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Predicting softwood quality attributes from climate data in interior British Columbia, Canada

Lisa J. Wood [a,*], Dan J. Smith [a], Ian D. Hartley [b]

[a] University of Victoria Tree-Ring Laboratory, Department of Geography, University of Victoria, Victoria, British Columbia V8W 3R4, Canada
[b] University of Northern British Columbia, Ecosystem Science and Management Program, 3333 University Way, Prince George, British Columbia V2N 4Z9, Canada

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ABSTRACT

Ongoing and future climate changes are expected to result in fundamental shifts in forest productivity and wood quality over wide regions of interior British Columbia. This study was conducted to investigate the relationships between climate and wood property attributes within Douglas-fir and spruce forests, and to use those relationships to develop a non-invasive approach wood quality attribute prediction. Historical climate station data was correlated to tree-ring samples collected at five sites and climate–tree growth relationships were established to measure and predict wood density, cell-wall thickness, and microfibril angle attributes. Time series models were developed to reconstruct the measured wood properties, and a strong correspondence between the predicted and measured wood attributes was verified. The results confirm that climate parameters provide a useful index for assigning wood quality attributes to forest stands at many sites in BC's interior. The findings of this research provide insight into the impact future climates may have on wood quality characteristics and could be applied elsewhere to investigate the impacts of climate change on forest fibre supplies.

1. Introduction and background

Over the next century, mean annual air temperatures in British Columbia (BC) are expected to increase from 1 to 4 °C, and be accompanied by precipitation events of increased intensity and severity (IPCC, 2013). These climate changes are certain to have an impact on BC's forests (Kozlowski, 1979; Larsen, 1993; Wang et al., 2006) and are expected to initiate long-term alterations in cellular wood structure that could result in fundamental shifts in productivity and wood quality over wide regions (Williamson et al., 2009; Adams, 2014). To accommodate the accompanying social and economic impacts of these shifts, BC needs to develop informed stand management plans that take into account any climatically-induced wood quality changes in future forests (Spittlehouse, 2007).

The term wood quality is often used in discussions concerning the contributions of cell growth and maturation to the radial development of a tree. Higher wood densities are most often equated with wood structure and properties of superior quality for the production and manufacturing of wood products (Haygreen and Bowyer, 1996). For example, wood with long tracheids and lower lignin content is preferred for producing most paper types (Taylor et al., 1982). Likewise, high-density wood with a high percentage of latewood in each annual ring, or a high cell wall-to-cell lumen diameter ratio, is often desired by solid wood and pulp and paper manufacturers because of its increased strength properties and high fibre yield (Haygreen and Bowyer, 1996). Fundamentally, every anatomical characteristic of a wood fibre, including the tracheid diameter, the lumen diameter, the cell-wall thickness, and the microfibril angle (MFA), controls the mechanical property of wood and the quality of any fibre-related products (Burdon et al., 2004; Vahey et al., 2007). Functional properties of wood products, such as axial stiffness and longitudinal shrinkage, are characteristics that rely heavily upon MFA in the S_2 layer of the secondary cell wall (Ansell, 2011). As MFA increases, longitudinal shrinkage increases exponentially and stiffness in the axial direction decreases. Cave (1968) notes that cell-wall stiffness increases five-fold with a decrease from 40° to 10° in mean MFA. Microfibril angles greater than 35° lead to shrinkage as high as 5% of the total board length. For solid wood of good quality, it is important then that MFAs are as low as possible with respect to the longitudinal direction. Low stiffness leads to strength issues and high shrinkage leads to warping of timber, which are both serious wood quality issues (Barnett and Jeronimidis, 2003).

Climate conditions throughout the growing season have a large influence on the development of radial cells and related wood

* Corresponding author.
E-mail address: ljwood@uvic.ca (L.J. Wood).

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anatomical characteristics in temperature-limited coniferous trees (Tardif et al., 2001; Deslauriers et al., 2007). Annual tree ring growth begins with the production of large, thin-walled earlywood cells (Creber and Chaloner, 1984; Barnett and Jeronimidis, 2003). As environmental conditions change through the summer months, the cells transition to small thick-walled latewood with decreasing lumen size (Brown et al., 1949; Wort, 1962; Creber and Chaloner, 1984; Barnett and Jeronimidis, 2003). Consequently, where temperature is the primary limiting factor of growth (D'Arrigo et al., 1992; Davi et al., 2002; Watson and Luckman, 2002; Savva et al., 2010), developing an understanding of conditions at the time of ring formation may provide the insight needed to assess specific wood quality attributes in a specific area (Fonti et al., 2010).

Climate variables such as air temperature and precipitation directly affect energy accumulation within a tree by influencing net photosynthesis, and thus influence the resources available for construction of tracheids and cell walls. During periods of low net photosynthesis, radial growth slows significantly and the cells produced are smaller and/or thinner-walled. For example, Tardif et al. (2001) reported on the radial growth of seven boreal tree species in response to increases in soil and air temperature. Periods of substantial and continuous radial diameter were positively associated with precipitation and soil temperature, and negatively associated with the photoperiod (Tardif et al., 2001). Because of the existing relationship between climate and cell formation, intra-specific tree-ring and tracheid variability can be used to determine variability in climate and ecosystem conditions (Fonti et al., 2010). By identifying trends in the relationship between climate parameters and wood anatomical characteristics over time, it should be possible to predict how climate variables will effect wood production in specific locations, and therefore certain wood quality attributes produced at that site in the future. These insights would be valuable for forest managers as they design management and rotation strategies tuned to future climates (Williamson et al., 2009; MFLNRO, 2013; IPCC, 2013).

The objectives of this study were to investigate the relationships between climate and wood anatomical development, and to use the relationships identified to predict certain wood quality attributes in interior BC forest stands. Time series were developed to predict wood properties based on correlations to historical climate station data, and the predicted values were compared to measured wood attributes. For the purposes of this study, we focus solely on cellular wood quality attributes including density, cell wall thickness, and MFA. The findings of the research provide preliminary insight into whether changing climates are likely to have a positive or negative impact on wood quality attributes within future forests in interior BC.

2. Methods

Tree-ring samples were collected from five sites: four sites in northern BC and one site in southern BC (Fig. 1). All of the sites contain mature, open canopy, mixed-species forests dominated by softwoods. Sites were located on well-drained, nutrient-rich sites found in close proximity to long-term climate stations. High-elevation or northern latitude sites were identified to ensure that climate was the primary factor limiting tree growth (Fritts, 1976). Samples were collected from three hybrid Engelmann spruce (*Picea glauca* (Moench) Voss *x engelmannii* (Parry)) stands in the Smithers area (sites A (NSx1), B (NSx2), and C (NSx3)) and from Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco) trees located at sites near Babine Lake (site D (NDf4)) and Pemberton (site E (SDf7)) (Fig. 1).

Two 5.2 mm cores from opposite and one 12 mm core were collected from each tree at breast height (Stokes and Smiley, 1968). The 5.2 mm cores were allowed to air dry, glued to a grooved mounting board, and were sanded until the annual ring boundaries were clearly visible (Stokes and Smiley, 1968). Mounted cores were scanned with a high resolution Epson XL1000 flatbed scanner to create digital images, which were then used to measure the width of each annual ring to 0.001 mm using Windendro® software (Version 2006). Annual rings that were exceptionally narrow or unclear were measured to 0.001 mm using a Velmex® tree-ring measurement system equipped with a trinocular boom-mounted microscope and CCD video display.

Following air drying, each 12 mm core was prepared for densitometric analysis by gluing it flush to the surface of a 2.5 cm-wide fibreboard block. Once dry, a 2 mm thick wood lath was cut (pith to bark) with a Waltech high precision twin-bladed saw to reveal the radial surface of the core (Haygreen and Bowyer, 1996). Resins add to wood's structural mass and must be removed prior to wood density measurement (Lenz et al., 1976). In this instance, wood resins were chemically extracted using an acetone Soxhlet apparatus (Jensen, 2007). Acetone was placed in a round-bottomed flask resting on a hot plate, and the wood lathes were placed in the Soxhlet chamber sealed by a condenser cycling cold tap water. Acetone was cycled over the samples for five hours by consecutively evaporating and condensing the liquid to remove the resins (Schweingruber et al., 1978; Grabner et al., 2005). The samples were air-dried after resin extraction and mounted vertically on pins in an ITRAX scanning densitometer. To ensure accurate light attenuation by the laser scanner, care was taken to orient samples perpendicular to the X-ray beam. Scanned images were measured using Windendro® ITRAX density software (Version 2008b).

Sectioned and extracted 12 mm × 2 mm samples were sent to Dr. R. Evans at the Australian Commonwealth Scientific and Research Organization (CSIRO) for SilviScan analysis. The SilviScan system allowed for precise measurement of density, microfibril angle and tracheid radial and tangential diameters, and also calculates cell-wall thickness (Eq. (1)) (Vahey et al., 2007; Lundgren, 2004; Jones et al., 2005). The 12 mm radial width of the core was trimmed to a precise 7 mm prior to scanning with SilviScan.

Various wood property measurements were obtained as tree-ring series: total ring width (RW); maximum, mean, and minimum density (MXD, MD, MND); maximum, mean, and minimum microfibril angle (XMFA, MMFA, NMFA); maximum, mean, and minimum cell radial and tangential diameters (XRD, MRD, NRD and XTD, MTD, NTD); and maximum, mean, and minimum fibre coarseness (XC, MC, NC). Data for maximum, mean, and minimum cell-wall thickness (XCWT, MCWT, NCWT) were calculated by SilviScan as a function of the measured density (d), coarseness (C), and cell perimeter distance (P) (Eq. (1)); cell perimeter (P) is calculated using radial vs. tangential cell diameter dimensions (Eq. (2)) (Vahey et al., 2007; Lundgren, 2004).

$$CWT = P/8 - 1/2(P/16 - C/d)^{1/2} \tag{1}$$

where

$$P = 2(R + T) \tag{2}$$

and, R and T are the radial and tangential tracheid diameters, respectively (Jones et al., 2005).

2.1. Chronology development

Each tree-ring series was cross-dated with respect to characteristic annual ring width patterns (Stokes and Smiley, 1968). The series cross-dating was verified using COFECHA (Holmes, 1983), and annually resolved chronologies were developed for each species and wood property identified (Table 1). Changes made to the time series during the ring width cross-dating process, such as the