Kennedy et al. *New Zealand Journal of Forestry Science* (2023) 53:13
https://doi.org/10.33494/nzjfs532023x315x
E-ISSN: 1179-5395
published on-line: 7/11/2023

Research Article **Open Access**

New Zealand Journal of Forestry Science

Wood density and stiffness of New Zealand native trees and shrubs

Georgia Kennedy, Meike Holzenkaempfer, Monika Sharma and Clemens M. Altaner*

School of Forestry | Te Kura Ngahere, University of Canterbury, Christchurch 8140, New Zealand

*Corresponding author: clemens.altaner@canterbury.ac.nz

(Received for publication 28 May 2023; accepted in revised form 16 October 2023)

Abstract

Background: New Zealand's native forests are species-rich. Little information has been documented about the properties and historic uses of the lesser-utilised species. Xylaria, archives of wood samples, can be used to obtain information on timbers which are difficult to source.

Methods: Wood density and stiffness of 115 native tree species archived in the New Zealand School of Forestry | Te Kura Ngahere's xylarium were measured and put into context with available information from literature.

Results: The range of wood density and stiffness of the New Zealand native tree species was comparable with that found globally, indicating a wide range of potential uses.

Conclusions: Open access to wood properties of lesser-used New Zealand native tree species is essential to successfully implement New Zealand's government policy of establishing a commercial native forestry sector. Wood density information can aid carbon accounting of native forests under the Emissions Trading Scheme.

Keywords: Acoustic velocity; Density; Modulus of Elasticity (MoE); School of Forestry | Te Kura Ngahere; Wood collection; Xylarium

Introduction

Aotearoa New Zealand is home to several hundred woody tree and shrub species (de Lange & Rolfe 2010). In the past, these have been a rich source of food, medicine, materials and other uses for Māori and later settlers (Kirk 1889; Manaaki Whenua | Landcare Research 2023). Use of Aotearoa New Zealand's native forest has undergone drastic changes during human presence (Kerr & Stewart 2013; McGlone et al. 2022; Star 2002; Swarbrick 2007). Due to overharvesting, for the last decades the management of native forests was largely restricted to conservation and recreation while production forestry has focused on exotic species, predominately *Pinus radiata* D.Don. Currently, there is a resurging interest in native afforestation in New Zealand (Ministry for Primary Industries 2022). This is driven by establishing carbon sinks to mitigate greenhouse gas emissions (Ministry for the Environment 2022) along with other non-timber benefits, such as to improve native biodiversity, soil and water health, and to realise recreational and cultural benefits. Establishing native species forests is economically challenging in Aotearoa New Zealand (Dungey et al. 2022; Forbes 2022). Among other factors, only few wood processors exist which utilise native timbers. Supplying wood processors could create revenues to offset the significant establishment and management costs of native forests. The government's recent Te Ara Whakahou – Ahumahi Ngahere | Forestry and Wood Processing Industry Transformation Plan includes *'Develop a productive native forestry sector'* as an action item and states *'Increase in the supply of sustainable and high-value timber'* as an envisaged outcome (Ministry for Primary Industries 2022).

Good information on the characteristics of native trees is necessary if they are intended to be utilised. Māori and settlers had good knowledge of properties and suitable uses of wood for New Zealand native trees. This expertise has been lost with the forest industry shifting away from native species to domestically grown *P. radiata* and speciality timber imports. Unfortunately, information on the uses and characteristics of native timbers, in particular mātauranga Māori (indigenous knowledge), was scarcely documented e.g. Anonymous (1931), scattered and typically difficult to access. It should be noted that a database holding information on Māori and later non-timber use of New Zealand native plants exists (Manaaki Whenua | Landcare Research 2023), and that there are some key publications detailing timbers native to New Zealand (Bier & Britton 1999; Blair 1879; Brasell c.1950; Clifton 1994; Hector 1879; Hinds & Reid 1957; Kirk 1889; Wardle et al. 2011). While there is more information on wood properties of the historically more commonly used tree species such as rimu, kauri, tōtara, tawa or the New Zealand beeches (Buchanan 2020; Hinds & Reid 1957; Steward & McKinley 2019; Steward & Quinlan 2019; NZS3602), little is known about the lesser-used species, a situation not uncommon for countries with species-rich natural forests (World Wildlife Fund/ Global Forest & Trade Network 2013). Probably the most complete record of what is known about the uses of New Zealand's native trees is the book by Wardle et al. (2011). Tāne's Tree Trust and others (Nguyen et al. 2021) have also started to collate and distribute information on indigenous forestry including wood properties of lesser-used native trees. Information on our lesser-used tree species is often restricted to qualitative data, not assessed according to today's standards (Blair 1879; Kirk 1889), based on small sample numbers (Bier & Britton 1999), or focused on wood anatomy (Meylan & Butterfield 1978) and biology (Salmon 1996). In contrast to Aotearoa New Zealand, extensive information is available for Australia's native timbers including current standards, with some Australian timbers even adopted by Standards New Zealand (AS1720.2; AS5604; Bootle 2005; AS/NZS2878).

It is challenging to source wood samples of lesser-used New Zealand native trees. Wood collections, also known as xylaria or xylotheques, are a readily available resource that can be used to obtain the properties of difficult to access species (Deklerck et al. 2019; Deklerck et al. 2020). While these samples usually do not conform to sampling methods and dimensions required by national standards, they can be used to obtain useful information. The New Zealand School of Forestry | Te Kura Ngahere's wood collection contains specimens from many native trees. These samples are of various (often unclear) origin, but some labels date back to the 1920s. Other xylaria exist in Aotearoa New Zealand, for example, at Scion and the Allan Herbarium (Anonymous 1925, 1935, 1938). These could be used to supplement this work, however, it is possible that some of the specimens in the different xylaria originate from the same boards.

This study aims to:

(1) collate some existing information on timbers native to New Zealand; and

(2) add to the existing data, the density and acoustic velocity of native timber samples from the New Zealand School of Forestry | Te Kura Ngahere's wood collection.

Methods

The New Zealand School of Forestry | Te Kura Ngahere's wood collection contains 197 wood samples representing 115 native woody species with dimensions allowing for the assessment of density and acoustic velocity (Fig. 1). Species were regarded as native to New Zealand when listed in de Lange and Rolfe (2010).

The samples were equilibrated to constant mass at 20°C and 65% RH, equating to ~12% moisture content (MC) before measurement. The volume was calculated from the sample dimensions measured with a calliper. The average width and thickness of the samples were 13 mm and 75 mm, respectively. The average length along the grain was 153 mm (ranging between 101 mm and 161 mm). Density (at 20°C and 65% RH equilibrium) was defined as the ratio of mass to volume. Acoustic velocity along the grain was calculated by dividing the sample length by the transit time of an acoustic signal measured with a Fakopp UltraSonic Timer (Fakopp Enterprise Bt, Agfalva, Hungary). This allowed the calculation of the dynamic Modulus of Elasticity ($\mathrm{MoE_d}$) by multiplying density with the square of the acoustic velocity. Data was analysed and visualised in the statistical software R (R Core Team 2022).

Results

Table 1 lists wood density and $\mathrm{MoE_d}$ at 12% MC of samples sourced from 115 woody species native to Aotearoa New Zealand. Most species were represented by only one sample, preventing the calculation of standard deviations. For some species, density and $\mathrm{MoE_d}$ values were reported in the literature, and these, along with tree size and form, were included in Table 1 to provide context. Key historic references holding information on timber properties, uses, processing and durability were also matched to the species in Table 1.

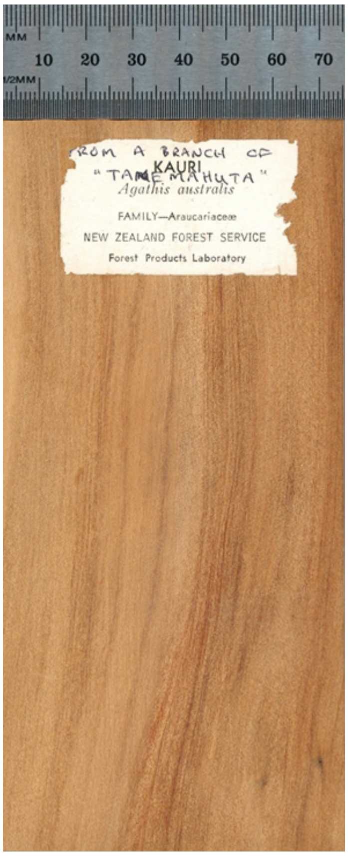

FIGURE 1: A typical timber sample from the New Zealand School of Forestry | Te Kura Ngahere's wood collection, specifically *Agathis australis* (kauri) from a branch of the iconic Northland specimen Tāne Mahuta.

TABLE 1: Wood properties of New Zealand native trees measured on samples from the New Zealand School of Forestry | Te Kura Ngahere's wood collection. Standard deviation where known is provided in parenthesis.

Species	Common name(s)	Family	Height (m) ♦	Form♦	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Gymnosperms / softwoods											
Agathis australis (D.Don) Lindl.	Kauri	Araucariaceae	12 (30)	t	14	630 (156)	9.4 (1.7)	A, B, C, D, E, F	B, C, D, E, F	A, B, C, D, E, F	D, E
					196[#]	468 - 570[#]	6.2 - 11.8[#]				
						560[†]	9.1[†]				
						623*					
						561 (61)[$]	13.3[$]				
Dacrycarpus dacrydioides (A.Rich.) de Laub.	Kahikatea/ White pine	Podocarpaceae	15 – 45 (60)	tt	4	492 (83)	7.7 (2.0)	A, B, C, D, E, F	A, B, C, D, E, F	A, B, C, D, E, F	D, E, F
					39[#]	429[#]	10.7[#]				
						450[†]	10.7[†]				
						488*					
						449 (43)[$]	7.9[$]				
Dacrydium cupressinum Sol. ex G.Forst.	Rimu	Podocarpaceae	20 – 35 (50)	tt	4	754 (173)	10.3 (4.4)	A, B, C, D, E, F	A, B, C, D, E, F	A, B, C, D, E, F	D, E, F
					301	455 - 591[#]	8.5 - 10.9[#]				
						595[†]	9.6[†]				
						563*					
						593 (50)[$]	9.0[$]				
Halocarpus biformis (Hook.) Quinn	Pink pine	Podocarpaceae	10 (12)	st	1	554 (-)	7.8 (-)	E, F		F	E, F
Halocarpus kirkii (F.Muell. ex Parl.) Quinn	Monoao	Podocarpaceae	15 – 20	mt	1	627 (-)	12.3 (-)	B, F	B	B	
Lepidothamnus intermedius (Kirk) Quinn	Yellow silver pine	Podocarpaceae	10	s to st	1	766 (-)	10.5 (-)	B, F	B, F	B, F	

TABLE 1: *continued*

Species	**Common name(s)**	**Family**	**Height (m)** ♦	**Form**♦	**n**	**Density**$_{(\sim12\%)}$ **(kg/m^3)**	**MoE**$_{d(\sim12\%)}$ **(GPa)**	**Further information**			
								Background	**Durability**	**Uses**	**Processing**
Libocedrus bidwillii Hook.f.		Cupressaceae	3 - 16 (20)	mt	2	344 (18)	4.8 (0.5)	A, B, C, D, E, F	B, C, D, E, F	A, B, C, D, E, F	D, E, F
					61$^{\#}$	344$^{\#}$	5.1$^{\#}$				
						415†	5.1†				
						416 (34)$^{\$}$	6.0$^{\$}$				
Libocedrus plumosa Druce	Kaikawaka/New Zealand cedar	Cupressaceae	20 – 25		1	380 (-)	5.4 (-)	A, B, F	B, F	A, B, F	
Manoao colensoi (Hook.) Molloy	Manoao/Silver pine	Podocarpaceae	6 – 23 (15)	st to mt	1	556 (-)	7.7 (-)	A, B, C, D, E, F	A, B, C, D, E, F	A, B, C, D, E, F	D, E, F
					45$^{\#}$	515$^{\#}$	6.4$^{\#}$				
						610†	6.4†				
						788*					
						609 (53)$^{\$}$	7.4$^{\$}$				
Pectinopitys ferruginea (D.Don) C.N.Page	Miro	Podocarpaceae	15 – 25		3	634 (66)	11.6 (2.8)	A, B, C, D, E	A, B, C, D, E	A, B, C, D, E	D, E
						625†	10.1†				
						658*					
						625 (59)$^{\$}$	10.8$^{\$}$				
Phyllocladus toatoa Molloy	Toatoa	Phyllocladaceae	6 – 15	t	1	675 (-)	9.9 (-)	B		B	
Phyllocladus trichomanoides D.Don	Tānekaha	Phyllocladaceae	18 – 20	t	3	631 (145)	11.7 (2.6)	A, B, C, D, E, F	A, C, D, E, F	A, B, C, D, E, F	D, E
					50$^{\#}$	553$^{\#}$	11.4$^{\#}$				
						610†	11.4†				
						609 (56)$^{\$}$	11.2$^{\$}$				
Phyllocladus trichomanoides var. *alpinus* (Hook.f.) Parl.		Phyllocladaceae	2 or 9	s to t	1	645 (-)	9.1 (-)	A, B, F	B, F	A, B	
Podocarpus laetus Hooibr. ex Endl.	Tōtara/ Halls tōtara	Podocarpaceae	20	t	1	619 (-)	10.7 (-)	B, D, F	B, D, F	B, D, F	D

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) ♦	Form♦	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Podocarpus totara D.Don	Tōtara	Podocarpaceae	20 – 30 (39)	t	6	521 (52)	8.8 (1.4)	A, B, C, D, E, F	A, C, D, E, F	A, B, C, D, E, F	B, D, E, F
					78#	435#	6.4#				
						480†	6.4†				
						559*					
						481 (38) $	7.4$				
Prumnopitys taxifolia (Sol. ex D.Don) de Laub.	Mataī/ Black pine	Podocarpaceae	20 – 25	mt	4	616 (130)	9.6 (2.4)	A, B, C, D, E, F	B, C, D, F	A, B, C, D, F	B, D, E, F
					5#	534#	8.1#				
						610†	8.1†				
						787*					
						609 (43)$	9.1$				
Angiosperms (dicots) / hardwoods											
Ackama rosifolia A.Cunn	Makamaka	Cunoniaceae	6 - 15	st	1	485 (-)	10 (-)	B, F		F	
Alectryon excelsus Gaertn.	Tītoki	Sapindaceae	10 (16)	mt	2	863 (97)	18.6 (0.5)	A, B, E, F	B, E, F	A, B, E, F	E, F
					7#	854#	11.4#				
						916*					
Archeria traversii Hook.f.		Ericaceae	s	s	1	688 (-)	8.6 (-)				
Aristotelia serrata Oliv.	Makomako/ Wineberry	Elaeocarpaceae	6 (10)	s to st	1	575 (-)	8.2 (-)	A, B, F	B, F	A, B, F	
						593*					
Ascarina lucida Hook.f.	Hutu	Chloranthaceae	6 (8)	s to st	1	500 (-)	10 (-)	B, F		B	
Avicennia marina subsp. *Australasica* (Walp.) J.Everett	Manawa/ white mangrove	Acanthaceae	0.3 – 9	s to st	1	701 (-)	5.7 (-)	B, E, F	B	F	E, F

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m)[♦]	Form[♦]	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Beilschmiedia tarairi Kirk	Taraire	Lauraceae	20	t	2	701 (75)	15.2 (4.2)	A, B, C, D, E, F	B, C, D, E, F	A, B, C, D, F	D, E, F
					37[#]	591[#]	10.8[#]				
						675[†]	10.8[†]				
						888*					
						673 (42)[$]	12.3[$]				
Beilschmiedia tawa Kirk	Tawa	Lauraceae	25	tt	6	710 (52)	13.9 (0.6)	A, B, C, D, E, F	C, D, E, F	A, B, C, D, E, F	D, E, F
					212[#]	637 - 780[#]	11.2 – 13.2[#]				
						720[†]	13.2[†]				
						761*					
						721 (30)[$]	14.2[$]				
Brachyglottis repanda J.R.Forst. & G.Forst.	Rangiora/ Bushmans friend	Asteraceae	7	s to st	1	681 (-)	6.3 (-)	B, F		B	
Carpodetus serratus J.R.Forst. & G.Forst.	Putaputawētā/ Marbleleaf	Rousseaceae	6 (8)	st	1	742 (-)	10.9 (-)	A, B, F	F	A, B, F	
						822*					
Ceodes brunoniana Skottsb. Parapara	Māmāngi	Nyctaginaceae	<8	s to st	1	226 (-)	2.6 (-)	B, F			
Coprosma arborea Kirk	Tree coprosma	Rubiaceae	10	t	1	654 (-)	9.3 (-)	B, F	F	B, F	
Coprosma linariifolia Hook.f.	Mikimiki/ Yellow-wood	Rubiaceae	6	s to t	1	835 (-)	16.4 (-)	B, F		A, B, F	
Coprosma lucida J.R.Forst. & G.Forst.	Karamū/ shining karamū	Rubiaceae	5	s to st	1	674 (-)	9.3 (-)	F			
Coprosma repens A.Rich	Taupata	Rubiaceae	8	t	1	599 (-)	11.6 (-)	B, F	B	B	
Coprosma robusta Raoul	Karamū/ glossy karamū	Rubiaceae	6	s to st	1	664 (-)	8.7 (-)	F			
Coriaria arborea Linds.	Tutu/tree tutu	Coriariaceae	3 – 4 7	s	1	618 (-)	9.4 (-)	A, B, F		F	
Corynocarpus laevigatus J.R.Forst. & G.Forst.	Karaka	Corynocarpaceae	6 – 12 (15)	st	1	791 (-)	8.8 (-)	B, F	B, F	F	

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) ♦	Form♦	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	**Durability**	**Uses**	**Processing**
Discaria toumatou Raoul	Matagouri	Rhamnaceae	1 – 2 6	s to st	1	819 (-)	8.7 (-)	A, B, F	B	B, F	
Dodonaea viscosa Jacq.	Akeake	Sapindaceae	0.3 – 8	s to st	1	1179 (-)	20.7 (-)	B, C, E, F	F	A, B, C, E, F	E, F
							13.5†				
Dracophyllum latifolium A.Cunn.	Neinei/ spider wood	Ericaceae	7	s to st	1	779 (-)	15.9 (-)	A, B, F	B	A, B	
Dracophyllum traversii Hook.f.	Mountain neinei	Ericaceae	5 – 10 (13)	st	1	615 (-)	8.2 (-)				
Dysoxylum spectabile Hook.f.	Kohekohe	Meliaceae	10 15 (19.5)	t	3	590 (17)	12.2 (1.5)	A, B, C, E, F	A, B, C, E, F	B, C, E, F	E, F
					40#	491#	9.5#				
						554†	9.5†				
						678*					
Elaeocarpus dentatus Vahl	Hīnau	Elaeocarpaceae	15 20	t	6	656 (57)	12.1 (3.4)	A, B, C, D, E, F	A, B, C, D, E, F	B, C, D, E, F	D, E
						705†	10.4†				
						562*					
						708 (53)$	11.1$				
Elaeocarpus hookerianus Raoul	Pōkākā	Elaeocarpaceae	15 (22)	t	2	568 (8)	12.1 (1.5)	B, F	B, F	B, F	
					66#	514#	8.4#				
Entelea arborescens R.Br.	Whau	Malvaceae	6	st	1	281 (-)	4.8 (-)	B, F		B, F	
						137*					
Fuchsia excorticata L.f.	Kōtukutuku/tree fuchsia	Onagraceae	6 (14)	st to t	1	788 (-)	11.5 (-)	A, B, F	A B, F	B, F	E
Geniostoma rupestre var. ligustrifolium (A.Cunn.) B.J.Conn	Hangehange	Loganiaceae	s‖	s‖	1	562 (-)	8.3 (-)				
Griselinia littoralis Raoul	Broadleaf	Griseliniaceae	6 (15)	t	1	763 (-)	13.1 (-)	A, B, F	B, F	A, B, F	E, F
*Griselinia lucida (*J.R.Forst. & G.Forst.) G.Forst.	Kāpuka/ broadleaf	Griseliniaceae	8	s to st	1	655 (-)	8.5 (-)	B, F	B, F	B, F	

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) ⬧	Form⬧	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Hedycarya arborea J.R.Forst. & G.Forst.	Porokaiwhiri/ pigeonwood	Monimiaceae	6 – 12	st	1	584 (-)	11.8 (-)	A, B, F	B, F	A F	
Hoheria angustifolia Raoul	houhi puruhi/ narrow-leaved lacebark	Malvaceae	10	t	1	738 (-)	13.1 (-)	F	F	F	
Hoheria lyallii Hook.f.	Mountain lacebark	Malvaceae	6 (10)	st	1	747 (-)	12.1 (-)	B		B	
Hoheria populnea A.Cunn.	Houhi/ whauwhi/ houhere	Malvaceae	10	mt	1	793 (-)	15 (-)	A, B, F	A, B, F	B, F	
Ixerba brexioides A.Cunn		Strasburgeriaceae	10 15	t	1	675 (-)	12.2 (-)	B, F		B, F	
					4$^{\#}$	648$^{\#}$	9.5$^{\#}$				
Knightia excelsa R.Br.	Rewarewa/ New Zealand honeysuckle	Proteaceae	30	tt	5	750 (143)	14.1 (3.5)	A, B, C, D, E, F	B, C, D, E, F	A, B, C, D, E, F	D, E, F
						740†	18.3†				
						785*					
						721$^{\$}$	17.4$^{\$}$				
Kunzea ericoides (A.Rich.) Joy Thomps.	Kānuka	Myrtaceae	15 (20)	s to t	1	785 (-)	12.8 (-)	A, B, C, E, F	A, B, C, E, F	A, B, C, E	E, F
					13$^{\#}$	731 - 780$^{\#}$	11.6 – 12.7$^{\#}$				
						760†	12.5†				
						943*					
Laurelia novae-zelandiae A.Cunn.	Pukatea	Athero-spermataceae	20 – 25 (30)	tt	3	455 (2)	9.2 (0.5)	A, B, C, D, E	A, B, C, D, E	A, B, C, D, E	D, E, F
					31$^{\#}$	382$^{\#}$	11.0$^{\#}$				
						465†	11.0†				
						456 (35)$^{\$}$	11.7$^{\$}$				
Leptospermum scoparium J.R.Forst. & G.Forst.	Mānuka/ red mānuka	Myrtaceae	0.1 – 6 (10)	s to st	1	1076 (-)	18.8 (-)	A, B, E, F	E, F	A, B, E, F	F

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) [♦]	Form[♦]	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	**Durability**	**Uses**	**Processing**
Leucopogon fasciculatus A.Rich.	Mingimingi	Ericaceae	s[‖]	s[‖]	1	901 (-)	16.7 (-)				
Litsea calicaris Kirk	Mangeao	Lauraceae	10 – 12 (15)	mt	4	630 (37)	11.1 (2.3)	B, C, D, E, F	C, D, E, F	B, C, D, E, F	D, E, F
					37[#]	502 - 518[#]	8.5 - 9.0[#]				
						595[†]	8.8[†]				
						621*					
						593 (61)[$]	11.2[$]				
Lophomyrtus bullata Burret	Ramarama	Myrtaceae	6 (8)	s to st	1	694 (-)	9.3 (-)	B, F		B, F	
Macropiper excelsum (G.Forst.) Miq.	Kawakawa	Piperaceae	3 – 4 (6)	s to st	1	519 (-)	7.1 (-)	F			
Melicope ternata (J.R.Forst. & G.Forst.	Wharangi	Rutaceae	6 – 8	s to st	1	808 (-)	14.5 (-)	B, F	F	B, F	
Melicytus lanceolatus Hook.f.		Violaceae	3 – 5	s to st	1	597 (-)	8.8 (-)				
Melicytus ramiflorus J.R.Forst. & G.Forst.	Māhoe	Violaceae	10	s to st	1	654 (-)	9.8 (-)	A, B, F	F	B, F	
Meryta sinclairii (Hook.f.) Seem.	Pukanui	Araliaceae	4 – 8	st	1	462 (1)	6.4 (-)	B, F			
Metrosideros excelsa Sol. ex Gaertn.	Pōhutukawa	Myrtaceae	18 (25)	t	1	915 (-)	16 (-)	A, B, C, E, F	B, C, E, F	A, B, C, E, F	E
Metrosideros robusta A.Cunn.	Northern rātā	Myrtaceae	20 – 30	lt	1	915 (-)	18.5 (-)	A, B, C, E, F	A, B, C	A, B, C, E, F	E
					100[#]	710[#]	11.4[#]				
						880[†]	11.4[†]				
Metrosideros umbellata Cav.	Southern rātā	Myrtaceae	15 (18)	tt	1	1039 (-)	21.1 (-)	A, B, E, F	F	A, B, E, F	E, F
					40[#]	968[#]	21.2[#]				
						1140[†]	21.2[†]				
						1045*					

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) ♦	Form♦	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Mida salicifolia A.Cunn	Maire	Santalaceae	6 – 8	t	2	733 (7)	12.7 (0.2)	B, F	F	B, F	
Myoporum laetum G.Forst.	Ngaio	Scro-phulariaceae	10	t	1	630 (-)	9.4 (-)	B, E, F	B, F	B, F	
Myrsine australis (A.Rich.) Allan	Mapou	Primulaceae	3 – 6	st	1	805 (-)	14.4 (-)	B, F	B, F	B, F	
						991*					
Myrsine salicina Heward	Toro	Primulaceae	10	st	1	844 (-)	8.8 (-)	B, F	B, F	B, F	
Neomyrtus pedunculata (Hook.f.) Allan	Rōhutu	Myrtaceae	6	s to st	1	741 (-)	10.9 (-)	B, F		B, F	
Neopanax arboreus Murr.) Allan	Whau-whaupaku/ fivefinger	Araliaceae	8	st	1	677 (-)	9.1 (-)				
Neopanax colensoi (Hook.f.) Allan	Mountain fivefinger	Araliaceae	5	s to st	1	722 (-)	12.0 (-)				
Nestegis cunninghamii (Hook.f.) L.A.S.Johnson	Black maire	Oleaceae	20	tt	2	974 (8)	12.5 (2.9)	A, C, E, F	A, C, E, F	C, E, F	E, F
					39[#]	818[#]	11.6[#]				
						995[†]	11.6[†]				
						790 - 1159*					
Nestegis lanceolata (Hook.f.) L.A.S.Johnson	White maire	Oleaceae	15 (20)	mt	2	825 (37)	13 (2.9)	B, F	F	B, F	
Nestegis montana (Hook.f.) L.A.S.Johnson	Narrow-leaved maire	Oleaceae	6 – 15	t	1	1013 (-)	19.6 (-)	B, F	B, F	B, F	
Nothofagus cliffortioides (Hook.f.) Oerst.	Mountain beech	Nothofagaceae	12 – 15 (25)	st to mt	4	661 (98)	14 (1.8)	B, D, E, F	B, E, F	B, E	E, F
					47[#]	596 - 621[#]	12.2 - 13.0[#]				
						645[†]	12.5[†]				
Nothofagus fusca (Hook.f.) Oerst.	Red beech	Nothofagaceae	24 – 30 (43)	tt	4	664 (121)	11.2 (2.1)	A, B, C, D, E, F	A, B, C, D, E, F	A, B, C, D, E, F	D, E, F
					156[#]	490 - 705[#]	8.2 - 13.7[#]				

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) ♦	Form♦	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Nothofagus fusca (Hook.f.) Oerst.	Red beech	Nothofagaceae				560 - 700[†]	11.6[†]				
						780*					
						721 (59)[$]	13.3[$]				
Nothofagus fusca x cliffortioides	Hybrid beech	Nothofagaceae			1	591 (-)	9.7 (-)				
Nothofagus menziesii (Hook.f.) Oerst.	Silver beech	Nothofagaceae	20 – 25 (30)	t	5	700 (97)	12.6 (2.9)	A, B, C, D, E, F	B, C, D, E, F	A, B, C, D, E	D, E, F
					175[#]	419 - 712[#]	6.6 - 14.9[#]				
						585 - 705[†]	9.5 - 13[†]				
						626*					
						545 (37)[$]	11.5[$]				
Nothofagus solandri (Hook.f.) Oerst.	Black beech	Nothofagaceae	20 – 25 (30)	t	3	790 (101)	15.6 (2.3)	A, B, D, F	A, B, D, F	A, B, D, F	D, F
						609[$]	14.1[$]				
Nothofagus truncata (Colenso) Cockayne	Hard beech	Nothofagaceae	24 – 30	tt	5	782 (93)	17.3 (4)	D, E, F	D, E, F	D, E	D, E, F
					186[#]	615-705[#]	13.0 - 15.3[#]				
						745[†]	14.2[†]				
						769 (58)[$]	14.5[$]				
Olearia furfuracea Hook.f.		Asteraceae	5	s to st	1	783 (-)	8.9 (-)				
Olearia ilicifolia Hook.f.		Asteraceae	6	s to st	1	663 (-)	7.3 (-)				
Olearia lacunosa Hook.f.		Asteraceae	5	s to st	1	748 (-)	6.4 (-)				
Olearia paniculata Druce	Akiraho/ golden akeake	Asteraceae	6	s to st	1	1120 (-)	15.2 (-)	B		B	
Olearia rani Druce	Heketara	Asteraceae	8	s to st	1	850 (-)	9.4 (-)	B, F	B	B, F	
Olearia virgata Hook.f.		Asteraceae	6	s to st	1	776 (-)	8.5 (-)				

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) ♦	Form♦	n	Density$_{(\sim 12\%)}$ (kg/m^3)	MoE$_{d(\sim 12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Pennantia corymbosa J.R.Forst. & G.Forst.	Kaikōmako	Pennantiaceae	4 – 12	st to mt	1	526 (-)	8.9 (-)	B	B	A, B	
Pittosporum eugenioides A.Cunn.	Tarata	Pittosporaceae	15	t	2	796 (75)	13.1 (0.9)	B, F	B, F	B, F	
Pittosporum tenuifolium Gaertn.	Black matipo	Pittosporaceae	4 – 10	st	1	807 (-)	15.3 (-)	B, F	B, F	B, F	
						955*					
Pittosporum umbellatum Gaertn.	Haekaro	Pittosporaceae	7	st	1	827 (-)	11.0 (-)				
Plagianthus regius (Poit.) Hochr.	Mānatu/ ribbonwood	Malvaceae	15	t	1	506 (-)	9.3 (-)	B, F	B, F	B, F	E
Pseudopanax crassifolius K.Koch	Lancewood	Araliaceae	6 - 8 (12)	t	1	757 (-)	13.7 (-)	A, B, F	B, F	B, F	E
Pseudopanax lessonii K.Koch		Araliaceae	6	s to st	1	674 (-)	10.2 (-)				
Pseudowintera axillaris (J.R.Forst. & G.Forst.) Dandy	Lowland horopito	Winteraceae	3 – 8	s to st	1	643 (-)	12.5 (-)	A, B, F	B, F	A, B, F	
Pseudowintera colorata (Raoul) Dandy	Red horopito	Winteraceae	2 – 3 6	s to st	1	645 (-)	7.9 (-)	F		F	
Pterophylla racemosa (L.f.) Pillon & H.C.Hopkins	Kāmahi	Cunoniaceae	25	t	2	639 (45)	11.1 (1.6)	A, B, F	B, F	A, B, F	E
					32#	572#	8.8#				
Pterophylla sylvicola (Sol. ex A.Cunn.) Pillon & H.C.Hopkins	Towai	Cunoniaceae	6 - 20	t	1	680 (-)	13.2 (-)	B, C, F	C, F	B, C, F	F
					25	627#	10.4#				
Quintinia serrata A.Cunn.	Common quintinia	Paracryphiaceae	9	st	1	620 (-)	10.3 (-)	B, F	B, F	B, F	
Raukaua edgerleyi (Hook.f.) Seem	Raukawa	Araliaceae	10 – 12	t	1	581 (-)	11.6 (-)	B, F		B, F	

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) ⬧	Form⬧	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Raukaua simplex (G.Forst.) A.D.Mitch., Frodin & Heads		Araliaceae	8	s to st	2	576 (2)	6.0 (0.02)	B, F	B	B	
Schefflera digitata J.R.Forst. & G.Forst.	Patē	Araliaceae	4 – 6 (8)	st	1	559 (-)	7.4 (-)	F		F	
Sophora microphylla Aiton	Kōwhai	Fabaceae	10 – 12	st to mt	1	797 (-)	8.1 (-)	C, E, F	C, E, F	C, E, F	E
					11#	766 - 804#	12.0 – 15.0#				
							13.6†				
Sophora tetraptera L.f.	Kōwhai	Fabaceae	10 – 12 (14)	mt	1	961 (-)	12.3 (-)	A, B, E, F	A, B, E, F	A, B, E, F	E
							13.6†				
						884*					
Syzygium maire (A.Cunn.) Sykes & Garn.-Jones	Maire tawake/ swamp maire	Myrtaceae	6 – 10 (15)	t	1	637 (-)	8.5 (-)	A, B, F	A, B, F	A, B, F	
						637*					
Toronia toru (A.Cunn.) L.A.S.Johnson & B.G.Briggs	Toru	Proteaceae	12	s to st	2	836 (67)	14.8 (1.0)	B, F	B, F	B, F	
Veronica parviflora Vahl		Plantaginaceae			1	768 (-)	8.6 (-)				
Veronica salicifolia G.Forst.	Koromiko	Plantaginaceae	5	s to st	1	822 (-)	6.6 (-)	B, F		B, F	
Vitex lucens Kirk	Pūriri	Lamiaceae	15 – 20 (29)	lt	3	980 (42)	13.7 (0.8)	A, B, C, E, F	A, B, C, E, F	B, C, E, F	E
						959*					

TABLE 1: *continued*

Species	Common name(s)	Family	Height (m) ♦	Form♦	n	Density$_{(\sim12\%)}$ (kg/m^3)	MoE$_{d(\sim12\%)}$ (GPa)	Further information			
								Background	Durability	Uses	Processing
Angiosperms (monocots) / palms											
Cordyline australis (G.Forst.) Endl.	Tī kōuka/ cabbage tree	Asparagaceae	8 – 12	t	1	522 (-)	7.5 (-)	B, F		B, F	
Cordyline indivisa (G.Forst.) Endl.	Tōī/ Broad-leaved cabbage tree	Asparagaceae	8	st	1	626 (-)	4.1 (-)	F			
Rhopalostylis sapida H.Wendl. & Drude	Nīkau	Arecaceae	3 – 10	mt	1	401 (-)	3.9 (-)				

[A] Hector (1879)
[B] Kirk (1889)
[C] Brasell (c. 1950)
[D] Hinds and Reid (1957)
[E] Clifton (1994)
[F] Wardle et al. (2011)

[#] static MoE at 12% moisture content (Bier & Britton 1999)
[†] static MoE at 12% moisture content [E]
[*] moisture content not specified [A]
[$] static MoE at 12% moisture reported in imperial units [D]
[‖] according to the New Zealand Plant Conservation Network (2023)
♦ height and form [F]; form codes: s shrub; st small tree; mt medium tree; tt tall tree; lt large tree; t tree.

The four rimu (*Dacrydium cupressinum* Sol. ex G.Forst.) samples included a sample labelled 'Burr Rimu' and a sample labelled 'Resinous heart - very dense but fast grown' with densities of 854 and 947 kg/m^3, respectively. An interesting note is that one of the kauri samples in the collection (Figure 1) is from a fallen branch of the iconic kauri tree Tāne Mahuta that is located in the Waipoua Forest, Northland, New Zealand.

It should be noted that the table refers to historic references discussing the durability of New Zealand native timbers but does not state that they are durable. The historic references comment on observations of timber performance either in use or in nature, i.e. are not based on systematic measurements, and can mean that rapid decay or long service life had been observed. Quantitative natural durability data is available only for a few species, which is not always consistent (Page & Singh 2014; NZS3602).

Species with extreme wood properties are listed in Table 2. Density at ~12% MC varied between 226.4 and 1178.6 kg/m^3, while MoE$_d$ ranged from 2.6 to 21.1 GPa. The ten native trees with the stiffest, densest and highest AV are all hardwoods. Three softwoods and one palm are among the ten native species with the least dense wood.

No correlation (R^2 = 0.001) was found between wood density and acoustic velocity of the 115 New Zealand native tree species (Figure 2). As the MoE$_d$ was calculated as the product of density and acoustic velocity^2, stiffness continuously increased with increasing density and acoustic velocity from the bottom left to the top right corner of the graph.

Discussion

Summarising wood properties in a single number can never reflect the substantial variability inherent to this natural material. It is not uncommon to find an order of magnitude difference in a wood property within a single species or even tree (Walker 2006). Therefore, detailed sampling procedures are specified by standards describing methods to obtain characteristic values for technical applications. While the samples available in the New Zealand School of Forestry | Te Kura Ngahere's wood collection do not allow the quantification of wood properties for use in structural applications, they will in most cases represent the typical characteristics of the species. More confidence can be achieved by including more samples which are available in other xylaria.

Due to limited supplies, it is unlikely that New Zealand native species will substitute exotic timbers for structural and commodity uses, which require detailed knowledge of structural material properties such as MoE. New Zealand native trees have the potential for use in niche products and woodwork where aesthetics and cultural heritage are of primary importance. For some niche uses density can be a factor, but other properties such as hardness, durability, dimensional stability, flexibility, propensity to splinter or toughness are equally likely to define the suitability for a wood product.

Trees and shrubs native to New Zealand were diverse in their wood density and stiffness. The wood density

TABLE 2: The top ten New Zealand native tree species in New Zealand School of Forestry | Te Kura Ngahere's wood collection with the highest and lowest wood density, highest wood stiffness, and highest acoustic velocity (AV).

Rank	Most dense	kg/m^3	Least dense	kg/m^3	Stiffest	GPa	Highest AV	km/s
1	*Dodonaea viscosa*	1179	*Ceodes brunoniana*	226	*Metrosideros umbellata*	21.1	*Nothofagus truncata*	4.68
2	*Olearia paniculata*	1120	*Entelea arborescens*	281	*Dodonaea viscosa*	20.7	*Alectryon excelsus*	4.65
3	*Leptospermum scoparium*	1076	*Libocedrus bidwillii*[S]	344	*Nestegis montana*	19.6	*Beilschmiedia tarairi*	4.62
4	*Metrosideros umbellata*	1039	*Libocedrus plumosa*[S]	380	*Leptospermum scoparium*	18.8	*Nothofagus cliffortioides*	4.62
5	*Nestegis montana*	1013	*Rhopalostylis sapida*[P]	401	*Alectryon excelsus*	18.6	*Elaeocarpus hookerianus*	4.61
6	*Vitex lucens*	980	*Laurelia novae-zelandiae*	455	*Metrosideros robusta*	18.5	*Ackama rosifolia*	4.54
7	*Nestegis cunninghamii*	974	*Meryta sinclairii*	462	*Nothofagus truncata*	17.3	*Dysoxylum spectabile*	4.53
8	*Sophora tetraptera*	961	*Ackama rosifolia*	485	*Leucopogon fasciculatus*	16.7	*Dracophyllum latifolium*	4.52
9	*Metrosideros excelsa*	915	*Dacrycarpus dacrydioides*[S]	492	*Coprosma linariifolia*	16.4	*Laurelia novae-zelandiae*	4.50
10	*Metrosideros robusta*	915	*Ascarina lucida*	500	*Metrosideros excelsa*	16.0	*Hedycarya arborea*	4.50

[S] softwood (gymnosperm)
[P] palm (angiosperm – monocot)

of the least dense New Zealand native species *Entelea arborescens* R.Br. (whau) was 281 kg/m^3 which was not much denser than the commercially grown low-density wood balsa (*Ochroma pyramidale* (Cav. ex Lam.) Urb.) (Bootle 2005; Kotlarewski et al. 2016). Likewise, the wood density of the densest New Zealand native species was close to the density requirement for the highest strength groups SD1 (1200 kg/m^3) and SD2 (1080 kg/m^3) according to AS/NZS2878. The native species with the stiffest wood, *Metrosideros umbellata* Cav. (Southern rata), had a MoE_d of 21.1 GPa, which was close to the requirements for the highest Australian S1 (21.5 GPa) (AS1720.1 2010) and European D70 (20 GPa) (EN338) strength classes.

The collated density data might also be of use to establish more precise carbon accounts for New Zealand's species-rich native forests, as the carbon stored in a forest is not only determined by volume but also by wood density (Marden et al. 2021). However, it needs to be noted that basic density, rather than density at 12% MC, is the most suitable measure for such estimates.

To the best of our knowledge the data in this study is of scientific interest. For example, considering that the acoustic velocity has been shown to be a good surrogate of the microfibril angle in timber (Mason et al. 2017), the two variables which trees use to control the mechanical functionality of their stem, i.e. microfibril angle and density, are independent (Figure 2). Across species, both variables contribute independently to wood stiffness. This is mirrored within species where wood density and microfibril angle were found to be independent (Chauhan & Walker 2006).

This work does not consider forestry traits of the tree species native to Aotearoa New Zealand. Growth rate, abundance, size and form of the stem, among others, determine availability, dimensions and cost of the timber. However, even if the log supply is scarce, of small dimensions, or expensive, there are potential niche markets. For example, *Maclura pomifera* (Raf.) C.K.Schneid. (Osage orange) (Smith & Perino 1981) or *Santalum* L. spp. (Sandalwood) (McLellan et al. 2021) are small trees which are used because of their valuable wood. A small supply volume can still support a regional economy to export into a global niche market or substitute imports of high-value timbers for some products (Millen & Palmer 2021). Availability of lesser-used species is essential to keep cultural heritage alive and could be leveraged to secure customer demand (Ares et al. 2008; Nguyen et al. 2021; Pejchar & Press 2006). In a New Zealand context, obligations under the Treaty of Waitangi | Te Tiriti o Waitangi need to be considered in this respect, highlighted by the Wai 262 claim (Waitangi Tribunal 2011).

The list of niche products is endless. Speciality wood traders often offer more than a hundred timber species. Aesthetic appearance of the wood characterised by traits such as colour and texture, are key attributes for many uses. Xylarias such as the New Zealand School of Forestry

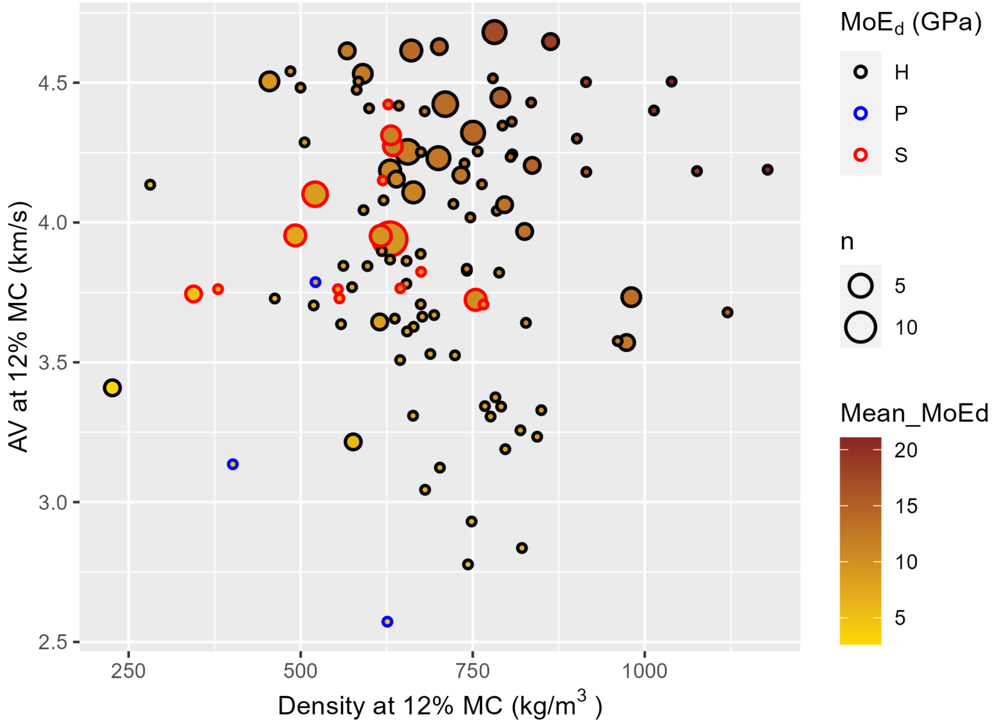

FIGURE 2: Relationship between wood density and acoustic velocity (AV) for 115 species native to New Zealand. The calculated MoE$_d$ is encoded by colour and the symbol size indicates the number of samples per species (n) represented by the data. (S) softwoods – gymnosperms, (H) hardwoods – angiosperms (dicots) and (P) palms – angiosperms (monocots) are encoded with red, black and blue borders, respectively.

| Te Kura Ngahere's wood collection could provide such information (Figure 1).

Collating descriptions of wood from trees native to Aotearoa New Zealand is a first step towards informing woodworkers and designers. This can create demand for lesser-used New Zealand native tree species. If New Zealand successfully establishes more native production forests, as envisaged by the government (Ministry for Primary Industries 2022), then a greater supply of native timbers will become available and a concomitant demand for wood can ensure a permanent financial return to the forest owners. A financial return is essential for private landowners to invest in establishing native forests (Norton 2000; Pejchar & Press 2006).

Conclusions

The ranges for wood density and stiffness of the 115 New Zealand species represented in the New Zealand School of Forestry | Te Kura Ngahere's wood collection matched those reported globally. Wood density at ~12% MC varied between 226.4 and 1178.6 kg/m^3, while MoE$_d$ ranged from 2.6 to 21.1 GPa. The ten native trees with the stiffest, densest and highest AV were all hardwoods. Three softwoods and one palm were among the ten native species with the least dense wood. No correlation was found between wood density and acoustic velocity across species.

Collating the historic documentation of New Zealand native timbers is useful as it contains valuable information when contemplating the future uses of this resource. Xylaria contain readily available wood samples for characterising lesser-used species, which can be used quickly and efficiently to assess wood properties. Information on the characteristics of these lesser-used tree species is essential if a financial return is to be realised from the proposed native afforestation encouraged by policies in New Zealand.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

GK carried out measurements, collated historic information and reviewed the manuscript. MS carried out measurements and reviewed the manuscript. MH carried out measurements, collated information and reviewed the manuscript. CA conceived the study, conducted the literature search, analysed the data, drafted and reviewed the manuscripts. All authors read and approved the final manuscript.

Acknowledgements

We would like to thank Pieter Pelser (University of Canterbury) for putting us on the right track forcataloguing the New Zealand School of Forestry | Te Kura Ngahere's wood collection.

References

Anonymous. (1925). The forestry museum. *Te Kura Ngahere, 1*(1), 3-4.

Anonymous. (1931). Forestry club. *Te Kura Ngahere, 3*(1), 47-48.

Anonymous. (1935, 15 January 1935). New exhibits at the museum, *The Press*. Retrieved from https://paperspast.natlib.govt.nz/newspapers/press/1935/01/15/14

Anonymous. (1938). Museum notes, *The Press*. Retrieved from https://paperspast.natlib.govt.nz/newspapers/press/1938/01/27/6

Ares, A., Fownes, J., & Simmons, P. (2008). Wood production and native vegetation conservation in Hawaii's uplands. *Western Journal of Applied Forestry, 23*(3), 177-182. https://doi.org/10.1093/wjaf/23.3.177

AS1720.1 (2010). *Timber structures Part 1: Design methods* (Vol. 1720.1, pp. 181): Australian Standard.

AS1720.2 (2006). *Timber structures Part 2: Timber properties* (Vol. 1720.2, pp. 20): Australian Standard.

AS5604 (2005). *Timber - Natural durability ratings*: Australian Standard.

AS/NZS2878 (2000). *Timber - Classification into strength groups.* Australian/New Zealand Standard

Bier, H., & Britton, R.A.J. (1999). *Strength properties of small clear specimens of New Zealand grown timbers.* [FRI Bulletin, Vol. 41] (26 pp.). Rotorua, New Zealand: New Zealand Forest Research Institute Limited.

Blair, W.N. (1879). *The building materials of Otago and south New Zealand generally*. Dunedin, New Zealand: J. Wilkie & Co.

Bootle, K.R. (2005). *Wood in Australia. Types, properties, and uses* (2nd ed.): McGraw-Hill Australia.

Brasell, A. (c.1950). *Native timbers of New Zealand*. Wanganui, New Zealand: Sovereign Woodworkers Ltd.

Buchanan, A. (2020). *Trees, timber, species & properties*. Retrieved from https://www.wpma.org.nz/uploads/1/3/2/8/132870817/ch-1.2-trees-timber-species-properties.pdf

Chauhan, S.S., & Walker, J.C.F. (2006). Variations in acoustic velocity and density with age, and their interrelationships in radiata pine. *Forest Ecology and Management, 229*(1-3), 388-394. https://doi.org/10.1016/j.foreco.2006.04.019

Clifton, N.C. (1994). *New Zealand Timbers - The complete guide to exotic and indigenous woods* (Rev ed.). Wellington, New Zealand: GP Publications.

de Lange, P.J., & Rolfe, J.R. (2010). *New Zealand indigenous vascular plant checklist*. Wellington, New Zealand: New Zealand Plant Conservation Network.

Deklerck, V., De Mil, T., Kondjo, P., Beeckman, H., Van Acker, J., & Van den Bulcke, J. (2019). Sleeping beauties in materials science: unlocking the value of xylarium specimens in the search for timbers of the future. *Holzforschung, 73*(10), 889-897. https://doi.org/10.1515/hf-2018-0269

Deklerck, V., De Linge, L., Espinoza, E., Beeckman, H., Van den Bulcke, J., & Van Acker, J. (2020). Assessing the natural durability of xylarium specimens: mini-block testing and chemical fingerprinting for small-sized samples. *Wood Science and Technology, 54*(4), 981-1000. https://doi.org/10.1007/s00226-020-01186-1

Dungey, H., Ford, C., Lloyd, A., & Turner, K. (2022). Can we make establishing native forests cheaper by growing native plants in smaller pots? *New Zealand Journal of Forestry 67*(4), 8-13.

EN338 (2009). *Structural timber - Strength classes*. European Committee for Standardization (CEN).

Forbes, A. (2022). *Review of Actual Forest Restoration Costs, 2021*. 22. Retrieved from https://www.mpi.govt.nz/dmsdocument/50209-Review-of-actual-forest-restoration-costs-Contract-Report-Prepared-for-Te-Uru-Rakau-New-Zealand-Forest-Service-November-2021

Hector, J. (1879). *Handbook of New Zealand*. Wellington: Lyon & Blair.

Hinds, H.V., & Reid, J.S. (1957). *Forest trees and timbers of New Zealand*. Wellington, N.Z: Government Printer.

Kerr, G., & Stewart, G. (2013). The Native Forests of New Zealand.

Kirk, T. (1889). *The forest flora of New Zealand*. Wellington, New Zealand: Government Printer.

Kotlarewski, N.J., Belleville, B., Gusamo, B.K., & Ozarska, B. (2016). Mechanical properties of Papua New Guinea balsa wood. *European Journal of Wood and Wood Products, 74*(1), 83-89. https://doi.org/10.1007/s00107-015-0983-0

Marden, M., Lambie, S., & Burrows, L. (2021). Species-specific basic stem-wood densities for twelve indigenous forest and shrubland species of known age, New Zealand *New Zealand Journal of Forest Science, 51*(1). https://doi.org/10.33494/nzjfs512021x121x

Mason, E.G., Hayes, M., & Pink, N. (2017). Validation of ultrasonic velocity estimates of wood properties in discs of radiata pine. *New Zealand Journal of Forestry Science, 47:* 16 . https://doi.org/10.1186/s40490-017-0098-y

McGlone, M., Bellingham, P., & Richardson, S.J. (2022). Science, policy, and sustainable indigenous forestry in New Zealand. *New Zealand Journal of Forestry Science, 52:* 8. https://doi.org/10.33494/nzjfs522022x182x

McLellan, R.C., Dixon, K., & Watson, D.M. (2021). Prolific or precarious: a review of the status of Australian sandalwood (*Santalum spicatum* [R.Br.] A.DC., Santalaceae). *The Rangeland Journal, 43*(4), 211-222. https://doi.org/10.1071/RJ21017

Meylan, B.A., & Butterfield, B.G. (1978). *The structure of New Zealand woods* (Vol. 222). Wellington, New Zealand: New Zealand Department of Scientific and Industrial Research

Millen, P., & Palmer, H. (2021). Establishing an industry group for New Zealand's small-scale sawmilling sector. *New Zealand Tree Grower* (February).

Ministry for Primary Industries (2022). *Te Ara Whakahou – Ahumahi Ngahere | Industry Transformation Plan*. Retrieved from https://www.mpi.govt.nz/dmsdocument/54472-Te-Ara-Whakahou-Ahumahi-Ngahere-Forestry-and-Wood-Processing-Industry-Transformation-Plan

Ministry for the Environment (2022). *Te hau mārohi ki anamata | Towards a productive, sustainable and inclusive economy - Aotearoa New Zealand's First Emissions Reduction Plan*: Retrieved from https://environment.govt.nz/assets/publications/Aotearoa-New-Zealands-first-emissions-reduction-plan.pdf

New Zealand Plant Conservation Network (2023). Retrieved from https://www.nzpcn.org.nz/

Nguyen, L., Bayne, K., & Altaner, C. (2021). A review of kowhai (*Sophora* spp.) and its potential for commercial forestry. *New Zealand Journal of Forestry Science, 51:* 13. https://doi.org/10.33494/nzjfs512021x157x

Norton, D.A. (2000). Conservation biology and private land: Shifting the focus. *Conservation Biology, 14*(5), 1221-1223. https://doi.org/10.1046/j.1523-1739.2000.01451.x

NZS3602 (2003). Timber and wood-based products for use in building. Standards New Zealand.

Page, D., & Singh, T. (2014). Durability of New Zealand grown timbers. *New Zealand Journal of Forestry, 58*(4), 26-30.

Pejchar, L., & Press, D.M. (2006). Achieving conservation objectives through production forestry: The case of *Acacia koa* on Hawaii Island. *Environmental Science and Policy, 9*(5), 439-447. https://doi.org/10.1016/j.envsci.2006.03.007

Manaaki Whenua | Landcare Research (2023). *Ngā Rauropi Whakaoranga*. Retrieved from https://RauropiWhakaoranga.landcareresearch.co.nz

R Core Team (2022). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/

Salmon, J.T. (1996). *The native trees of New Zealand* (Rev. ed.). Auckland, New Zealand: Reed.

Smith, J.L., & Perino, J.V. (1981). Osage orange (*Maclura pomifera*): History and economic uses. *Economic Botany, 35*(1), 24-41. https://doi.org/10.1007/BF02859211

Star, P. (2002). Native Forest and the Rise of Preservation in New Zealand (1903-1913). *Environment and History, 8*(3), 275-294. https://doi.org/10.3197/096734002129342675

Steward, G., & McKinley, R. (2019). Indigenous plantations - implications for wood quality. *New Zealand Journal of Forestry, 64*(2), 42-45.

Steward, G., & Quinlan, P. (2019). Totara industry pilot project: A fresh look at a familiar Northland species. *New Zealand Tree Grower,* November.

Swarbrick, N. (2007). *Logging native forests*. Retrieved from http://www.TeAra.govt.nz/en/logging-native-forests

Tāne's Tree Trust. *Resources* [Web page]. Retrieved from https://www.tanestrees.org.nz/resources/

Waitangi Tribunal (2011). *Ko Aotearoa tēnei: a report into claims concerning New Zealand law and policy affecting Māori culture and identity. Te taumata tuatahi.*

Walker, J. (2006). *Primary wood processing. Principles and practice* (2nd ed.). Dordrecht: Springer.

Wardle, J.A., Platt, I., & New Zealand Farm Forestry, A. (2011). *Wardle's native trees of New Zealand and their story*. Wellington, New Zealand: New Zealand Farm Forestry Association.

World Wildlife Fund/Global Forest & Trade Network (2013). *Guide to lesser known tropical timbers*. Retrieved from https://files.worldwildlife.org/wwfcmsprod/files/Publication/file/fu9tsl8gr_wwf_gftn_lkts_guide_final_oct_2013.pdf