To the heart of the matter – heartwood content in tōtara

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Abstract

The amount of durable heartwood present in sub-mature New Zealand tōtara (*Podocarpus tōtara* D.Don) is not well understood, as it has been difficult to predict or accurately identify. Durability is seen as one of the value propositions for harvesting relatively young tōtara from farm sites in the Northland region. With the objective of identifying tree or site characteristics related to heartwood content, a dataset of observations of heartwood content has been compiled from geographically separated tōtara stands. The findings on heartwood content found in 420 tōtara from 15 natural second-growth and six planted stands are presented.

Heartwood, based on colour, was identified in almost 70% of tōtara that were between 35 and 127 years old and from 10 to 87 cm in diameter. Cross-sectional discs from log ends were better for identifying heartwood content than 5 mm bark-to-pith increment cores. Small diameter tōtara (<20 cm) that averaged over 70 years old were found to contain small quantities of heartwood when measured from cross-sectional discs. Conversely, trees with no heartwood were found in all diameter classes from 10 cm to almost 70 cm.

Tōtara in planted and natural stands displayed similar levels of heartwood content. The presence and quantity of heartwood was highly variable, although variability decreased markedly with increasing stem diameter. There was greater certainty in predicting heartwood content at the population and stand level than for individual trees.

Introduction

Heartwood is a naturally-occurring component of the xylem in trees. Tōtara heartwood has properties of durability, which may influence its usefulness and therefore its commercial value. Definitive boundaries between heartwood and sapwood zones in many softwood tree species can be difficult to visually determine (Grekin, 2007; Taylor et al., 2002). This can be compounded by making observations using only small, potentially non-representative, wood samples such as increment cores.

The heartwood of mature tōtara is generally an even pinkish-brown to reddish colour, but was thought to vary considerably according to age and the soil in which it grew (Blair, 1876). In contrast, sapwood is almost white when freshly cut, darkening to a pale-brown after a period of exposure (Garratt, 1924), and has been variously described as having no durability (Clifton, 1990) or as moderately durable (Entrican & Reid, 1949). It was largely viewed as a waste product or fuelwood. While identifying the delineation zone between heartwood and sapwood is important to maximise the recovery of wood based on its durability properties (i.e. economic value), identifying site, genetic and management factors that affect heartwood formation is important to develop tōtara as a valuable resource for the future.

Confounding the identification of heartwood in tōtara has been the frequently observed variable width zone between heartwood and sapwood. The zone is referred to as intermediate or transition wood, and typically contains low amounts of the extractives that impart durability (and some colour), so is neither true sapwood nor heartwood (Hillis, 1987). The segregation of tōtara lumber appears to be based primarily on these colour variations within the log, which are presumed to denote various grades and qualities, even though the changes associated with heartwood formation may not have occurred.

The durability of mature tōtara heartwood is rated as Class 1: >25 years for in-ground use and >50 years in protected situations (Page & Singh, 2014). The presence and quantity of durable heartwood in young (<100 years old) small diameter tōtara is not currently predictable within standing trees. It is likely that heartwood is either not uniformly produced, or that it is not easily or accurately differentiated using colour alone. This could potentially impede the promotion of tōtara for solid wood end uses, particularly where lumber grade outcomes are likely to contain significant volumes of sapwood or mixed grades.

Methods

One planted and 11 natural tōtara stands were sampled in Northland between 1995 and 2007. A further five planted and two natural stands were sampled from Northland, Bay of Plenty, Taranaki, Gisborne and Hawke's Bay during 2015/16. Two further natural stands from Northland were sampled in 2017/18. Sites ranged in elevation from 40 to 550 m. The average age of the tōtara assessed was over 70 years old, with nearly 60 years between the youngest and oldest stands. Tōtara was either the dominant or sole canopy species in most stands. Stand density remained high, particularly in the natural stands. Few of the stands had received regular and ongoing silviculture after establishment to improve survival, growth, productivity and tree form beyond early releasing operations.

For the purposes of this study the heartwood-sapwood boundary was defined as the point, if it existed, where a consistent colour change occurred vertically through the core or disc consistent with the descriptions of heartwood and sapwood by Garratt (1924). Heartwood content in tōtara was assessed using three different methods: increment cores, a chemical indicator and cross-sectional discs (see below).

- **Increment cores** (5 mm) were obtained from trees that represented the diameter range for the site. Cores were extracted at 1.4 m above ground on a random side of the tree with the corer directed toward the physical centre. Heartwood content was determined with a visual assessment of the core immediately on removal. Where a colour change occurred in the core, this point was marked and the radial distance for each presumed wood type measured.
- A **chemical indicator** on a selection of cores was used to attempt to validate the initial visual observations. An acid alcohol reagent was prepared by adding 20 ml concentrated hydrochloric acid (37%) to 80 ml ethanol (96%). When applied to cores, any heartwood present was expected to remain its natural colour, while sapwood and intermediate wood would develop a pinkish-purple colour (Timber Preservation Authority, 1980). Where colour changes occurred, boundaries were marked and the radial distance was measured.
- **Cross-sectional discs** were taken from the large end of the butt log of felled trees. Trees sampled represented the range of diameters present in the stand, including relatively small trees that were only 10 cm diameter at breast height (DBH) and some edge trees. On each log end, three equally spaced transects from bark-to-pith were located and the radial length of sapwood and heartwood, based on changes in wood colour, were measured. A mean radial length was then calculated for each assumed wood zone.

For each tree assessed, data of the tree and stand were collected (DBH, height, stems/ha and age). In particular, age was potentially an important relationship to heartwood content. For planted stands, an establishment date was known. In stands where discs were obtained at the large end of each log, age was estimated by counting annual rings on the same transects where heartwood was measured. These discs tended to be taken at ~1.0 m. An average of the counts from each disc were considered to represent tree age at felling. In all stands, the age values reflected only those trees sampled.

One Northland planted stand had assessments at 90 and 110 years old, and had heartwood assessed from discs and increment cores. During the assessment at age 90 years, the samples came from cross-sectional discs from stems both within the stand and from edge trees. These were treated as separate datasets in the analysis. Only a small sample size was obtained from each site for the natural stands assessed in 1995 and 2007. These ad hoc samplings were combined into a single combined dataset (33 observations) that could function as a proxy for tōtara in natural stands. The other natural stands surveyed retained their own identity as these were intensively sampled.

Results

Four hundred and twenty tōtara were assessed from all sites. Tōtara in planted stands averaged 69 years old and 31.9 cm DBH, while those in natural stands averaged 78 years old and 41.7 cm DBH. Diameter growth (DBH MAI) was 0.49 cm/year across all sites and generally reflected the high residual stocking (Table 1). The measured heartwood radial length, heartwood basal area and percentage basal area were used as the basis for comparisons of heartwood content. Heartwood content was correlated with the tree variables of age, diameter, diameter MAI and height.

Heartwood was identified in 68.8% of all tōtara sampled, and from all stands, with the exception of one 53-year-old planted stand. It occurred more frequently, and in larger proportions of the total wood, in cross-sectional discs from natural stands than from increment cores from either planted or natural stands. Heartwood radial length averaged 6.4 cm and was 17.9% of the basal area for all sites, with small amounts observed in individuals only 10 cm DBH.

In planted stands, heartwood radial length was moderately correlated with age, DBH and tree height (Table 2). In natural stands heartwood radial length was moderately correlated with Age, moderately to strongly

Table 1: Stand characteristics at assessments

Type	No. stands	N	Age (years)		DBH (cm)			Stems/ha
			Mean	Range	Mean	Range	MAI	Range
Planted	7	230	69	52–110	31.9	10.5–69.0	0.46	975–3300
Natural	15	190	78	35–127	41.7	10.3–86.5	0.53	900–2500

correlated with DBH MAI, and strongly correlated with DBH. Heartwood content in the combined dataset was most strongly correlated with DBH, with age a secondary factor. The largest diameter where no heartwood was found was 69 cm from a 79-year-old planted tree.

Table 2: Correlation matrix of heartwood radial length

Type	Age (years)	DBH (cm)	DBH MAI (cm)	Height (m)
Planted	0.534 0.000	0.527 0.000	0.001 0.984	0.508 0.000
Natural	0.522 0.000	0.800 0.000	0.642 0.000	0.045 0.615
Combined	0.523 0.000	0.716 0.000	0.366 0.000	0.338 0.000

Note: Cell contents: Pearson correlation; P-value

Heartwood content was extremely variable, with significant differences in this content observed both within and between different forests. The coefficient of variation (CoV) in heart radial length was 92.2% for all trees, with a strong trend for declining variation with increasing diameter (Table 3). The development of sapwood and heartwood was similar in planted and natural stands.

Sapwood radial length in all trees averaged 11.5 cm and exceeded 20 cm in only 5% of the tōtara assessed. The heartwood identified in the smaller diameter classes resulted from over 95% of these stems being assessed from cross-sectional discs. The heartwood radial length in these samples averaged only 3.1 cm. Had these been observed by bark-to-pith increment cores it is highly likely that the corer may have missed the small amount of heartwood present, as off-centre piths were relatively common on all sites.

Initial modelling of heartwood indicated a high degree of variability, therefore development of sapwood (radial length) was also modelled (Figure 1). As colour was the only consistent method that indicated differences between sapwood and heartwood, the results should be viewed as 'presumed heartwood' throughout the analysis. If any intermediate wood zone existed it was most likely included, based on colour, in the heartwood measurements.

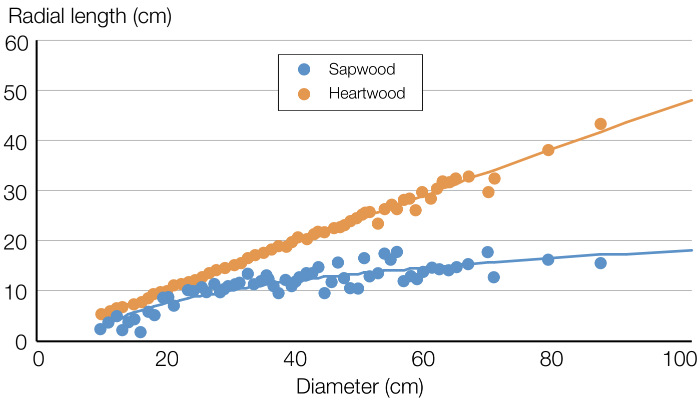

Figure 1: Heartwood and sapwood radial development

Discussion

Only two wood zones were identified in this study – sapwood and heartwood. While some transition wood was likely to exist in each tree assessed, attempts to identify an intermediate zone were largely unsuccessful. Any colour change was used to determine a heartwood zone when observations were made on fresh disc surfaces and increment cores freshly extracted from the stem. However, colouration within the stem appeared in many forms from bark to pith, a proportion of which was not necessarily related to heartwood. While discs were easier to form a better visual reference to the entire colour changes, it was not consistent (Figure 2).

The use of 5 mm increment cores to assess heartwood has likely resulted in a larger margin of error as these colour variations were not consistent, either through or along the length of the core. A small initial sample of increment cores was tested with chemical reagent to determine whether observed heartwood matched actual heartwood. Later, a larger sample from a range of sites was tested. Drying of the cores before the application of the acid/alcohol reagent tended to improve the visual identification of heartwood, although not consistently enough to suggest it was a conclusive result.

The intermediate zone suggested by this test was relatively large in some tōtara, particularly larger diameter trees with deep crowns that were near the margin of the stand, although in these trees cores were extracted on the side of the tree facing into the stand.

Table 3: Heartwood development by diameter classes

	Diameter classes (cm)							All
	10–19	20–29	30–39	40–49	50–59	60–69	70+	
Number	23	129	126	78	38	20	6	420
Sap radius (cm)	4.4	10.3	11.8	12.5	14.1	15.9	17.6	11.5
Heart radius (cm)	3.1	2.6	5.2	9.6	12.1	16.1	20.1	6.4
Heart radius CoV	55.2	100.0	84.6	52.6	41.2	32.0	15.3	92.2
Radius heart %	42.4	19.7	30.3	47.3	46.5	50.6	53.7	32.9
Basal area heart %	23.8	9.0	15.4	24.5	28.9	31.5	33.9	17.9

The use of 12 mm increment cores may give a better indication of heartwood content, although it would create a larger defect in standing trees.

Other recent studies of heartwood content in tōtara lumber had similar difficulties in identifying boundaries between sapwood and heartwood. While the chemical reagent test gave a slightly better result on larger piece sizes (100 x 50 mm boards) than increment cores (5 mm), it was still inconclusive (Dave Page, pers. comm.). During the assessment of dried sawn lumber, a further method of determining boundaries was made by dripping water across the surface of the end of the board and using absorption as an indication of the presence of oily exudates typically found in heartwood (Bennett & Jansen, 1990). However, the boundary between rapid and slow absorbency areas did not coincide with the visible colour change in the wood.

Hillis (1987) observed that the transition wood zone between heartwood and sapwood 'often contained living cells that were impermeable to liquids' and confirmed the findings that suggested that there was an intermediate wood zone in the tōtara lumber assessed. Although relatively narrow and appearing like sapwood, it neither absorbs water nor responds to the reagent in the way that sapwood did. While this method gave a better result than the chemical reagent test, it was also not conclusive. A future investigation of heartwood presence will be undertaken attempting to produce a chemical signature along radial transects from cross-sectional discs recovered from a selection of tōtara of an age and size where heartwood is most likely to be present. These tests will be correlated with visual assessments of colour change on the same samples.

The use of fresh increment cores is most likely to overestimate the heartwood content in any individual tree, but is also likely to underestimate the heartwood content in a stand. The use of cut discs would be a better method by which a more robust estimate of the extent of heartwood and sapwood could be determined. The fluted nature of some stems also potentially gave 'false' amounts of sapwood and heartwood, depending on where exactly the core was taken. How much that over-prediction amounts to is not known. However, in a stem of 50 cm DBH, with an intermediate zone estimated width of 3.0 cm, this would equate to ~10% of the total stem basal area.

Some authors have identified an overestimation of heartwood heritability (Ericsson & Fries, 1999; Fries & Ericsson, 1998), while others found the genetic control of heartwood formation to be reasonably strong (Zobel & Jett, 1995). In general, it is presumed that there is a significant genetic control of heartwood proportion within a species and a reasonable opportunity to breed for this characteristic, although environmental influences were seen as being important contributing factors (Taylor et al., 2002).

Many of the stems were very wet internally when extracting increment cores during early spring and it

Figure 2: Examples of variability in heartwood content

was not uncommon for fluid to flow from the corer. No sign of internal rot or decay was evident on the outside of these stems or the extracted cores. Wet cores tended to be darker in colour over their entire length and may have had some influence on the observations of heartwood.

No heartwood was observed in one 53-year-old planted stand. This stand was at 550 m elevation in the Central North Island, with tōtara sub-dominant to a *P. ponderosa* canopy and near its altitudinal limit (Wardle, 2011). Initially, it was thought that this elevational extreme may be influencing the presence or development of heartwood. However, other stands at similar elevation had some heartwood present. The apparent lack of heartwood could not be explained. Analysis that both included and excluded this anomalous stand did not affect the overall results markedly.

Conclusions

The heartwood content in tōtara has been shown to be highly variable at the individual tree level, with greater certainty of heartwood content occurring at the stand and species level. Increasing DBH is the best predictor of heartwood content, with tree and stand age a secondary predictive factor. While this was only an initial survey of heartwood content, it suggested that:

- More trees in an individual stand are likely to contain heartwood than observations might suggest
- The estimated volume of recoverable heartwood present is still relatively small in the diameter range assessed – the percentage of basal area in heartwood would not approach 50% until diameters are ~90 to 100 cm
- With a zone of intermediate wood there is less true heartwood in a tree than a single sample would suggest
- The use of increment cores and their visual assessment of heartwood content is unreliable
- Drying of cores before a visual assessment may improve the reliability of the method.

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