Predicting wood value in Queensland Caribbean pine plantations using a decision support system

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Summary

A decision support system has been developed in Queensland to evaluate how changes in silvicultural regimes affect wood quality, and specifically the graded recovery of structural timber. Models of tree growth, branch architecture and wood properties were developed from data collected in routine Caribbean pine plantations and specific silvicultural experiments. These models were incorporated in software that simulates the conversion of standing trees into logs, and the logs into boards, and generates detailed data on knot location and basic density distribution. The structural grade of each board was determined by simulating the machine stress-grading process, and the predicted graded recovery provided an indicator of wood value. The decision support system improves the basis of decision-making by simulating the performance of elite genetic material under specified silvicultural regimes and by predicting links between wood quality and general stand attributes such as stocking and length of rotation.

Keywords: plantations; management; silviculture; models; conversion; computer software; wood properties

Introduction

A decision support system (DSS) that allows managers of commercial plantations to evaluate the effect of various silvicultural regimes on the graded recovery of structural timber has been developed in Queensland by staff of Forestry Plantations Queensland (FPQ) and the Department of Primary Industries and Fisheries (DPI&F). The DSS is focussed on tropical and subtropical commercial softwoods destined for sawlog and structural timber markets, and initially has been calibrated for Caribbean pine (*Pinus caribaea* var. *hondurensis*).

The DSS provides a suite of software tools that evaluates silvicultural scenarios and simulates the effects of changes in stocking and rotation age on the branch architecture and wood properties of logs and boards destined for structural timber products. Development entailed constructing models for Caribbean pine that describe stand growth, taper, branch architecture, wood density and wood stiffness for a range of stockings and rotation ages, using data collected from specific silvicultural experiments and routine plantations. These models are applied in conversion software[1] that uses commercial sawing patterns and specified log lengths to simulate cutting each tree into logs and then into boards. The size and location of all knots and the distribution of density in each board are outputs from the conversion software and are used in separate grading software to predict the structural Machine Graded Pine (MGP) grade of each board based on Australian Standard 1720.1 (SAA 1997). The DSS links graded recovery with stand parameters such as stocking and clearfall age to assist plantation management decision-making in relation to clonal selection and silvicultural options.

A number of similar decision support systems exist for different species. Wood quality and the location and dimension of branches can influence the recovery of timber from logs and in turn affect the grades of timber obtained from a given tree (Leban *et al*. 1999; Maguire *et al*. 1999; Pinto *et al.* 2003; Todoroki 2003). In order to understand the relationship between branching patterns, wood quality and graded recovery it has been advantageous to assess these properties at the tree and stand level, and link them to silvicultural practices in computer-based decision support systems. For example, models of wood properties such as basic density, spiral grain, ring width and mechanical properties have been developed for Norway spruce (*Picea abies*) for use in conversion software to link tree height, crown development, wood quality and branch architecture to the quality of sawn boards (Houllier *et al*. 1995; Lindström 2000). Conversion software has been developed for radiata pine (*Pinus radiata*) that links wood properties with sawing and end-use of timber (Todoroki 1996), and detailed models of branching were developed and incorporated in conversion software to determine the influence of branching on timber value (Pont *et al*. 1999).

This paper provides an overview of the decision support system developed by FPQ and DPI&F and discusses its development and potential applications.

[1]In the context of this paper, 'conversion software' refers to specific software that is designed to model the process of cutting trees into logs and boards.

Components of the decision support system

The DSS consists of a suite of models and custom-built computer software tools (Fig. 1), and relies on the input of external data and models. One of the software tools called STEPS (Software Tools for Evaluating Plantation Scenarios), developed as part of the DSS, was previously described in detail by Catchpoole and Nester (2003, 2004). STEPS provides a user-friendly interface to evaluate a range of silvicultural scenarios in economic terms. The French Win-Epifn software (Leban *et al.* 1999; Meredieu *et al.* 1999) developed by the Institut Nationale de Reserches Agronomique (INRA) has been adopted as the conversion software. Win-Epifn was used to simulate the cutting of trees into logs and boards and to assign the virtual board details (dimensions, knot sizes and positions) that are used in separate board grading software. The grading software was specifically written to incorporate the Australian grading rules for Machine Graded Pine and assigns a structural grade to each board. These structural grades and the graded recovery provide an indication of wood value. The graded recovery estimates that are generated by the grading software can be returned to STEPS to enable the internal rate of return and net present value to be predicted. However, this function of the DSS has not yet been developed, as shown by the dashed line in Figure 1.

STEPS: The financial evaluation component

STEPS is a financial evaluation software tool developed using Visual Basic for Applications in Microsoft Excel®. It allows the economic outcomes of various silvicultural scenarios to be analysed and compared. The program takes into account growth and yield, all costs that occur over a rotation including costs associated with thinnings and pruning, and specifications of the timber products and prices applicable at thinning and clearfall. The user may provide parameters including site index, thinning age, clearfall age, pruning strategies and stocking to evaluate silvicultural scenarios by estimating internal rate of return and net present value. Options include the choice of discount rate and whether or not the net present value is calculated over one rotation or an infinite number of rotations. STEPS is currently being used by Forestry Plantations Queensland as a stand-alone software tool to evaluate silvicultural scenarios for purposes of strategic planning. It allows the simultaneous comparison of economic and growth parameters to select optimum silvicultural regimes for specified estate areas.

Win-Epifn: The conversion software component

The French-developed conversion software called Win-Epifn©$_{\mathrm{INRA}}$ was customised for commercially grown Caribbean pine in Queensland and was used to simulate the process of sawing trees into logs and structural timber. It requires standard inventory data (i.e. tree height, diameter, age and stocking), models of branch architecture, models of wood properties, and a selection of optimised sawing patterns that vary according to log small-end diameter. The individual board descriptions that are generated include board dimensions, the within-tree position of each board, the position and size of each knot, and the distribution of within-board density on the four sides of every board.

Branch models used in the conversion software

Considerable research has been undertaken in modelling branch architecture in *Pinus radiata* (Pont *et al*. 1999), *Picea mariana* (Lemieux *et al*. 2001) and *Picea abies* (Mäkinen *et al.* 2003). The purpose of the branch models is to characterise the relevant branch architecture for each branch in the tree, and relate this to knot size and distribution for descriptions of individual boards. The models of branch architecture predict branch diameter, branch height, branch position (orientation within the whorl and branch angle) and number of branches per whorl.

As models for *Pinus caribaea* var. *hondurensis* grown in Queensland were not available, they were developed for this project (Catchpoole *et al*. 2002) using data from a broad-scale direct thinning trial in south-eastern Queensland.

Wood property models used in the conversion software

Substantial research has been undertaken to model various wood properties in a range of species. Models for radiata pine estimate wood density distribution and spiral grain (Tian and Cown 1996),

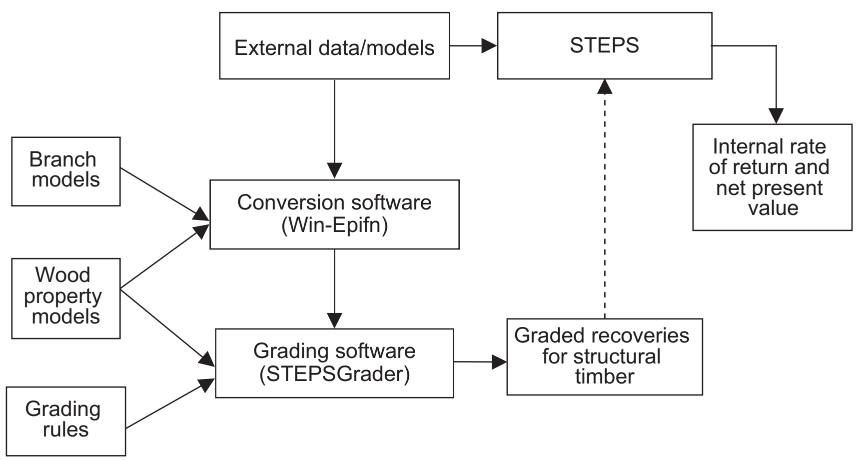

Figure 1. Structure of the decision support system

and strength and stiffness (Burdon *et al.* 2001). In Norway spruce, properties modelled include wood density distribution (Lindström 2000), spiral grain (Kliger 2002) and ring width (Saint-Andre *et al.* 2000). In Queensland, research has been undertaken to estimate genetic parameters for wood quality traits in Caribbean pine (Harding *et al.* 1991) and more recently into variation in wood properties of the interspecific slash × Caribbean pine F_1 hybrid (Harding and Copley 2000).

The models of wood properties used in this project predict within-tree distributions of basic density and ring width, and were developed from data collected from sawing studies and mechanical testing of timber from routine Caribbean pine plantations.

STEPSGrader: The grading software component

The grading software, called STEPSGrader, has been custom-built by FPQ and was developed in Microsoft Excel®. Data on wood density, ring width, knot size and knot location from the conversion software are used to predict wood stiffness (modulus of elasticity — MOE) of mechanically stress-graded pine timber. User-specified MOE thresholds and the predicted minimum MOE of a board are used in the grading software to assign MGP structural grades to each board. MGP 15 is the highest stiffness grade, and timber of this grade is of higher value to industry than grades MGP 12 and MGP 10. The standards for machine stress grading (SAASANZ 2006) were used when setting the grading rules in STEPSGrader. The grading software outputs are summarised in terms of graded recovery at the log, tree and stand level. The recovery achieved in the various structural grades can be assigned a value to provide an estimate of the total value of the wood recovered.

Development and application of the DSS

The development and application of STEPS has been described by Catchpoole and Nester (2004). This section therefore focuses on the development and application of the conversion software and the grading software components of the DSS. The conversion software is species-dependent, and customisation for a particular species is done by supplying either a suite of model parameters or a suite of detailed data files. It was decided that maximum flexibility could be achieved by customising the conversion software for Caribbean pine using data files as inputs, because this allowed independence from the software developer (INRA). The customisation process involved the following steps:

1. developing and evaluating models for tree height, diameter at breast height, height to first dead branch, height to first live branch, height to first live whorl, whorl height, number of branches per whorl, individual branch diameter and branch insertion angle (Catchpoole *et al.* 2002)
2. developing models for within-tree wood density and ring width
3. from each model listed in 1 and 2, generating files of simulated data in the format required as input by the conversion software
4. incorporating sawing patterns based on Queensland commercial pine operations.

Steps 1–3 were undertaken with minimal assistance from the software developer, INRA. Data were readily available from long-term experiments to develop the models for tree growth, branch architecture and wood properties. Developing the models and generating the input files, however, was time consuming given the limited availability of staff with mathematical and programming expertise. INRA assisted in Step 4 to 'hardwire' the sawing patterns into the conversion software.

Input files were created for the stocking classes of 100 stems ha^{-1} (sph), 200 sph, 300 sph, 500 sph and 750 sph, and rotation ages ranging from 15 to 32 y. These were efficiently and automatically generated using a combination of Unix®, Maple© and Microsoft Excel® platforms. Simulations were performed for each of the input files using the conversion software. The options selected in the software to model the conversion process included cutting each tree systematically into logs up to a top diameter of 10 cm under bark, an initial stump height of 15 cm and a log length of either 490 cm or 610 cm. Each log was then virtually sawn into boards using a sawing pattern that was available in the software and varied depending on small-end diameter. The conversion software produced outputs in graphical and tabular formats at the stand, tree, log and board level. At the board level this included detailed descriptions of knot size and location on the four sides of every board, as well as knot area ratio and board density profiles. The tabular outputs were exported to other software packages for analysis, and were used in STEPSGrader where structural machine grades were assigned to each board.

These simulations have been completed and the results are undergoing validation. This has involved a thorough analysis to ensure that all tabular output from the conversion software including that on knot size and location, knot area ratio calculations, board dimensions and wood density profiles makes sense against the data provided in the input files. This check revealed that the conversion software required several modifications to adequately model Caribbean pine grown in Queensland. WinEpifn was developed for northern-hemisphere species such as Douglas-fir and Sitka spruce; customisation for Caribbean pine required the ability to accurately model trees that produce multiple branch whorls per year and may also produce foxtails (elongated sections of stem producing no branches for several growing seasons).

Several limitations of the DSS need to be recognised when interpreting the results from STEPSGrader; these include an assumption that trees are straight and free of internal defect such as resin shake and streak. Such limitations are inherent in the conversion software, but they could have considerable effect on the graded recovery from *P. caribaea* var. *hondurensis* in circumstances where these defects are important. Because accurately modelling these defects is complex and difficult, a standard discount for downgrade due to resin defects and distortion is necessary. The cross-checking of results from the conversion and grading software and validation of the graded recoveries against actual sawmill recoveries will continue for several months.

The outputs of this DSS have many potential applications for commercial forest growers, particularly those focusing on production of solid wood for the structural timber market. The system is sophisticated in its ability to link stand silviculture parameters with wood quality and can be used to:

- evaluate the effect of spacing and resulting branch architecture on graded recovery. This could be used simply for predicting volume distributions across structural grades, or in decision-making to determine optimum spacing to achieve a desired volume of boards of a particular structural grade
- evaluate the effects of a change in rotation age on wood quality. The models that have been developed can be confidently applied to rotations aged from 15 to 32 y, and therefore input files for the conversion software can be created for any age within this range. This allows the effects of rotation age on within-tree density, knot area ratio, stiffness and in turn graded recovery to be assessed
- provide a better understanding of the wood quality of an existing resource for the purposes of short- to medium-term planning
- evaluate individual genotypes. The models will be modified to suit the genotypes of interest, and the results of simulated sawing and grading used to choose among genotypes as an alternative to or in conjunction with selection indexes.

Conclusion

The value of recovered wood product is predicted in this decision support system by integrating data and models that describe tree growth, branch architecture, wood properties and the stiffness of timber to generate a distribution of graded timber recoveries. These graded recoveries are linked to silviculture through the tree growth, branch architecture and wood property models that are supplied for different stockings and clearfall ages. The complex suite of such models required in this decision support system is species-dependent. Customisation of the software for other species requires relevant data and capacity to develop the required models. Such a process is potentially time consuming, particularly if data need to be collected in the field. As with most decision support systems it is necessary for the user to have a good understanding of the input models and their limitations in order to be able to reliably interpret the outputs.

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