requirements into log specifications and employ in-line acoustic tools.

There are potential gains for both forest growers and wood processors in being better able to predict wood quality and hence value. At both the site and individual stem level there is high variability in key performance traits such as stiffness, stability and appearance, due to a complex interaction of site, silviculture and genetics. Knowledge of the drivers of performance traits lags behind that for growth and form, to the extent that planning tools do not cater well for their prediction.

ATLAS Forecaster has been developed as a modelling platform to allow users to predict yields and value at rotation age, and as such requires data to initiate model runs and to predict variation over time. This can be limiting where forests are planned for bare land, or when actual data are not available.

This philosophy is changing, as evidenced by the development of 300 Index and Site Index maps.

METHODS

As far as wood quality is concerned, there are several characteristics which can influence the harvest value, and many of these have been investigated in isolation from growth modelling research.

The approach adopted here was to review some of the past work on the effects of site, silviculture and genetics on important wood properties, and consider whether the information could or should be included in a future version of ATLAS Forecaster.

RESULTS

The development of wood property algorithms has been sporadic in New Zealand (Tian and Cown, 1995, 1995; Tian *et al.*, 1996a,b). Functions for a range of wood properties – wood density, fibre length, spiral grain – were linked to a simple growth model to produce average values according to crop age.

WOOD DENSITY

Wood density is by far the most heavily researched characteristic, and it has long been recognised that a strong driver is mean annual temperature. Harris in 1965 found a correlation of 0.94 between outerwood density (10 rings) and site temperature.

A more comprehensive survey carried out in the late 1970s confirmed the earlier results and identified drivers for both corewood and outerwood density (Cown *et al.*, 1991):

Corewood density = 8.6 x mean temp. – 15.7 x pH - 31.5 x N – 0.12 x P + 371

(r^2 = 46%)

Outerwood density = 12.0 x mean temp. + 0.02 x Ave rain – 6.0 x pH – 50.8 x N – 0.19 x P + 344 (r^2 = 63%)

This work identified three “density zones” differing up to 30% in outerwood density (Figure 1).

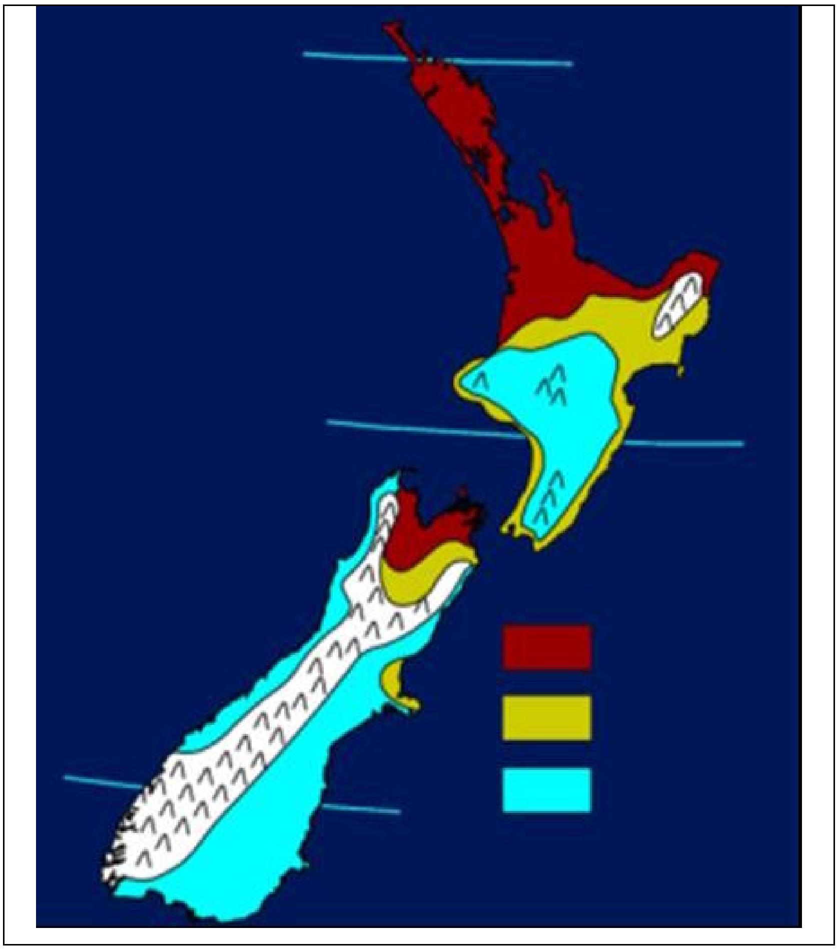

Figure 1: Density Zones (Cown *et al.* 1991).

Subsequent studies (including WQI work – Cown *et al.,* 2005; Mason and Dzierzon, 2007) have also confirmed that density is strongly controlled by climate and site factors.

Other density models have been created for different purposes (Beets *et al.,* 2007; Woolons and Manley, 2008a). The latter uses WQI data to predict outerwood density based on age and topographic information (like Cown *et al.* 1991) and also current stand data (slenderness).

It has long been recognised that basic density is highly heritable (Burdon & Harris, 1973; Bannister & Vine, 1991).

Most of the past research has dealt with outerwood density because it is relatively easy to assess non-destructively, is responsive to site and silviculture, and has a strong link to wood stiffness, particularly in mature wood. However, it does not necessarily represent stem and log differences, because the within-tree radial and vertical density patterns are themselves influenced by climatic factors. Therefore the most useful density algorithms relate outerwood values to stem components.

Forecaster deals with density prediction by using the functions developed by Scion in the 1980s, and also a dataset complied for WQI by Rawley (2007). The two density models in Atlas Forecaster have been shown to perform similarly (Cown *et al.* 2002). The driver for wood density prediction is outerwood density at breast height. Growth models predict the individual tree data to harvest age, and density values are assigned based on a separate density growth model, driven by stand age from date of density assessment. The models can predict the average density of stem sections though time, and also assign values to logs up the stem using a bucking algorithm.

Wood density is relatively simple to measure, and a lot of historical information is available with which to refine the existing models should this be required. What are not readily available are the data for new breeds. These may be collected by RPBC at an early stage (8 years?), and could be used to benchmark crops at that stage, but forward projections would involve an element of risk – particularly if the number of parent genotypes is small, as with clones. Studies have documented different within-tree patterns for clones (Cown *et al.* 2002.

Suggested improvements:

1. Density is much an important variable for both product value and carbon sequestration that a single database and model is desirable.
2. Using the best database, create density maps to indicate regional effects (as in Figure 1 but using modern professional maps, say in 10-year intervals.
3. Combine density and biomass models.
4. Create a model to allow density input from about age 8 years to allow capture of RPBC data[1]. The predictions can be adjusted later using actual evaluations.
5. Allow for breeds by using genetic modifiers from RPBC data, and consider silvicultural effects (Cown *et al.,* 2006).
6. Include a section summarising knowledge in a Forecaster User Guide.

ACOUSTIC STIFFNESS

Stiffness is one of the key properties which determine the value of timber. Actual stiffness of wood products cannot be measured directly from logs and stems, but acoustic readings from standing trees and logs are becoming used as surrogates for average stiffness (McConchie *et al.*, 2006; Watt *et al.* 2006; Weilinga *et al.*, 2009). Numerous studies have shown the benefits of segregating logs on the basis of acoustics (Carter *et al.*, 2005; Ross *et al.,* 2005; Treloar, 2005, Waghorn *et al.*, 2007; Lasserre *et al.* 2007, 2008).

[1] This may require a different sample protocol – using 5-ring outerwood samples instead of 50 mm outerwood cores in young stands (<15 years?).

Standing tree acoustic velocity is a convenient and non-destructive measure, which can be used to predict log stiffness. Studies have indicated good relationships between standing tree values and whole stem values in young trees (Ivkovic *et al.,* 2009), but less reliable individual tree correlations in older stands (WQI data). Relationships to timber stiffness are even less predictable (WQI data and Cown *pers. comm.*).These may not be major issues as the principal use of the technology will be to compare groups of trees (forest stands or trial plots). Differences between tool types (FAKOPP, ST300, TreeTap, IML Hammer[2]) and possible operator bias may also contribute to a degree of uncertainty.

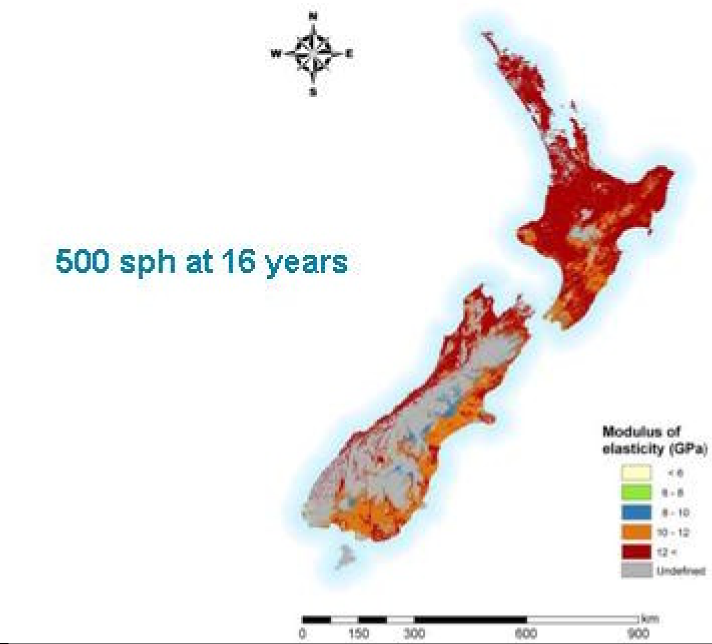

Figure 2: Predicted Dynamic Acoustic Velocity (Watt, 2009)

Forecaster deals with stiffness prediction by using the functions developed by Woolons *et al.* (2008) for WQI, to predict acoustic velocity at chosen stand ages and along the stem. Stand averages or individual stems may be modelled, based on either standing tree velocity or outerwood density, but it is recommended that both be used if possible. The dataset contains over 100 trees. Model inputs include:

- Standing tree velocity
- Outerwood density
- Stand age
- Latitude
- Altitude
- DBH
- Height

The use of velocity or density alone gives an almost identical result, explaining around 80 to 90% of the variation in log resonance values. The inclusion of the ratio of DBH/Ht ("fatness" or "slenderness") is an additional factor, related to both stocking and latitude, which improves the prediction of log velocity.

[2] WQI derived correction factors to standardise measurements.

A characteristic of the "velocity models" is that they predict log resonance values which are themselves only an estimate of timber stiffness[3]. WQI studies and other data point to the involvement of several other factors in the conversion of acoustic velocity to stiffness (type of tool used; log size; heartwood content (green density); branch size[4]; presence of bark; log freshness; method of timber grading; timber moisture content).

Future predictions may be made from topographic and stand variables (Lasserre *et al.* 2007, 2008; Woolons and Manley, 2008b, Watt *et al.,* 2009). Watt *et al.* (2009) have been working on enhancing the prediction of acoustic velocity by including site and silviculture (stem slenderness) as drivers (Fig. 2). This gives a good visual overview of predicted velocity distribution, and is a first step towards prediction of timber stiffness (which is the real value trait[5]).

There are several issues with the use of acoustic measures:

- Different tools can give different results.
- Predictive algorithms (BH to log values; predicting forwarding time) are not very well developed.
- Acoustic measures are only **estimates** of stiffness, based on assumptions. They may be acceptable for comparing stands, but have not been well validated against timber grades[6].

Proposals

1. Improve the velocity/timber stiffness predictions by undertaking well-planned sawing studies (including standing tree assessments of density, heartwood content and velocity)[7]. Investigate the basis for the velocity "hook" observed with acoustic tools, by undertaking targeted sawing studies so that a better prediction of actual timber stiffness can be obtained. An added bonus will be more data on the influence of other wood property traits (spiral grain and compression wood) and the improvement of timber stability prediction.
2. Using the best database, create velocity maps as in Figure 2, accounting for climatic and environmental variables. The inclusion of soil properties has the potential to improve predictions. Allow for breeds by using RPBC data.
3. Include a section summarising knowledge in a Forecaster User Guide.

MICROFIBRIL ANGLE

Microfibril angle (MFA) has been shown to have strong radial and vertical trends and large between-tree differences in radiata pine (Cown *et al.*, 2004; Donaldson, 1992, 1995; Donaldson and Burdon, 1995). Ball (2008) performed a validation exercise using a ring-based model developed from the WQI Benchmarking dataset (Mason and Dzierzon, 2007) to examine two independent datasets. The model used ring width, distance from the pith, height in the stem, mean winter temperature and soil P as independent drivers. He found that the model gave "reasonable agreement" across a range of breeds and stockings in one case, but that substantial differences were found in the other. It was concluded that the greatest departures from the model were due to silviculture (spacing) and site effects.

It was recommended:

[3] In fact, log velocity values often show a peak above the butt log, which is an feature] most likely caused by heartwood % affecting the log moisture content. No sawing studies based on commercial log lengths have shown an increase in stiffness recovery above the base bottom log.
[4] Knot size does not affect the sonic reading much, but has an important effect of timber grade through knot size limitations (visual override).
[5] Several studies have indicated that outerwood density is actually a better predictor of timber value ($/m^3).
[6] In fact, recent studies have shown that on a stem basis they are not very accurate.
[7] WQI data have shown that inclusion of log average green density can improve the prediction of timber stiffness. At present this can only be assessed using the heartwood algorithm, which is based on a small dataset.

"To use known generic patterns of radial and vertical variation in conjunction with growth models, and incorporate the effect of growth rate and genotype where known. Use mixed non-linear or smoothing spline models and incorporate estimates of between-tree variability".

Another study proved a small but statistically significant reaction of MFA to weed control. It is unrealistic to assign specific values to individual stems and logs in a predictive model, but the overall effects of spacing can be assessed at the stand and log height class level using a generic model.

However, the question to be asked as far as Forecaster is concerned is: will a Microfibril angle algorithm be used? Knowledgeable users will know that the contribution of MFA is mainly in the juvenile wood, where it is included in acoustic values, and in compression wood, which is highly unpredictable. While MFA is acknowledged to be an important wood property, particularly in the juvenile wood, it is very expensive to acquire new data via SilviScan, and its use in current predictive models not robust.

Proposal:

1. Do not implement an MFA algorithm at present, but collect more data in routine wood quality studies. The long term objective should be to validate the effect of growth rate in relation to site and thinning, and incorporate it into an improved ring-based model for prediction of stiffness and stability.
2. Include a section summarising knowledge in a Forecaster User Guide.

HEARTWOOD AND GREEN DENSITY

Heartwood formation in radiata pine has not been a research priority, but data have been collected in many studies over the years. Heartwood develops at about 12 years of age and advances outwards from the pith at a rate of about 0.5 rings/annum. Plantation-grown radiata pine has a relatively small proportion of heartwood. A 20-year-old stem has about 10% of its volume as heartwood (Kininmonth and Whitehouse 1991). The heartwood volume increases with tree age. At 30 years of age, heartwood is about 20% of the tree volume, and at 40 years of age, heartwood is about 30% of the tree volume (Cown and McConchie, 1982).

Two issues make heartwood important for modelling.

- The introduction of acoustic methods for estimating stiffness and the realisation that log moisture content (MC) is an important factor affecting the results, has led to increased interest. It is well known that radiata pine fresh sapwood MC can range up to and over 200%, whereas heartwood MC is fairly constant at 45%. WQI have produced improved stiffness models using adjustments for moisture content (Xu *et al.*, 2008; Rawley, 2009). Unfortunately, actual moisture content is not easily measured, and heartwood % can be used as a surrogate (Emms *et al.*, 2008). Without adjustments, log resonance values usually show the highest values above the butt log (Cown *et al.,* 2005; Woollons *et al.*, 2008), whereas sawing studies have consistently show a decrease in average stiffness up the stem (Roper *et al.,* 2004; Gaunt *et al.* 2004). It is believed that log average green density (heartwood %) explains a lot of this difference.
- Clearwood users consider heartwood a defect in some timber grades, so there is interest in being able to predict heartwood diameter in pruned logs in relation to the defect core.

Forecaster includes an algorithm developed jointly by WQI and FFR, based on data collected in wood quality studies over the years to predict the formation of radiata heartwood in terms of heartwood diameter and volume percentage number using data collected from both North-Island and South-Island sites. This allows an adjustment to predicted log velocity values up the stem based on estimated heartwood %. However, for heartwood predictions within growth models, the development of heartwood in terms of number of growth rings is required.

Proposal:

1. Ensure that heartwood and moisture content data (both diameter and ring numbers) are collected in all destructive sampling, along with acoustic measures to enhance the limited database and improve the predictive algorithm. Because heartwood development is very closely related to stem age at any level, a ring-based model may be more useful for assigning heartwood % and green density between stems.
2. Include a section summarising knowledge in a Forecaster User Guide.

SPIRAL GRAIN

Wood stability is a crucial issue caused by the shrinkage of wood as it dries. Shrinkage patterns in radiata pine have been described by Cown *et al.,* 1991). Spiral grain contributes to additional problems – particularly twist.

Twist of wood during drying and in use is a major issue for softwoods, including radiata pine (Haslett *et al.*, 1991). Spiral grain (both absolute level and gradient) has been strongly implicated (Mishiro and Booker, 1988; Harris, 1989; Cown *et al.,* 2009). Traditionally, tree stem grain angles in wood quality studies have been measured on standing stems using a scribe (Harris, 1984) or from discs removed from stems, splitting growth rings tangentially and scribing the outer faces (Cown *et al.,* 1991). This method has the advantage that samples at equivalent positions on either side of the pith can be averaged to eliminate bias in disc levelling (hence giving 'absolute' values referenced to the vertical axis of the stem[8]. The bulk of wood quality studies in NZ have used this approach (Cown *et al.* 1991; Haslett *et al.* 1991; Tian *et al.,* 1995). The procedure is destructive and can be time-consuming.

Attempts have been made to assess external grain angles in standing trees by measuring grain angles through bark windows at breast height, using the protractor (Cown *et al.,* 1991; Lausberg*.* 1995), but this gives only a very local value, and outerwood in the lower stem is usually the least affected by grain distortion. Attempts to use increment cores (5 and 10 mm) with the scribing method were only partially successful (Harris, 1984). Samples of larger diameter (10 or 12 mm cores) have been shown to be more suitable, particularly if the "true" vertical is marked on the outer portion before extraction (Lausberg, 1995), but difficulties in applying a reference angle, and measuring over a short distance contributed to significant errors. It was also found that the torque required to turn the borer did not seem to cause permanent distortion of the samples. The use of outerwood values to classify stems has been shown to be of limited value, due to the greater expression further up the stem.

The most common convention is to consider the left-hand, or "S" pattern (as viewed from the bark side) as a positive angle and right-hand "Z" pattern as negative.

Discs have given the most reliable and repeatable data, particularly when opposite radii are measured to compensate for disc tilt, but require destructive sampling. Sampling has been done at fixed heights in the stem, often representing commercial log lengths (e.g. 5 m). A lot of research has been done using the disc scribing method, and most species have been shown to exhibit left-hand (positive) angles near the pith, decreasing or reversing with age.

Spiral grain has proved costly to assess using the traditional disc scribing method. Values have been shown to vary radially, circumferentially and longitudinally but not necessarily in a predictable fashion. More intensive approaches, like the Spiralometer (using BH cores) have shown that grain variation can also be within growth rings. The generic patterns are now well accepted, but site, silvicultural and genetic factors are not well documented because of the degree of variation present. Hence it is not possible to model the regional patterns, let alone individual trees, with any confidence (Ball and Cown, 2008).

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[8] This "corrected" value is only an absolute angle under the assumption that the only reason for the differences between sides is a tilted disc and the real SGA has no circumferential variation.

Proposal:

1. Do not attempt to incorporate generic spiral grain patterns into Forecaster. There is not enough information to permit allocation of values to sites or stems with any degree of confidence.
2. Include a section summarising knowledge in a Forecaster User Guide.

RESIN BLEMISHES

Clearwood from radiata pine (particularly from pruned logs) can be seriously devalued by resin blemishes. Resin pockets have been the subject of research for several years (Clifton, 1969, Cown, 1973; Somerville, 1980) and risk-prone areas were identified as having high winds and lower water availability. This has been further quantified by Woolons *et al.*, (2008) and partially validated by Lausberg *et al.* 2009). Across the country they found the stand average level of resin pockets to be highly variable, ranging between 0 and 7.65 pockets/m^2 in clearwood from pruned logs. Fifty per cent of the variation in stand average resin pocket incidence was explained by considering site vapour pressure deficit, total solar radiation, soil water availability, stem top-outs (a measure of exposure) and a factor related to the defect core relative to stem diameter at BH. The most important predictor was site vapour pressure deficit, and national maps confirm that coastal Canterbury and Hawkes Bay have high values and also high resin pockets (Cown, 1973; Park, 2004). The susceptible areas predicted by the algorithjm are essentially the same as those outlined by Cown (1973 – Figure 3). However, individual tree studies have consistently shown that tree-to-tree variation is high (indicated both by external resin bleeding and destructive sampling). Genetic studies have also shown a strong heritability for resin pockets (McConchie, 1997).

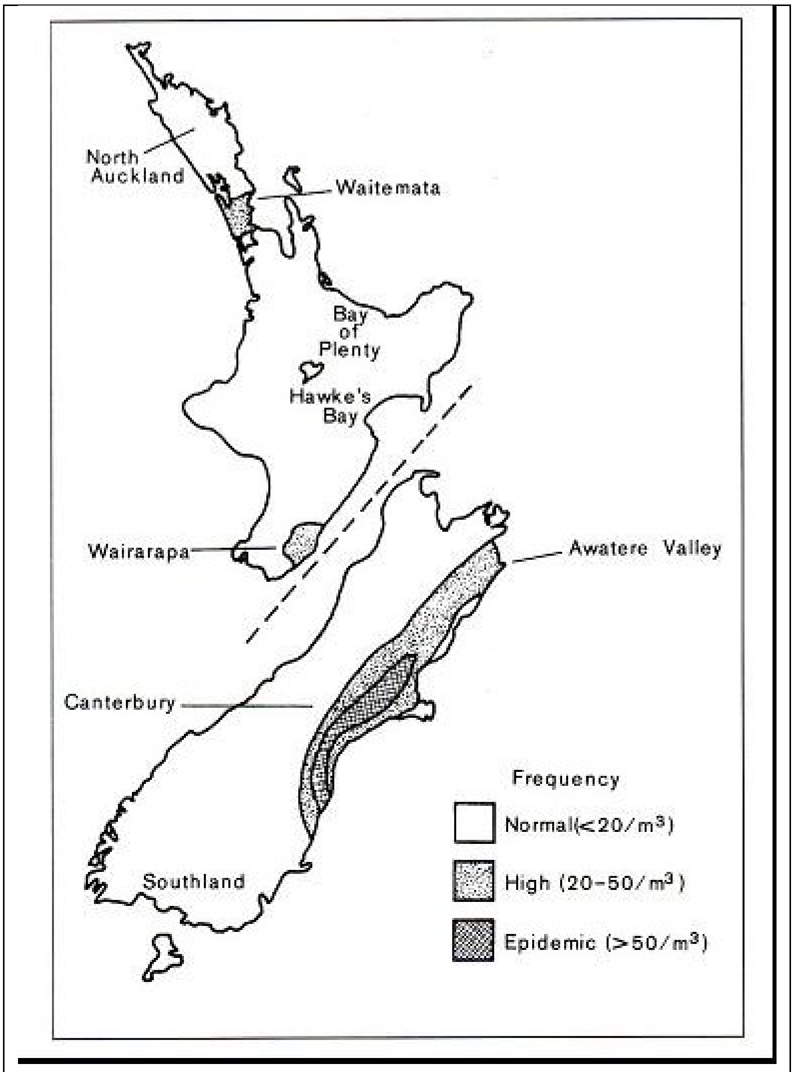

Figure 3: Resin pocket distribution (Cown, 1973)

Forecaster currently does not include resin prediction capability. The information available shows large tree-to-tree variations in external resin bleeding and resin pocket incidence, so it is best handled at the site level. Some studies have indicated that, at least on some site types, annual weather patterns can influence resin (Cown *et al.,* 2006). There are some indications of a silviculture effect – wider spacing leading to more blemishes (Cown *et al.* 2006a,b; McKinley and McConchie, 2000) but this is not well quantified.

There is clearly also a genetic influence (M[c]Conchie, 1997; Kumar, 2004; Kumar and Stovold, 2008), this information can be used as a guide for foresters contemplating clearwood regimes.

Proposal:

1. Prepare "resin maps" for inclusion in a Forecaster Information page, using all available data.
2. Incorporate any information on site and silviculture from Scion and WQI, and breeds available from RPBC.
3. Include a section summarising knowledge in a Forecaster User Guide.

COMPRESSION WOOD

Compression wood is a common occurrence in radiata pine (sometimes up to 20%) and has a significant effect on timber stability. However, except in severe cases, compression wood occurrence is not predictable in stems (Grace *et al.*, 2004; Gardiner and Macdonald, 2005), and neither is its impact on value. In fact, it has often been shown that straight stems are likely to contain compression wood as a mechanism for correcting stem malformation. A complicating factor is the lack of an agreed classification system (Altaner *et al.*, 2009).

Proposal:

1. It is not yet practical to consider the prediction of compression wood in modelling systems.
2. Include a section summarising knowledge in a Forecaster User Guide.

INTRA-RING CHECKING

Intra-ring checks are a sporadic issue for wood processors, affecting the lower part of the stem prior to heartwood formation and reducing with tree age. The defect occurs only after wood drying and is not apparent until after further processing. It can seriously affect the value of clearwood. While the incidence has been found to be high on some sites, extensive studies have uncovered no links to site, silviculture or climatic factors (Cown *et al.,* 2008a,b). Genetic studies have indicated moderate heritability (Kumar *et al,* 2004).

Proposal:

1. It is not yet practical to consider the prediction of intra-ring checking in modelling systems.
2. Include a section summarising knowledge in a Forecaster User Guide.

CONCLUSION

Wood quality models need to be operationally useful. Forecaster currently includes models for wood density, acoustic velocity and heartwood (green density), as these are all related to the prediction of timber stiffness. As such it is important to build the algorithms based on the current resource, but to allow for incorporation of genetic parameters which may change over time.

Validation studies have been performed on the wood density algorithms (2) and they have been shown to provide reasonable estimates of the average and ranges of stand characteristics. It is recommended that Forecaster provide only one density algorithm, and that FFR maintain it as new data comes available.

The velocity algorithms are relatively new, and hence poorly validated. There are two issues: the prediction of log velocity from BH measures, and the relationship between log resonance and timber stiffness. The first will improve over time with the collection of data from PSP plots, but the second requires further validation from sawing studies, particularly to explain the velocity “hook” within stems (strongly suspected by the author to be an artificial phenomenon due to moisture content patterns within the stem).

The heartwood algorithm is required to predict stem and log moisture content for adjustment of the velocity values. It is based on a small dataset from old wood quality studies and limited WQI data. This is at least part of the issue with the “hook” and warrants further research, either by FFR or SWI.

Twist is another issue which affects timber from the juvenile wood of radiata pine. There are no clear signs of site, silviculture or breed effects – between-tree variation seems to be by far the largest component. Also, there are currently no known non-destructive techniques to reliably predict spiral grain in the centre of the stem in a cost-effective way. It is therefore not feasible to include models to predict spiral grain on a stem or log basis in Forecaster.

As far as clearwood quality is concerned, Forecaster relies on estimates of PLI. In practice, these values can be significantly affected by the presence of defects such as resin blemishes and intra-ring checks. In the case of resin blemishes, there are large tree effects and strong climatic factors which can be used to predict the propensity of the site to exhibit problems. It is also known that there is a strong genetic influence and probably a link to stocking level. It is too soon to include functions to assign individual stem resin scores based on models, but early stem scoring of stands could be used as a guide to the validity of pruning, and resin maps could be used for decision support.

Intra-ring checking can be a serious defect, but like spiral grain, there is not enough known about the drivers to permit predictive modelling.

To date Forecaster has been used purely as a predictive model. To make it more operationally useful, the inclusion of a Guide should be considered. As far as wood properties are concerned this could include a description of the main wood properties influencing value and a summary of the effects of site, silviculture and breeding.

ACKNOWLEDGEMENTS

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