Forest Ecology and Management 255 (2008) 3524–3533

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Full length article

Predicting timber properties from tree measurements at felling: Evaluation of the RetroSTEM model and TreeViz software for Norway spruce

Anu Kantola [a,*], Sanna Härkönen [b], Harri Mäkinen [a], Annikki Mäkelä [c]

[a] Finnish Forest Research Institute, Vantaa Research Unit, P.O. Box 18, FIN-01301 Vantaa, Finland
[b] University of Joensuu, Faculty of Forest Sciences, P.O. Box 111, FIN-80101 Joensuu, Finland
[c] University of Helsinki, Department of Forest Ecology, P.O. Box 27, FIN-00014 University of Helsinki, Finland

ARTICLE INFO

Article history:
Received 29 November 2007
Received in revised form 6 February 2008
Accepted 21 February 2008

Keywords:
Branches
Stem taper
Norway spruce
Wood density
Wood quality

ABSTRACT

The RetroSTEM model was developed for predicting three-dimensional stem and wood quality characteristics in conifer stems from simple measurements at felling. The model has been previously parameterised and tested for Scots pine. This study adapts the model to Norway spruce and evaluates its prediction power regarding stem and wood quality simulations from tree base to tree top, with the objective of identifying any systematic errors in the estimation. This information will be used for future model development. The selected quality factors – stem taper, branch size, ring width and wood density distributions – are critical for visual and strength-based timber grading and for timber yield estimations. The wood density simulations provided through visual tool, TreeViz, were embedded in the RetroSTEM. The model testing indicated that the height growth model embedded in RetroSTEM should be revised regarding growth at early ages. The predicted early height growth was too fast, which led to bias in the number of annual rings at the middle and lower parts of the stem and in stem diameter at the middle stem. However, the average bias in stem diameter was relatively small (−0.3 cm) at tree level. Similarly the average bias of branch maximum diameters was low (0.2 cm) at tree level, but RetroSTEM underestimated branch diameters in trees with long crowns. Overestimation in the number of annual rings also led to underestimation of average ring width. The TreeViz estimates of wood density seem realistic. At this stage the model is applicable to estimating stem quality distributions at stand level, particularly in dense stands younger than 100 years of age.

1. Introduction

The quality of wood from forest harvest operations is an important issue for both sawmills and pulp mills. Especially, log buyers need to assess the properties of the existing resource to allocate the raw material to appropriate end uses. This includes the prediction of internal stem characteristics and lumber quality from external stem or log properties. Most evaluation methods currently in use are based on the prediction of log or lumber grade from external indicators, such as diameter at breast height (1.3 m, DBH), or height of the lowest dead branch (Uusitalo and Kivinen, 1998; Uusitalo and Isotalo, 2005). Modern industrial wood conversion simulators, however, could make use of much more detailed information about stem structure, both in sawing and pulping simulation (Lundgren, 2000; Lundqvist, 2002; Poukka et al., 2003; Pinto, 2004).

Simulation models of detailed three-dimensional stem structure have already been developed in the framework of stem growth as a function of growing conditions, including stand management (Mäkelä et al., 1997; Kellomäki et al., 1999; Meredieu et al., 1999; Mäkelä, 2002; Seifert, 2003). Such models can be used for the analysis of the dynamic effect of environment and stand management options on wood quality. However, they are not readily applicable to the estimation of stem structure if measurements and information are only available at the time of harvest.

RetroSTEM (Retrospective Stand and Tree Evaluation Model) has been developed for the assessment of stem properties from easily available external measures of stems (Mäkelä et al., 2002). It reconstructs the stems as three-dimensional objects with annual rings and knots. The knots are further divided into sound and dead parts, and the growth rings have been assigned properties such as density, latewood proportion and tracheid dimensions. These properties can be further applied to the grading of sawn timber; visual grading is largely based on the occurrence and size of knots, while strength grading relies on knots, ring width, and wood density (Hanhijärvi et al., 2005; Lycken, 2006). Roughly similar

* Corresponding author. Tel.: +358 10 2112322; fax: +358 10 2112203.
E-mail address: anu.kantola@metla.fi (A. Kantola).

0378-1127/$ – see front matter
doi:10.1016/j.foreco.2008.02.034

geometric reconstruction of stems (stem shape, branching pattern, and wood properties) have been provided earlier by Win-EPIFN model, which estimates the past growth of a tree from forest inventory data to predict the internal structure of logs and their grading (Leban et al., 1996).

RetroSTEM utilises theories about structural regularities in trees, notably the pipe model (Shinozaki et al., 1964a,b), the profile theory (Osawa et al., 1991), and regular crown allometry (Ilomäki et al., 2003; Mäkelä and Valentine, 2006). These structural models have been parameterised for Scots pine (*Pinus sylvestris* L.) (Mäkelä and Vanninen, 2001; Vanninen, 2003) and Norway spruce (*Picea abies* [L.] Karst.) (Kantola and Mäkelä, 2004, 2006). In addition, RetroSTEM includes empirical models of branch population dynamics (Mäkinen et al., 2003) and wood properties (Mäkinen et al., 2007), the latter through an embedded visual tool, TreeViz.

RetroSTEM has already been described and tested for wood quality predictions in Scots pine (Mäkelä et al., 2002). A process-based model using the same stem structure module as RetroSTEM has been tested in a small data set for Norway spruce (Kantola et al., 2007). The objective of this study is to (1) adapt RetroSTEM to Norway spruce and (2) test its performance for predicting wood properties (stem diameters, branch maximum diameters, ring widths and wood densities) over individual stems at felling in an independent data set, to pinpoint any further needs of improvement of the model.

2. Material and methods

2.1. Simulation of stem structure and properties

2.1.1. RetroSTEM

RetroSTEM reconstructs stem structure and properties from measured input (tree age, DBH, tree height and crown ratio) at felling (Fig. 1). The method and its parameterisation for Scots pine have been described by Mäkelä et al. (2002), but a brief summary is given below and in Appendix A.

RetroSTEM consists of three modules: (1) a "growth engine" at tree level (TREE); (2) a structural module at whorl level (WHORL); and (3) a module for individual branches (BRANCH). TREE produces values for tree height, height to the live crown base, and foliage mass, to be input to WHORL each year. The crown base is defined as the lowest whorl with at least one living branch that is separated from the other living whorls above it by no more than one dead whorl. Based on this information, WHORL and BRANCH update the structure of the stem and the individual branches each year (Appendix A). The WHORL and BRANCH modules are the same as in the PipeQual model (Mäkelä and Mäkinen, 2003) parameterised previously for Norway spruce (Kantola et al., 2007). The photosynthesis-driven TREE module of PipeQual, however, has been replaced in RetroSTEM by simple empirical equations that reproduce the past height growth, development of the crown base, and the respective foliage mass of the tree.

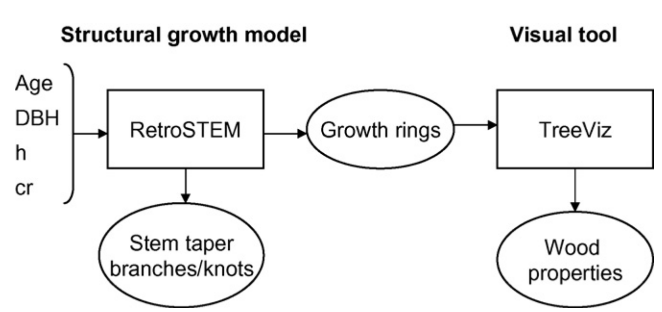

Fig. 1. Schematic presentation of the model inputs and outputs. Age is tree age, DBH is stem diameter at breast height, ***h*** is tree height and cr is crown ratio.

In RetroSTEM, the estimation of past height from current height at felling is based on a family of empirical site index curves (Vuokila and Väliaho, 1980). The curves were parameterized using the height function developed by Meng et al. (1997):

$$H(t) = H_{\mathrm{m}} \frac{1 - X(t)}{1 + X(t)/C} \tag{1}$$

$$X(t) = \frac{H_{\mathrm{m}} - S}{(H_{\mathrm{m}} + S/C)^{t/t_{\mathrm{s}}}} \tag{2}$$

where t is time, H_{m} is the maximum attainable height, C is a parameter determining the initial rate of height growth, and S is site index according to Vuokila and Väliaho (1980), *i.e.* tree height at age $t_{\mathrm{s}} = 100$ (Table 1, Fig. 2).

For any given height at felling, RetroSTEM selects the parameters for the height function such that (1) the curve passes through the measured (height, age) point, and (2) it falls between the nearest members in the family of curves with fixed parameter values. In practice, this is done in two phases. First, the current height at the current age is compared with the curves in the family, and the closest curve of those pre-parameterised is selected. The parameter C is taken from this curve. Secondly, H_{m} is selected such that the height growth curve yields the current height at the current age, given the chosen value of C.

The height to crown base, H_{c}, is calculated from tree height as follows:

$$H_{\mathrm{c}}(t) = 0, \qquad \text{if } H(t) < H_{\mathrm{ref}} \tag{3}$$

$$H_{\mathrm{c}}(t) = a(H(t) - H_{\mathrm{ref}}), \qquad \text{if } H(t) \geq H_{\mathrm{ref}} \tag{4}$$

where H_{ref} is tree height at the age when crown rise begins, and a is a coefficient calibrated to bring crown base to the measured value

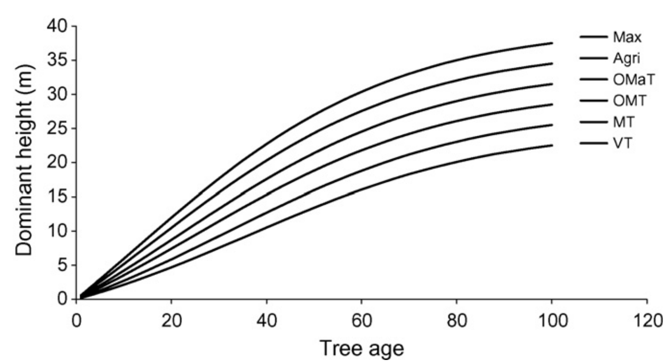

Fig. 2. Height curves for Norway spruce based on Vuokila and Väliaho (1980), and the corresponding forest site types according to Cajander (1949) from highly fertile to poorer sites. The abbreviations are given in Table 1.

Table 1
Parameters for height curves in Fig. 2 in different site fertility classes (Cajander, 1949)

Parameters	Site fertility class					
	Max[a]	Agri[b]	OMaT[c]	OMT[d]	MT[e]	VT[f]
C	0.65	0.58	0.45	0.4	0.3	0.25
S	37.5	34.5	31.5	28.5	25.5	22.5
H_{m}	40	37	34	31	28	25

[a] Maximum curve is added for remarkably high trees.
[b] Trees grown on abandoned agricultural land.
[c] *Oxalis-Maianthemum* type.
[d] *Oxalis-Myrtillus* type.
[e] *Myrtillus* type.
[f] *Vaccinium* type.