Indigenous plantations – implications for wood quality

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Abstract

The New Zealand timber industry's interest in indigenous species is contingent on identifying new resources for sustainable harvesting, as well as supply and wood quality criteria being met. Native tree plantings have been undertaken in New Zealand since at least the late 1800s. It is estimated there is a few thousand hectares of well-established single or mixed species plantings that could be considered plantations and where future timber recovery is an option. Kauri (*Agathis australis* (D.Don) Lindl.) and tōtara (*Podocarpus totara* (D.Don)) have been identified as significant components of these planting programmes. At the time of planting, rotation lengths were presumed to be extended (>150 to 200 years). Many of the stands have now reached a stage (age and stature) where some consideration could be given to their future role.

Sixteen planted kauri and seven planted tōtara stands were assessed for whole-core and radial density patterns. Whole-core density averaged 449 kg/m^3 for kauri and 443 kg/m^3 for tōtara. Density for each species was generally similar between sites and was not affected by diameter, age or latitude. Both species displayed a flat radial density gradient, with a slight increase in density within 50 mm of the core. Density was comparable to that observed in natural second-growth stands of similar diameter and stature.

55-year-old planted kauri

110-year-old planted totara

Introduction

'How much wood has your woodlot got?' was coined in 2000 (Maclaren, 2000). However, the value of a resource will only be realised when its characteristics are known and aligned to appropriate end uses, rather than simply 'pumping out' volume. Therefore, the timber industry is trending towards being less concerned with how much, and more concerned with what sort of wood they have. There has been a longstanding presumption that wood quality of comparatively young indigenous trees would be compromised by a focus on shortening rotations to increase productivity, especially where sapwood would likely be a significant volume outcome. While this has been true for some exotics, was it also the case for New Zealand native conifers?

Growing native species for timber production has been considered since natural forest resources were severely depleted and lumber began to be sourced from exotic species (Clifton, 1990). The development of models of height, basal area and volume for kauri and tōtara indicating better growth and productivity in plantations has increased that interest. Prior to the development of growth models, it was generally believed that both species were likely to perform similarly to natural stands, with productivity presumed to be only a few m^3/ha/year. In fact, the growth model for planted kauri found increases in productivity of 12 to 20 times that for natural stands at the same age (Steward et al., 2014). The tōtara growth model was developed from only a few stands (Bergin & Kimberley, 2003), so the predictions for yield were understandably more conservative. However, recent tōtara regime trials have shown an almost immediate diameter response to silviculture (thinning) despite many years of stagnant growth (Bergin & Kimberley, 2010).

In the case of wood, density is one of the defining physical properties as it is a vital characteristic for wood processors and wood product users due to its contribution to important performance requirements, such as stiffness and strength and also carbon sequestration (Cown, 2015). Wood properties are generally age dependent and may be compromised by shorter rotations and faster growth rates (McConchie, 2000). Both kauri and tōtara planted on fertile sites grow significantly better (height and diameter) than in old-growth forests or unmanaged densely stocked second-growth forests. An expectation arose that planted rotations could be as short as 50 to 60 years for kauri and around 80 years for tōtara. Their value and uses would be determined by a better understanding of their wood properties and its variability.

Small one-off studies of kauri and tōtara wood properties have been undertaken (Bergin et al., 2007; Steward & McKinley, 2003). While they provided glimpses of the potential of both species, there was a lack of a wider perspective from more sites that might reveal age, site and silviculture influences, if they existed. Air-dry wood density of 480 to 576 kg/ m^3 for mature kauri and tōtara has been reported (Clifton, 1990; Rendle, 1970), although sample sizes tended to be small and usually represented only one source. The density gradients from pith-to-bark were relatively flat, with minimal difference between heartwood and sapwood components. Confounding the promotion of native plantations has been the currently-held perception that lumber outturn from fast-grown, young forests will be dominated by sapwood or mixed grades that are presumed to be inferior to mature heartwood. While mixed grades pose some problems for the industry, observations suggest that young trees and sapwood may have been a missed opportunity when used appropriately.

Methods

Even-aged planted stands of kauri and tōtara were sampled to determine wood density patterns and influences of age, diameter, growth and site characteristics. Towards this, tree age, stand density, average height, and variables of elevation and latitude, annual rainfall and sunshine were also acquired for each site. Comparisons for each species were also made with natural second-growth stands of comparable diameter range.

Sixteen planted kauri stands were sampled from near Kaitāia in Northland to the Taieri Plains south of Dunedin. Six stands were on sites south of the species' current natural range. Planted stands were still in the monopodial or 'ricker' form and averaged almost 50 years old (Table 1). Four natural second-growth kauri stands were also sampled that averaged 162 years old and represented almost the entire natural latitudinal range of the species.

For tōtara, seven planted stands were assessed that were located from near Kāeo in Northland to Taranaki and Hawke's Bay. They were from a combination of farm, forestry and urban reserve sites. Two stands were near the upper altitudinal limit for the species (500 to 550 m) in the central-North Island. Whole-core density data was also obtained from a provenance trial that represented provenances from Kaikohe in Northland to Dean Forest in Southland (Bergin et al., 2007). Age across all sites averaged 61 years, with almost 100 years between the youngest and the oldest stand. Seven second-growth naturally regenerated stands on farmland that averaged 64 years old were also assessed. Only a few samples were obtained from natural stands for several of the Northland sites and these were amalgamated into a proxy Northland site.

Density was assessed from 5 mm bark-to-pith increment cores taken at 1.4 m above ground for standing trees, and from discs recovered from the butt log of trees felled during other projects. Outerwood and whole-core basic density values were derived using the maximum moisture content method (Smith, 1954). No core and disc samples were extracted for resin. The results were correlated with site and stand characteristics to identify any trends for each species.

Radial density patterns were assessed by dividing cores or transects from discs into equal sized segments from the bark-end and assessing density for each segment. For each segment, its mid-point distance from the pith was calculated, including missing distances. Density results for individual segments that were obviously affected by proximity to branch stubs were excluded. Models of radial pattern were developed that combined wood density and the mid-point distance from the pith for each segment, using the pith as the datum point.

Density

Kauri whole-core basic density averaged 449 kg/ m^3 across all planted sites (Figure 1). At the stand level, the difference between the lowest and highest average density was 58 kg/m^3, and almost all stands had individuals that exceeded 500 kg/m^3. A 37-year-old stand planted near Ruatōria on the East Coast had the lowest average density of 406 kg/m^3. Age and latitude had only a minor relationship to density, while diameter and DBH mean annual increment (MAI) had a small negative relationship for density in natural stands. Outerwood density (outermost 50 mm), at 432 kg/m^3, was less than 4% lower than whole-core. In natural second-growth stands, both whole-core and outerwood density were marginally higher than in planted stands.

Tōtara whole-core density averaged 443 kg/m^3 in planted stands and 436 kg/m^3 in natural stands. Outerwood density averaged 421 kg/m^3 for all tōtara

Table 1: Stand characteristics at the time of wood density assessments

Species	Type	No. stands	N	Age (years)		DBH (cm)			Stems/ha
				Mean	Range	Mean	Range	MAI	Range
Kauri	Planted	16	234	49	10–69	29.2	6.6–69.5	0.68	250–2,500
	Natural	4	91	162	80–287	33.4	11.7–59.0	0.21	225–1,889
Tōtara	Planted	7	623	61	14–110	32.7	3.2–69.0	0.62	975–3,300
	Natural	7	108	64	35–91	37.3	11.0–78.0	0.59	900–6,850

stands combined. There was higher variation for density both within and between stands; planted stands had less variation (coefficient of variation = 7.8) than natural stands. A 63-year-old planted stand in Kāingaroa Forest, near the species' upper altitudinal limit, had the lowest average density (397 kg/m^3) and was significantly different to all other tōtara stands. Whole-core density was not correlated in planted stands with any of the tree or stand parameters. In comparison, wood density in natural stands was moderately negatively correlated with both DBH (r = –0.627, *p-value* <0.0001) and DBH MAI (r = –0.616, *p-value* <0.0001), and positively correlated to stand density (r = 0.538, *p-value* <0.0001).

Outerwood and whole-core density were significantly correlated for both kauri (r^2 = 0.8) and tōtara (r^2 = 0.7) in planted and natural stands (r = >0.818, *p-value* <0.001). Outerwood cores would usefully estimate whole-core density using the equations in Table 2. Radial density pattern in both kauri and tōtara generally showed a flat gradient with around a 9% to 10% rise in density within 50 mm of the central pith (Figures 2 and 3). This pattern was similar for both planted and natural stands. The rise in density near the pith was possibly related to resin deposition and proximity to unseen branches.

Table 2: Models for predicting whole-core density and radial density pattern in kauri and tōtara

Species	Model	Equation
Kauri	Predicting whole-core density	y = outerwood density × 0.8395 + 89.393
	Radial density	y = 445.8 + 85.7 × EXP(–0.021 × distance from the pith)
Tōtara	Predicting whole-core density	y = outerwood density × 0.90 + 55.42
	Radial density	y = 416.4 + 67.57 × EXP(–0.0245 × distance from the pith)

Discussion

Whole-core wood density was in line with that seen in mature trees of each species, and in comparatively young second-growth natural stands. The radial density patterns also suggest relatively uniform wood characteristics across the width of the stem that were likely to include both sapwood and some heartwood.

Wood density characteristics appear to be set at relatively young ages in both species. In two kauri stands that were 10 and 14 years old, density averaged 451 kg/m^3, while planted stands that were 66 and 69 years old averaged 446 kg/m^3. Diameter growth rates for these two younger planted stands (DBH MAI 0.78 and 1.84 cm per year) were near the maximum seen for the species and without apparent detriment to density. In comparison, diameter growth rates in natural stands averaged only 0.21 cm per year and wood density was in general similar to planted stands. Similar trends were observed in tōtara with a 14-year-old stand averaging 448 kg/m^3, while in 79 and 110-year-old planted stands density averaged 443 kg/m^3.

Latitude also did not affect density with a planted kauri stand near Dunedin performing similarly to planted stands in Northland. In 1985, a tōtara provenance study was initiated with 36 individual provenances from the Far North to the Far South being collected and established on a coastal site near Auckland. Fourteen years after planting young tōtara trees were assessed for wood density. They showed no relationship of density to the latitude of the parent provenance.

In each stand, and for each species, a range of densities was observed. While the amount of variation within each species was similar to that found in radiata pine, it also indicates the potential to select and breed for improved wood characteristics using wood density as a proxy. Early results from the tōtara provenance trial indicated a moderate negative relationship between latitude and tree form (Bergin et al., 2007). However, it is likely that within provenances there are individuals of better form and wood density that could be selected for future breeding programmes where timber recovery is a priority. The same opportunity applies to growing kauri in plantations, although tree form is not the same problem for this species.

The planted stand of tōtara in Kāingaroa Forest had the lowest overall density for the species (397 kg/m^3). Initially the site elevation (~550 m) was suspected to be the cause. However, tōtara planted on the Mamaku Plateau at the same elevation and similar age had wood density (436 kg/m^3) that was more in line with other planted sites. The climatic and tree variables for the sites were comparable. The Kāingaroa stand was established beneath a canopy of *P. ponderosa* that was failing due to the effects of *Dothistroma pini*. At Mamaku, tōtara were planted into lanes and gaps created in a surrounding tall native cutover dominated by tawa (*Beilschmiedia tawa*) and kāmahi (*Weinmannia racemosa*). The Kāingaroa stand has also been shown to have no visible heartwood in an associated study. At the time of assessment the tōtara appeared healthy, so the results for this stand cannot be explained, unless either the *Dothistroma* present or the noted site nutrient deficiencies (Forbes et al., 2015) have had some influence.

The majority of stands assessed for both species were of unknown seed origin and few received any silviculture after planting. The results suggest that improving growth rates and productivity of planted stands through breeding programmes and developing management regimes will positively affect wood quality. As wood density is relatively uniform across the width of the stem it also suggests that sapwood and mixed grades will be useful outcomes where natural durability is not a requirement.

Increasingly, foresters in New Zealand are being required to meet goals that are not just financial. Forests are also expected to align to the nation's and landowners' values and environmental stewardship, visual aesthetics etc. The cultural values of forests are becoming increasingly important for the unique opportunities and values that they might provide, with many of the old state forests reverting to iwi ownership. The encouraging results of this and other ongoing studies suggest that kauri and tōtara have lain 'largely undiscovered' for far too long.

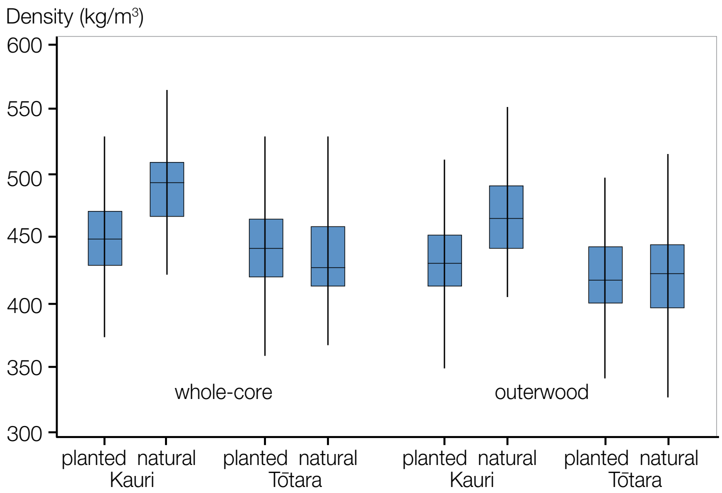

Figure 1: Whole-core and outerwood density comparisons

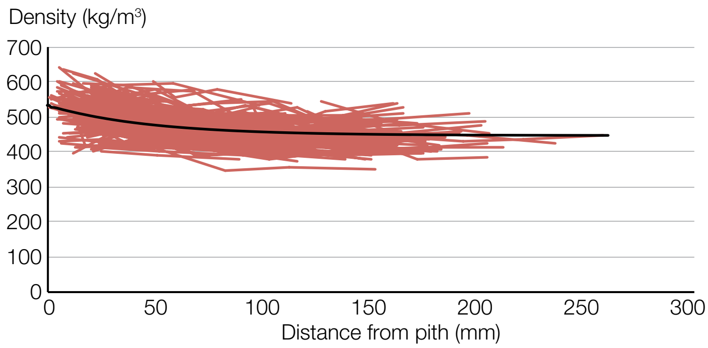

Figure 2: Radial density pattern in kauri (solid line represents the predicted density)

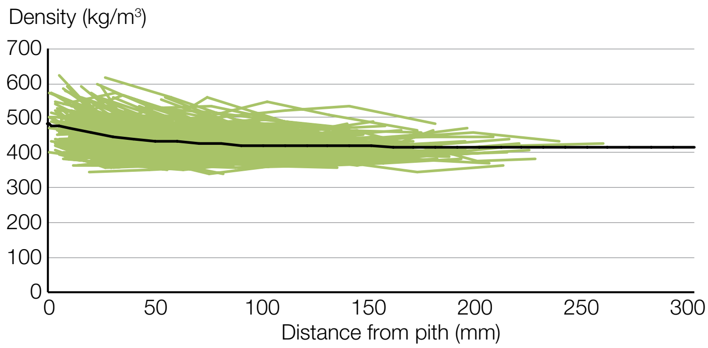

Figure 3: Radial density pattern in tōtara (solid line represents the predicted density)

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References

Bergin, D.O. and Kimberley, M.O. 2003. Growth and Yield of Totara in Planted Stands. *New Zealand Journal of Forestry Science*, 33(2): 244–264.

Bergin, D.O. and Kimberley, M.O. 2010. *Thinning and Pruning of Totara-Dominant Naturally Regenerating Forest in Northland*. Paper presented at Managing Native Trees: Towards a National Strategy. Proceedings of the Tane's Tree Trust 10th Anniversary Conference and Workshop, University of Waikato, Hamilton, 18–20 November 2009, 39–43.

Bergin, D.O., Kimberley, M.O. and Low, C.B. 2007. Provenance Variation in *Podocarpus totara* (D. Don): Growth, Tree Form and Wood Density on a Coastal Site in the North of the Natural Range, New Zealand. *Forest Ecology and Management*, 255(5-6): 1367–1378.

Clifton, N.C. 1990. *New Zealand Timbers: The Complete Guide to Exotic and Indigenous Woods*. Wellington, NZ: GP Publications Ltd.

Cown, D. 2015. Wood: Density. Reference Module in Materials Science and Materials Engineering. *Encyclopedia of Materials, Science and Technology*. Available at: https://doi.org/10.1016/B978-0-12-803581-8.02213-X. Elsevier 2016.

Forbes, A.S., Norton, D.A. and Carswell, F.E. 2015. Underplanting Degraded Exotic Pinus With Indigenous Conifers Assists Forest Restoration. *Ecological Management and Restoration*, 16(1): 41–49.

Maclaren, J.P. 2000. *How Much Wood Has Your Woodlot Got?: A Practical Guide to Estimating the Volume and Value of Planted Trees* (FRI Bulletin No. 217). Rotorua, NZ: New Zealand Forest Research Institute Ltd.

McConchie, D. 2000. *Quality Native Timber From Future Managed Stands*. Paper presented at Native Trees for the Future. Proceedings of a forum held at University of Waikato, Hamilton, 8–10 October 1999, 15–19.

Rendle, B.J. 1970. *World Timbers. Volume 3. Asia & Australia & New Zealand*. London, UK: Ernest Benn Ltd, University of Toronto Press.

Smith, D.M. 1954. *Maximum Moisture Method for Determining the Specific Gravity of Small Wood Samples*. U.S. Department of Agriculture, Forest Products Laboratory Report No. 2014, 8p.

Steward, G.A., Kimberley, M.O., Mason, E.G. and Dungey, H.S. 2014. Growth and Productivity of New Zealand Kauri (*Agathis australis* (D.Don) Lindl.) in Planted Forests. *New Zealand Journal of Forestry Science*, 44(27): 1–13.

Steward, G.A. and McKinley, R.B. 2003. *A Preliminary Study of the Wood Properties and Solid Wood Performance of Twenty Plantation Grown New Zealand Kauri (Agathis australis)*. Scion Internal Report, Output No. 36565, 23pp.

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