Quantification and spatial location of compression wood in softwood lumber: a spectroscopic and hyperspectral imaging study

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Introduction

As a response to wind or slope-induced lean, trees form reaction wood in an attempt to grow in an upright fashion. This reaction wood differs between gymnosperms and angiosperms. Gymnosperms or softwoods (such as pine) form compression wood on the downwind or downslope side of the tree in an effort to push the tree back to the vertical. Angiosperms or hardwoods (such as eucalypts) form tension wood on the upwind or upslope side of the tree in an effort to pull the tree back vertical.

The presence and severity of compression wood in softwood lumber can give rise to increased longitudinal shrinkage in lumber. This shrinkage can, in turn, cause lumber to distort by means of crook or bow. Identification of compression wood or tension wood is difficult, particularly once the wood is dry. Identification and quantification of compression wood is classically undertaken by anatomical investigation which involves tedious sectioning of samples for investigation by light, electron or confocal microscopy.[1-3] Compression wood is not solely a change in morphology; it is also characterised by a change in chemical composition, most notably an increase in galactan content.[4,5] Hence, near infrared (NIR) spectroscopy provides the potential to chemically identify compression wood in softwood prior to processing and may provide lumber processors with increased options for selection of saw patterns designed to minimise the inclusion of compression wood on board surfaces.

This study aimed to quantify compression wood in the softwood radiata pine (*Pinus radiata*) and to show the spatial variation of compression wood in a tree.

Materials and Methods

Samples

Samples of *Pinus radiata* were visually selected in the green (wet) state to contain regions of suspected compression wood. Samples were either prepared as whole cross-sectional discs (450 to 650 mm diameter), diametric strips (*ca*. 20 x 20 mm) taken from whole discs or sections from boards (*ca*. 90 x 35 mm).

Microscopic assessment

The severity of compression wood was assessed by microscopy and graded on a 0 to 4 point scale[6] as follows: (0) no presence of compression wood; (1) the extent of lignification of the S2 layer; (2) the presence of intercellular spaces; (3) absence of an S3 layer; and (4) the presence of helical checks.

Near infrared spectroscopy and imaging

The samples were spatially analysed by three separate means. Initial studies used a jury-rigged "microscope". The 5° fore-optic of an ASD Fieldspec NIR (ASD Inc., Boulder, CO, USA; www.asdi.com) was focussed down the barrel of a Zeiss trinocular microscope, providing a NIR spot size of *ca*. 150 µm diameter. A 5 W halogen lamp was used to illuminate the sample from one side at an angle of 45°. The samples (85 x 35 mm) for investigation were translated under the microscope using a manual X-Y stage in 2 mm steps to yield a raster of NIR data. Each individual spectrum was the average of 32 scans between 350 and 2500 nm at 2 nm resolution.

The second means of spatially resolving the NIR acquisition was to use a linear stage coupled via fibre optic to a Bruker MPA (Bruker Optik, Ettlingen, Germany; www.brukeroptics.com) to acquire a profile along strips of wood (*ca*. 70 to 120 mm long in the radial direction).[7] Spectra were obtained at 1 mm step intervals by averaging 32 scans per spectrum (10,000 – 4,000 cm^{-1} at 8 cm^{-1} resolution).

Thirdly, full hyperspectral data cubes were acquired using a Specim ImSpector N17E line camera (Specim Oy, Oulu, Finland; www.specim.fi) equipped with a VDS Vosskühler camera providing 320 spatial pixels x 256 spectral points in the range 1000 – 1700 nm. A selection of fore-optics and camera offsets allowed fields-of-view of 50 – 650 mm to be imaged with pixel sizes of between 1 and 4 mm^2. The hyperspectral datacubes were acquired using SpectralCube with 32 averages per image.

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Data analysis

Principal component analysis (PCA) and partial least squares (PLS) regression of spectroscopic data was performed using The Unscrambler (versions 5.11 to 10.1, Camo Software AS, Oslo, Norway; www.camo.com). The initial 2D mapping of PCA scores was undertaken using PV-WAVE 2.1 (Precision Visuals/Visual Numerics, Boulder CO, USA – now Rogue Wave Software, Boulder CO, USA; www.roguewave.com). Principal component analysis of the hyperspectral data was performed using Evince 2.5 (Umbio AB, Umeå, Sweden; evince.umbio.com) both with and without standard normal variate (SNV) pretreatment.

Results and Discussion

NIR spectra of the key compounds in wood (lignin – as softwood milled wood lignin, cellulose and galactose) are shown in Figure 1.

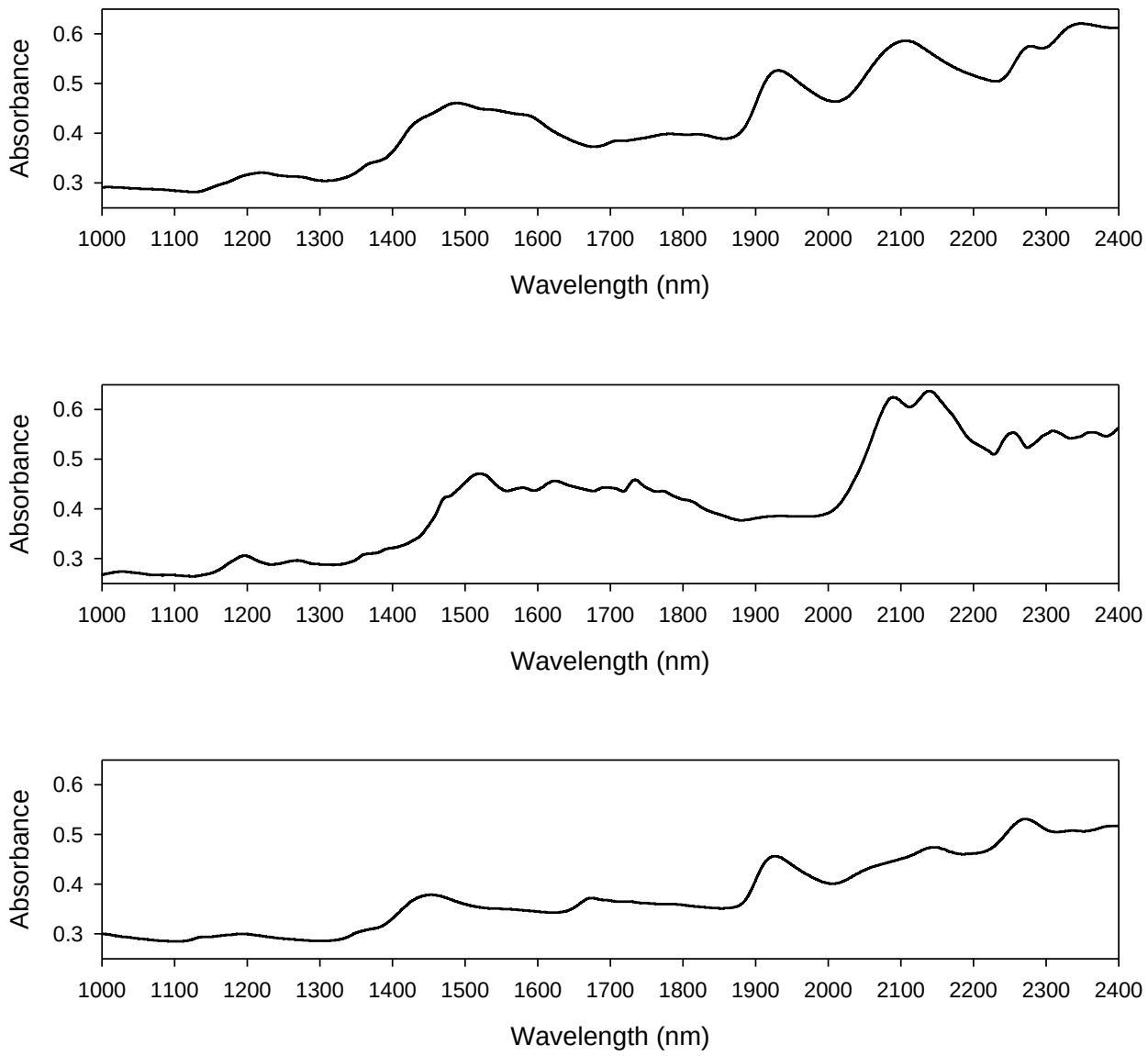

Figure 1. NIR spectra of (top to bottom) cellulose, galactose and milled-wood lignin.

The calibration plot of NIR spectra with severity of compression wood is shown in Figure 2. While the calibration statistics were satisfactory (Table 1), there was obvious scatter in the plot. This was due to the fact that compression wood is a continuum and the subjective visual assessment attempts to index this on a 5 point scale. The points highlighted in Figure 2 that were visually assessed as severity 3 could possibly be equally assessed by another microscopist as severity 2.

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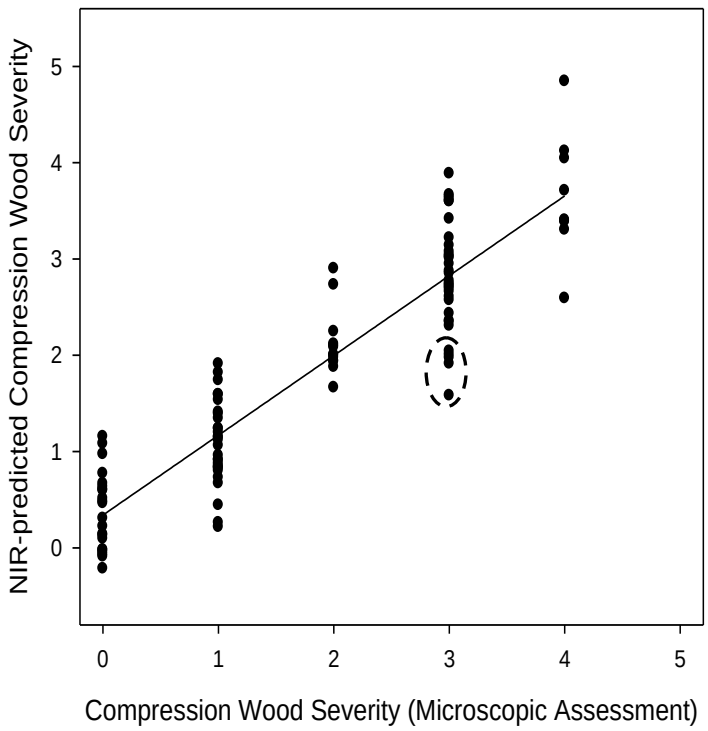

Table 1. Summary statistics.

R^2_{cal}	0.84
r^2_{val}	0.6
RMSEP	1.4

Figure 2. Calibration plot for compression wood severity as assessed by microscope.

This calibration was sufficient to enable identification of severe compression wood (severity classes 3-5), but the challenge remains to spatially locate the compression wood within a board or log end. Using the boards that were used to generate the calibration set, spectra were acquired at 2 mm intervals in a raster fashion and the PCA scores plotted as a series of 2D maps for consecutive components (Figure 3).

The first principal component corresponded to the latewood bands of the wood which are high density and have increased lignin content. The loadings correlated well with that of lignin. The second component was a bias offset from one edge of the board to the other due to changing focal length of the sloping surface of the board. The third loading was dominated by absorbance in the visible range of the spectrum and is the loading that appears to best correlate with the presence of compression wood.

Using a fully functional NIR line camera, the presence of compression wood can also be qualitatively identified in boards (Figure 4) and in cross-sectional discs (Figure 5). In Figure 4, the first factor loadings appeared to be similar to the raw cellulose spectrum while the second factor loading shares unique absorbances that appear to be the reciprocal of the raw galactose spectrum (960 nm and 1200 nm). The second factor loadings visually correlated well with the compression wood location in the left-hand region of the sample.

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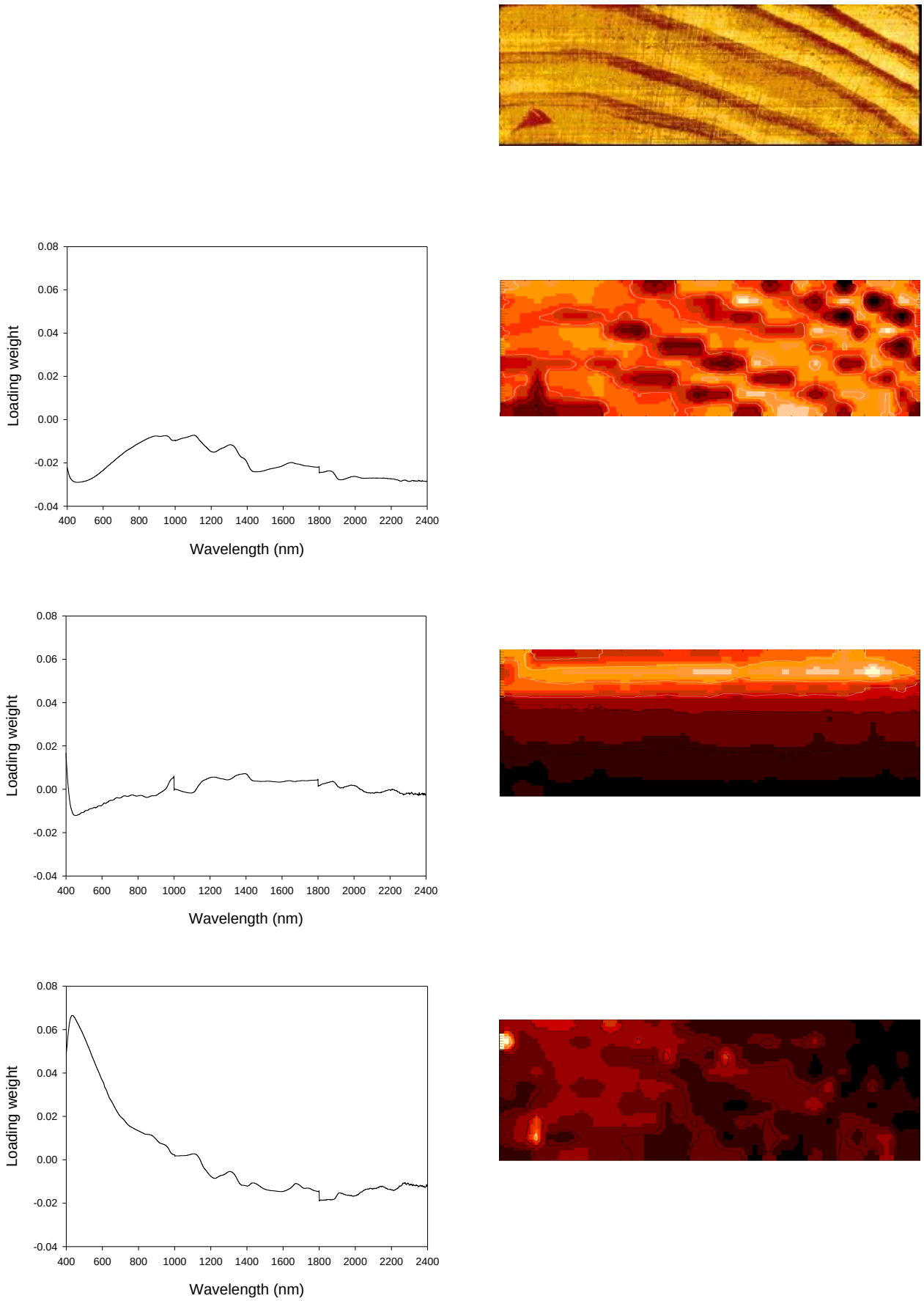

Figure 3. Photograph of board (top right) loading weights (left) and respective 2D scores map (right) for factors 1-3 using data from an improvised NIR "microscope".

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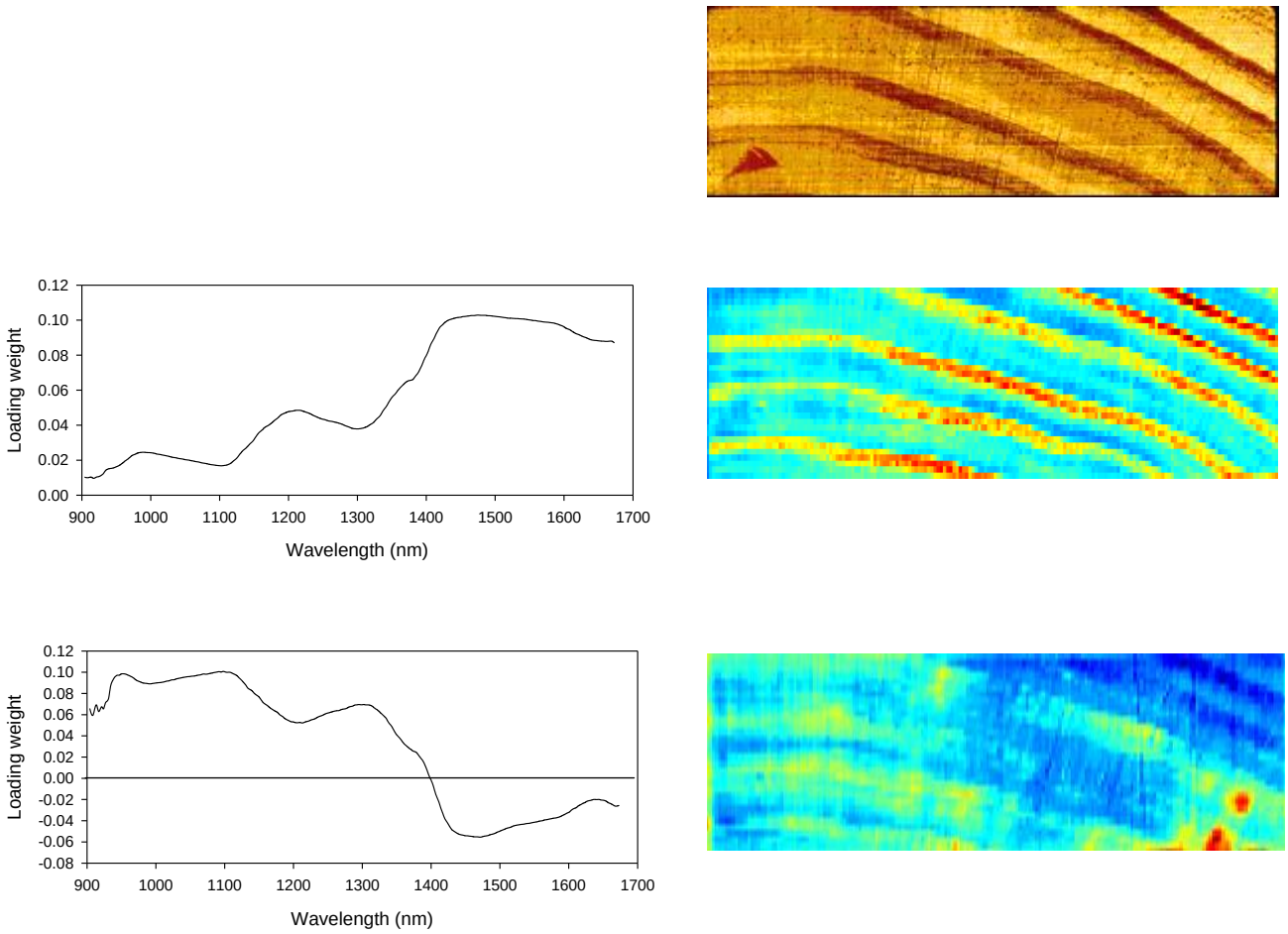

Figure 4. Loadings weights (left) and 2D scores maps (right) for factors 1 and 2 of the same board cross section in Figure 3 using an NIR line camera.

The qualitative assessment of compression wood distribution in an entire log cross-section using the NIR line camera is shown in Figure 5. This clearly showed the location of compression wood in the upper right quadrant. The next steps will be to quantify the extent of compression wood severity. NIR spectroscopy has previously been used to predict chemical composition of wood and this has been used to quantify the levels of galactan in discs.[8]

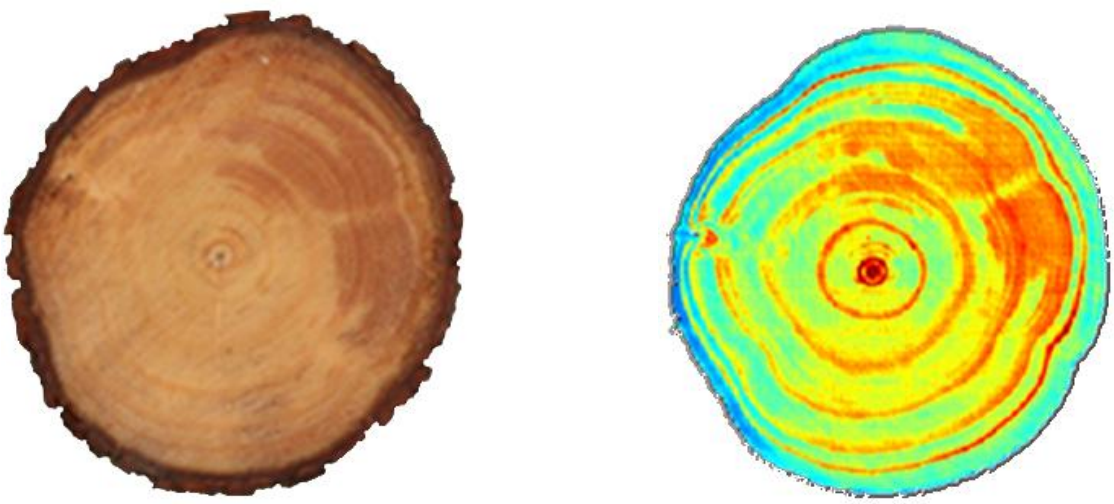

Figure 5. Photograph of disc (left) and 2D PCA scores map of principal component 2 (right). SNV pre-treatment.

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Conclusion

NIR spectroscopy can be used to predict compression wood severity in softwood pine using a 5 point classification scale based on visual assessment. This is however subjective. Qualitative assessment of NIR spectra for cross-sections of logs (discs) and boards, using an NIR line camera, has shown that compression wood can be spatially located. It is proposed that quantification of compression wood may be possible using galactan content and this is the basis of future effort.

The ability to visualise the location and severity of compression wood will enable wood processors to optimise log breakdown in order to minimise degrade that occurs from incorporation of non-uniform compression wood in boards.

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