Modelling the impact of silviculture treatments on the wood quality of interior spruce.

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Abstract

Interior spruce (*Picea glauca x engelmanii*) is a valuable commodity in British Columbia. There is concern that post-harvest spruce, which is regenerated at much lower densities than the orginal stands, will have lower wood quality because of excessively deep crowns. In 2007, we destructively sampled 30 interior spruces ranging from 27 to 107 years in age from two sites in northern interior BC: TFL52 and TFL53. Our first objective was to develop a statistical model to predict average inside bark diameter of interior spruce branches along the bole. These predictions link with equations predicting lumber distributions previously published by Forintek. We also fit an equation to predict maximum knot size used to grade logs for estimate value.

Our equations predicting average and maximum knot size and juvenile-mature wood transition were incorporated into a system of computer models, SYLVER, that includes a tree model (TASS), log bucking and grading routines (BUCK and GRADE), a sawmill simulator (SAWSIM), and a financial analysis system (FAN$Y). The results of this

project immediately assist forest managers to evaluate the economic efficacy of stand- and forest-level decisions.

Keywords: interior spruce, wood quality, stand management, knot distributions, TASS, growth and yield modelling

Introduction

Throughout the interior of British Columbia, interior spruce (*Picea glauca x engelmanii*) is a common commercial species. Interior spruce accounted for over 20% of the total volume harvested in British Columbia in the period April 2004 to March 2005; this amount was second only to lodgepole pine (55%). As the catastrophic effects of the current mountain pine beetle (MPB) outbreak unfold, the areas managed for spruce will no doubt expand greatly to help diversify interior forests and stabilize timber supplies. The Forest For Tomorrow (FFT) program will provide substantial investment dollars to offset the short- and long-term effects of the MPB epidemic through the establishment of new stands and the management of advanced regeneration. There is concern among experts, however, that the quality of the wood from these post-harvest and post-beetle stands could be substantially lower than historical levels.

Stand density management can control important tree, log and fibre characteristics. Previous work in coastal Douglas-fir (Mitchell and Polsson, 1993), lodgepole pine (Middleton et al., 1995; Mansfield et al., 2007) and coastal western hemlock (Goudie 2003) indicated that crown structure influences wood quality (density, strength and stiffness, and tracheid characteristics). Descriptive research into the current resource of interior spruce has shown that rapid growth reduces relative density, suggesting that wide spacing may reduce wood quality for some products. Furthermore, we cannot predict if silviculture treatments that promote rapid growth have positive or negative impacts on non-timber values such as wildlife habitat.

Realistic models must be developed to predict treatment effects not addressed by field research.. It is a biologically oriented model that has been calibrated for both coastal and interior conifer and broadleaf species. It is linked to decision support software that evaluates the effect of Silviculture on Yield, Lumber Value and Economic Return (SYLVER, Mitchell et al. 1989). TASS relies on individual tree growth functions derived from intensive stem analysis and branch growth data to simulate the development of crowns in a three-dimensional computer space. We propose to develop models to predict wood quantity and quality of managed interior spruce under different silvicultural strategies.

Methods

Site Selection

Two study areas were located in TFL52 and in TFL53. Within each of these locations, three stands of different maximum ages ranging from 27 to 107 years were selected. Sites were all in the SBS zone and ranged from mk to mw subzones (Table 1).

Field Methods

At each of the two areas, we sampled 15 trees. In each stand in an area, four to five interior spruce trees that were relatively free of defects (e.g., forks, crooks and pest damage) and that represented the range of mature trees in the stand were sampled. Sampling was timed to ensure that the needles had fully elongated and that radial and top growth was completed.

The crown perimeter of the sample tree was measured at 8-12 key points. All trees (DBH ≥4 cm) in a 0.04 ha circular plot (radius 11.28 m) around the sample tree were mapped and species, diameter and location recorded. The point of contact of branches with neighbouring trees was recorded in each of four quadrants. Pictures were taken of each site and the sample bole. Trees were felled in a safe, open location to minimise branch breakage. Safety of the faller and crew was, however, a primary consideration.

After felling, the total height, height to the base of live crown, and the height to the free-growing portion of the crown in each of four quadrants around the stem were measured. Evidence of branch abrasion was observed to determine the upper extent of crown

Table 1. Stand biogeoclimatic classification, age, and number of trees sampled at the study sites

Location	**Tree**	**SBS Subzone**	**Age**	
TFL52	16	mk	32	
	17	mk	33	
	18	mk	27	
	19	mk	31	
	20	mk	29	
	21	mk	79	
	22	mk	76	
	23	mk	69	
	24	mk	74	
	25	mk	67	
	26	mw	73	
	27	mw	54	
	28	mw	105	
	29	mw	103	
	30	mw	107	
TFL53	01	mm	31	
	02	mk	28	
	03	mm	34	
	04	mk	33	
	05	mm	31	
	06	mk	72	
	07	mk	68	
	08	mk	73	
	09	mk	74	
	10	mk	80	
	11	mk	100	
	12	mk	101	
	13	mk	90	
	14	mk	96	
	15	mk	103	

contact. The cumulative height to each annual whorl within the live crown was then measured. To check the accuracy of the whorl count, disk samples were cross-referenced to ensure that nodal ages at each whorl matched both bole ages and branch ages. Complete disks were removed at three fixed heights (0.30, 0.70 and 1.3m) and at 10 approximately equally spaced locations above breast height. Sample locations were adjusted if necessary to avoid large branches or whorls.

The Ministry of Forests and Ramsoft Systems Ltd. had previously developed a custom data logging program (Stem and Tree Analysis Recording System (STARS)) to guide and record the branch sampling. Using the STARS program, six to ten internodes were randomly selected for branch sampling. The STARS program is constrained to select at least one internode in each bole section containing live crown. For crowns occupying less than six bole sections, STARS locates surplus internodes in the middle third of the crown where most foliage exists. In each sample internode, all branches in the live crown were located and measured. Information gathered included distance from top of internode, azimuth, vertical and horizontal diameters outside bark, and total length. The horizontal and vertical diameters were sampled close to the bole edge but outside severe branch swelling. A damage code was assigned to broken branches. STARS randomly selects up to three branches per internode for detailed sampling. Selection probability is proportional to branch cross-sectional area at the base. We measured inside bark diameters (vertical and horizontal) and collected foliage for laboratory determination of biomass and leaf area. Biomass and leaf area data are to be analysed in the 2005-7 period.

Statistical Methods

Knot size

The measurements of vertical and horizontal diameters inside and outside the bark from the sample branches were used to determine inside bark dimensions of non-sample branches. For each tree, a matrix of regression coefficients of all combinations of inside and outside diameters was generated using PROC REG (SAS Institute Inc. 1995). These coefficients were used to estimate the vertical and horizontal diameter inside bark of all branches identified in each internode. The arithmetic average of vertical and horizontal inside bark diameters (DIB) corresponds to the measurement used by Forintek in their lumber grading software. The average of inside bark diameter (AVEDIB) was calculated and plotted against relevant independent variables that were measured during sampling. Based on these preliminary relationships, we tested relationships with several common equations: linear, power function, power function with intercept, exponential types I and II (Sit and Poulin-Costello 1994). The following generalised form of power function was determined to be appropriate:

[1] $$AVEDIB = b_o \cdot X_1^{b_1} X_2^{b_2} X_3^{b_3} ...... + \varepsilon$$

Where b_0, b_1.....b_I are unknown parameters estimated by standard regression techniques and ε is the random error, which is independently and normally distributed with a constant unknown variance. Because the allometric equation is intrinsically non-linear and to account for variation among, we used PROC NLMIXED (SAS Institute, Inc. 2004) to develop models of combinations of fixed parameters and random effects. We used trees as the ‘subject’ for random effects in the models. Independent parameters were added one by one to the base model until no further reduction in fit statistics was noted. The criteria to select the best model were the smallest values of Akaike’s information criterion (AIC) and Schwarz’s information criterion (BIC) (Burnham and Anderson 1998). Pearson residuals were calculated and tests were done to check the regression assumptions. The mean of the residuals was calculated and a t-test was used to determine if the mean was significantly different from 0. The residuals were plotted against the predicted values to check for homoscedasticity. The Shapiro-Wilk W statistic (Shapiro and Wilk 1965) tested for normality in the residuals.

Results

Knot size

The average inside bark diameter (AVEDIB) of branches on pines in the four sites was plotted against four independent variables: branch age, branch length, distance from top of tree, and total height of tree. A strong relationship between AVEDIB and average branch length was evident. Unfortunately, the length of individual branches is maintained only in TASS III model and not in the operational TASS II model, which depicts crowns as simple shells. Because in this stage of the project we are parameterizing SYLVER with TASS II, we chose a closely related variable that is consistent with TASS II crown growth equation: average length of two largest branches within an internode, referred to as BL_T henceforth.

Using PROC NLMIXED, we compared different models of the relationship of AVEDIB to a variety of independent variables. BL_T was the most important predictor variable, followed by total height (H_T), based on lowest AIC. Addition of other variables did not reduce AIC.

[4] $$AVEDIB = e^{a} \cdot {BL_T}^{b} \bullet e^{cH_T} \cdot\cdot$$

where a is the random effect varying among individual trees with

$\hat{\mu}_a = -2.215, \hat{\sigma}_a^2 = 0.003$ and $\hat{b} = 0.856$ $c = 0.024$ $\sigma_\varepsilon^2 = 6.316$.

The variation explained, estimated as 1-(residual sum of squares)/(corrected total sum of squares) was 0.92. Pearson residuals were normally distributed.

To determine log grades, the maximum knot size is needed. Maximum knot diameter (MAXDIB) was formulated as a function or average knot size to ensure that it was always the larger value. A quadratic function of *AVEDIB* provided the best fit (F=976.0, p<0.0001) as follows:

[5] $$MAXDIB = 2.783 + 1.201 \bullet AVEDIB - 0.007 \cdot AVEDIB^2$$

Discussion

Over the next few decades, the forest industry in interior BC will increasingly become dependent on a supply of interior spruce from plantations, particularly if the mountain pine beetle epidemic proceeds as expected. Josza and Middleton (1994) define wood quality as the "aptness of wood for a particular end use". Zhang (1997) suggests that wood quality is "all the wood characteristics and properties that affect the value recovery chain and the serviceability of end products". We know that in current markets, high grade lumber provides a premium return (Erikson et al. 2000). Until glass log models that explicitly depict internal defects are operational with growth and yield models, relationships from empirical mill studies must determine the distribution of boards. The computer program, SYLVER, passes log information, including log dimensions and the average knot size at the top and bottom of each log, from TASS to SAWSIM. Forintek previously determined that the percentage of select grade lumber depends on average knot size and the top diameter of the log (Middleton et al. 1995). The maximum knot size is used in grading the logs should forest managers prefer to value forest products by log grade rather than lumber.

This study showed that average branch length was the best predictor of average knot size. The total height of the tree also had a strong influence on average knot size: tall trees, at a given branch length, often have thicker branches with larger knots than short trees.

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