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Species-specific basic stem-wood densities for twelve indigenous forest and shrubland species of known age, New Zealand

Michael Marden[1,*], Suzanne Lambie[2] and Larry Burrows[3]

[1] *31 Haronga Road, Gisborne 4010, New Zealand*
[2] *Manaaki Whenua – Landcare Research, Private Bag 3127, Hamilton 3240, New Zealand*
[3] *Manaaki Whenua – Landcare Research, PO Box 69041, Lincoln 7640, New Zealand*

*Corresponding author: mardenm@landcareresearch.co.nz

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Abstract

Background: Tree carbon estimates for New Zealand indigenous tree and shrub species are largely based on mean basic stem-wood densities derived from a limited number of trees, often of unspecified age and from a limited number of sites throughout New Zealand. Yet stem-wood density values feed directly into New Zealand's international and national greenhouse gas accounting. We augment existing published basic stem-wood density data with new age-specific values for 12 indigenous forest and shrubland species, including rarely obtained values for trees <6-years old, across 21 widely-distributed sites between latitudes 35° and 46° S, and explore relationships commonly used to estimate carbon stocks.

Methods: The volume of 478 whole stem-wood discs collected at breast height (BH) was determined by water displacement, oven dried, and weighed. Regression analyses were used to determine possible relationships between basic stem-wood density, and tree height, root collar diameter (RCD), and diameter at breast height (DBH). Unbalanced ANOVA was used to determine inter-species differences in basic stem-wood density in 5-yearly age groups (i.e. 0–5 years, 6–10 years etc.) ($P<0.05$). As specific taxa of *Kunzea ericoides* (Myrtaceae) has only been identified at some study sites we combine the data from each site, and use the term *Kunzea* spp. We compare our age- and species-specific results with existing published data where age is specified versus non-age-specific values.

Results: *Kunzea* spp. and *Leptospermum scoparium* exhibited positive correlations between basic stem-wood density and tree height, RCD, and DBH. No relationships were established for *Melicytus ramiflorus*, *Coprosma grandiflora*, *Weinmannia racemosa* ≥6-years old, or for *Podocarpus totara*, *Agathis australis*, *Vitex lucens,* and *Alectryon excelsus* <6-years old. *Dacrydium cupressinum* and *Prumnopitys ferruginea* <6-years old exhibited a significant positive relationship with DBH only, while for *Dacrycarpus dacrydioides,* each correlation was negative. Irrespective of age, basic stem-wood density is not different between the hardwood species *L. scoparium* and *Kunzea* spp. but is significantly greater (P=0.001) than that of the remaining, and predominantly softwood species of equivalent age. For *Kunzea* spp., *L. scoparium, Coprosma grandiflora*, *Weinmannia racemosa*, and *Melicytus ramiflorus* ≥6-years old there was no evidence that basic stem-wood density increased with tree age, and values were within the range of published and unpublished data. For naturally reverting stands of *Kunzea* spp. located between latitudes 35° to 46° S, basic stem-wood density values tended to increase with decreased elevation and increased temperature.

Conclusions: Increasing basic wood density values in *Kunzea* spp. with decreased elevation and increased temperature suggest that where local data are available its use would improve the accuracy of biomass estimates both locally and nationally. Furthermore, refining biomass estimates for existing communities of mixed softwood species, stands of regenerating shrubland, and new plantings of indigenous species will require additional basic stem-wood density values for scaling from stem wood volume to total stand biomass.

Keywords: basic stem-wood density, allometric relations, 12 indigenous forest and shrubland species, New Zealand.

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Introduction

The variability in basic stem-wood density and age are critical factors influencing estimates of wood biomass and carbon storage capability (Chave et al. 2004, Dale 2013). Stem-wood density values feed directly into New Zealand's international greenhouse gas accounting of forest carbon stocks, and for internal schemes such as the Emissions Trading Scheme (ETS) (Ministry for Primary Industries 2017), and the 1 Billion Trees Programme (1BT) (Ministry for Primary Industries 2018).

Previously, New Zealand studies have estimated the biomass of indigenous forest stands for tree carbon stocks and sequestration using diameters and height measurements of individual trees in forest inventory plots (Carswell et al. 2012, Scott et al. 2000, Trotter et al. 2005, Beets et al. 2014, Schwendenmann & Mitchell 2014, Dale 2013, Holdaway et al. 2014). When basic wood density values are available for only a limited number of species and locations, wood volume is converted to carbon stocks using generic (as opposed to species-specific) functions based on the basic density of stem-wood (oven-dry mass/ 'green' volume). Where species-specific and/or regional basic stem-wood density values are unavailable, congeneric values are used instead, or in their absence, the mean of all published values e.g. Beets et al. (2012 and unpublished data[1]).

While most early studies in New Zealand collected basic stem-wood density data from sites of well-established indigenous shrubs and trees, age-specific and species-specific stem-wood density data for the early growth period of many species remain elusive. The absence of taxon-specific stem-wood density and age-class distribution data of a wide variety of species over a range of geographic sites introduces uncertainty in the accuracy of New Zealand's national carbon budget calculations (Scott et al. 2000, Chave et al. 2004, Holdaway 2014). The use of taxon-specific stem-wood density to scale tree volume, as yield or growth, to stem biomass, and from stem biomass to total biomass will improve the accuracy of species-specific allometric equations for estimating tree carbon storage, and avoid potential bias to national carbon budgets.

Furthermore, basic stem-wood density values for a few widespread indigenous species (Entrican et al. 1951, Hall et al. unpublished data[2]), and for specific species with a more restricted geographic range (Wardle 1991), can vary depending on geographic location, though no relationships have been verified with respect to climate or site factors (Hall et al. unpublished data[2]).

Clifton (1990) suggests that basic stem-wood density varies according to the age of the tree, the location of the wood within a tree (outer-wood/inner-wood, base or top of a tree), and while densities have been determined for some of New Zealand's historically important merchantable wood species (Hinds & Reid 1957, Beets et al. 2012), the age of the trees and variations in basic stem-wood density were not determined, the sample size was generally small, the methods uncertain, and the location vague. Stand basic stem-wood densities will also change with time, influenced by climatic variability and site-specific physical factors, including soil type, slope, aspect, elevation and rainfall regime, all of which can affect growth rates, plant survival, and carbon sequestration rates. Furthermore, as the area of indigenous species plantings and their diversity increases with age, age-specific and species-specific stem-wood density data, will be relevant for Afforestation/Reforestation reporting, for updating the national carbon inventory system (Land Use and Carbon Accounting System – LUCAS), and policy, to reduce net greenhouse gas emissions as required under the Kyoto Protocol (Ministry of the Environment 2010), and for comparison with pre-calculated forest carbon stocks (includes stem, bark, branch, leaves, litter, woody debris, stumps and roots expressed in units of tonnes of CO_2 ha^{-1}), by age, for given forest types in the Emissions Trading Scheme (Ministry for Primary Industries 2017).

We augment existing published basic stem-wood density data with new age-specific values for 12 of New Zealand's indigenous forest and shrubland species from 21 widely distributed sites located between latitudes 35° to 46° S. We explore relationships between basic stem-wood density and tree parameters commonly used to estimate stem carbon stocks, and applicable to future efforts to reduce the uncertainty of carbon stock estimates for forest and shrubland communities where basic stem-wood density values for different age classes of many species is currently missing.

Methods

Study sites

Basic wood density data was collected from 14 sites located in the North Island and from 7 sites in the South Island of New Zealand with a latitudinal range between 35° and 46° S (Fig. 1). Details of species, elevation, and substrate characteristics are summarised in Table 1, and presented in more detail in Appendix Table A1.

Species nomenclature

Since this study began, there has been a taxonomic revision of the New Zealand *Kunzea ericoides* (Myrtaceae) complex in New Zealand (de Lange 2014). Ten *Kunzea* species endemic to New Zealand are now recognised, seven of which are new. Where we have some confidence in the identification of new taxa these are presented in Table 1 and Appendix Table A1. As specific taxa have not been identified for all sites we have not attempted to analyse for possible inter-specific variations in basic stem-wood density for this genus but

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[1] Beets, P.N., Oliver, G.R, Kimberley., M.O, Pearce, S.H. (2008). Allometric functions for estimating above ground carbon in native forest trees, shrubs and ferns. Scion Report 12679 prepared for the Ministry for the Environment 63 p.

[2] Hall, G., Wiser, S., Allen, R., Moore, T., Beets, P., Goulding, C. (1998). Estimate of the carbon stored in New Zealand's indigenous forest and scrub vegetation for 1990. Landcare Research Contract JNT9798/147 Prepared for Ministry for the Environment, Wellington, New Zealand. 36 p.

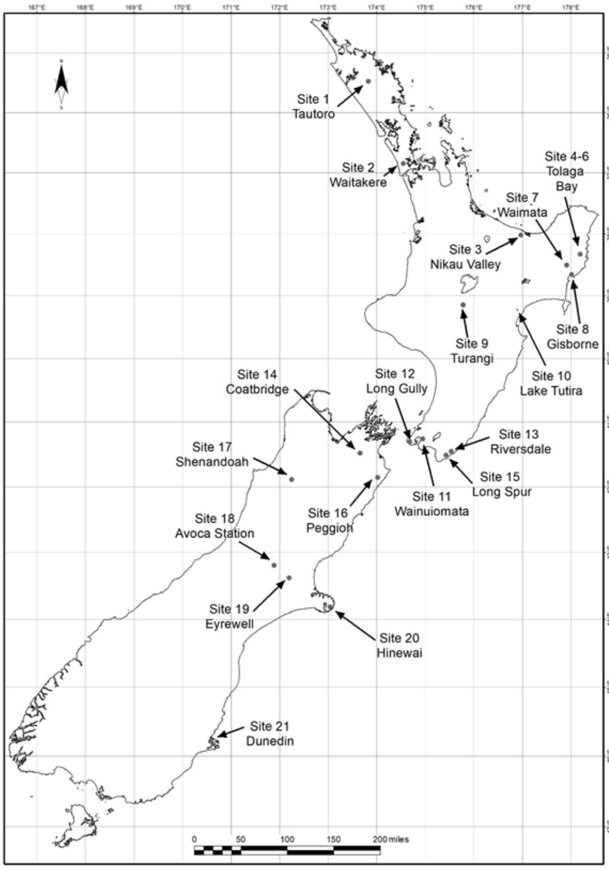

FIGURE 1: Location of 21 New Zealand indigenous forest, shrubland, and experimental trial sites where discs were collected for analysis of basic stem-wood density.

instead we combine data for all sites where present and use the generic term *Kunzea* spp.

Wood sampling and density

There are many methods of sampling wood and determining wood density (Chave 2005, Williamson & Wiemann 2010). In this study, wood density is defined as the ratio of the oven-dry mass of a stem-wood disc sampled at a standard height divided by the mass of water displaced by its green volume to give wood specific gravity (WSG). WSG is described as basic wood density or stem-wood density throughout the text.

Discs cut from the stem account for the change in density from pith to bark (Williamson & Wiemann 2010, Beets et al. 2012). Basic stem density measurements of discs were sourced from trees located in areas of naturally regenerating *Kunzea* spp. (sites 2–7, 9, 12–21), regenerating *Leptospermum scoparium* (sites 1, 2, 9, 14, 16, and 21), a lowland shrub community (site 11), a species growth trial of indigenous softwood and hardwood species (site 8), and from an area of low-density plantings of *L. scoparium* (site 10). As the purpose of the research undertaken at each site differed, 256 of the basic stem-wood density measurements were of discs with the bark intact (Cornelissen et al. 2003) (e.g. sites 2, 4-11 & 21) and 222 measurements were of discs with the bark removed (e.g. sites 1, 3, 12-20). All discs were sampled at breast height (BH) (1.4 m above ground-level). The fresh volume of each wood disc was determined by water displacement, then oven dried at 105°C (Cornelissen et al. 2003) and weighed. For multiple-stemmed trees, a disc was cut from each stem, and the density averaged for the tree. Tree age in naturally regenerating stands was based on ring counts of the single oldest stem. The age of the species established in the plant growth trial (site 8) was based on the known date that seedlings were 'pricked-out' into seed trays in the nursery. For the site established in *L. scoparium* for honey production (site 10), the year in which 1-year-old, nursery-raised seedlings were planted was known.

For *Melicytus ramiflorus* and *Coprosma grandiflora* (site 11), discs were collected in the field at BH and transported in a sealed container to avoid moisture loss. In the laboratory, discs were soaked before the volume was determined by water displacement. Discs were dried at 80°C until dry and weighed (Cornelissen et al. 2003). Tree height was based on the tallest single stem. Tree age was based on ring counts of a disc cut from a representative stem of the tree.

For *Kunzea* spp. and *L. scoparium* collected from sites 2, 9, and 21, discs were collected at BH and frozen at –20°C. The discs were thawed at room temperature and soaked in water for 2 days before their volume was assessed. As *L. scoparium* and *Kunzea* spp. tend to split during drying making ring counting and measuring difficult, the discs were partially dried at 35°C, the rings counted, and then dried at 80°C and weighed.

For *Kunzea* spp., and *L. scoparium*, tree parameters were predominantly measured in regenerating shrubland >6-years old. Other regenerating shrubland species including *Melicytus ramiflorus*, *Coprosma grandiflora,* and *Weinmannia racemosa* include measurements for a wide range of ages both < and >6-years old while regressions for plot-based *Alectron excelsus, Podocarpus totara, Agathis australis, Dacrydium cupressinum, Prumnopitus ferruginea*, *Dacrycarpus dacrydioides* and *Vitex lucens* include only data for trees <6-years old.

Statistical analyses

Linear regression analysis best fitted the data and was used within each tree species to determine the possible relationship between basic stem-wood density and tree height, root collar diameter (RCD), diameter at breast height (DBH), and tree age.

Unbalanced ANOVA with least significant differences (LSD) was used to determine differences in basic stem-wood density between species and for *Kunzea* spp. to assess if densities differed between 17 sites located throughout New Zealand.

Density values were grouped into 5-yearly age classes (e.g. 0–5-years, 6–10 years etc.). Only data sets within a species, and within an age class with three or more replicates (irrespective of the geographical position) were used in the analysis. The average basic stem-wood densities for younger (<6-years old) and older (≥6-years old) trees are compared with published values. For the

TABLE 1: Locations, tree species present, elevation above sea level (asl), and substrate characteristics for 21 study sites sampled for basic wood density. Map co-ordinates are New Zealand Map Grid (NZMG)

Site number and name	Grid reference	Species	Elevation asl (m)	Substrate
1: Tautoro	173° 50´ 13 15 E, 35° 28´ 52 00 S	*Leptospermum scoparium*	100–140	greywacke argillites and sandstones
2: Waitakere Range	174° 35´ 14 42 E, 37° 00´ 10 17 S	*Kunzea* spp. and *L. scoparium*	40	volcanic andesitic lava, conglomerates, and breccia
3: Nikau Valley	176° 58´ 23 85 E, 38° 01´ 25 27 S	*Kunzea robusta*	40–100	undifferentiated greywacke
4-6: Tolaga Bay	178° 12´ 19 29 E, 38° 20´42 58 S	*Kunzea robusta*	64	calcareous sandy siltstones with banded sandstones
7: Waimata Valley	178° 03´ 13 66 E, 38° 28´ 33 84 S	*Kunzea robusta*	207	calcareous sandy siltstones with banded sandstones
8: Gisborne	178° 00´ 16 02 E, 38° 38´ 44 82 S	*Agathis australis, Prumnopitys ferruginea*, *Podocarpus totara*, *Dacrycarpus dacrydioides*, *Dacrydium cupressinum*, *Alectryon excelsus*, and *Vitex lucens.*	5	alluvial gravels and silt.
9: Turangi	175° 47´ 11 53 E, 39° 09´ 19 20 S	*L. scoparium* and *Kunzea* spp.	800	rhyolitic and andesitic volcanics
10: Lake Tutira	176° 54´ 10 44 E, 39° 14´ 00 44 S	*L. scoparium*	200–375	mudstone, sandstone, and limestone
11: Wainuiomata & Cannons Creek	174° 57´ 19 75 E, 41° 17´ 45 29 S	*Coprosma grandiflora, Weinmannia racemosa*, and *Melicytus ramiflorus*	117	alternating dark grey argillite and greywacke sandstone
12: Long Gully	174° 40´ 55 30 E, 41° 18´ 34 82 S	*Kunzea amathicola*	300–400	argillite and greywacke sandstone with rare limestone and volcanics
13: Riversdale	175° 25´ 53 49 E, 41° 30´ 57 74 S	*Kunzea robusta*	60–200	greywacke-like dark grey muddy siltstone with minor conglomerates and spilitic lava
14: Coatbridge	173° 39´ 23 16 E, 41° 29´ 08 99 S	*L. scoparium* and *Kunzea* spp.	200–300	metamorphosed sedimentary lithologies and volcanics
15: Long Spur	175° 32´ 09 01 E, 41° 27´ 22 12 S	*Kunzea robusta*	40–200	sandstone and mudstone, minor conglomerates and volcanics
16: Peggioh	174° 01´ 13 67 E, 41° 51´ 31 57 S	*L. scoparium* and *Kunzea robusta*	200–300	greywacke and argillite with minor volcanics, conglomerates, and rare limestone
17: Shenandoah	172° 15´ 05 30 E, 41° 53´ 36 00 S	*Kunzea ericoides*	200–300	limestone and calcareous siltstone, local sandstone and coal measures
18: Avoca Station	171° 53´ 23 31 E, 43° 11´ 49 51 S	*Kunzea serotina*	420–540	greywacke and argillite with minor volcanics, conglomerates, and rare limestone
19: Eyrewell.	172° 11´ 41 76 E, 43° 22´ 59 35 S	*Kunzea serotina*	200	post-glacial alluvium and glacial outwash gravels
20: Hinewai.	173° 02´ 18 74 E, 43° 49´ 02 85 S	*Kunzea robusta*	20–450	basalt tuff, and associated intrusive rocks
21: Dunedin	170° 36´ 37 14 E, 45° 45´ 11 19 S	*L. scoparium* and *Kunzea robusta*	200–300	loess, basalt and phonolite

earliest of the published data (Kirk 1889, but mostly by Entrican et al. 1951, and republished by Hinds & Reid 1957, Harris 1986, and Clifton 1990), tree age is rarely specified, and variations in basic stem-wood density values derived from merchantable-sized trees after removal of the bark is not given. For comparative purposes we use these few available published values (Appendix Table A2) together with a larger data set of mean age-specific/non-age-specific wood density values (bark removed) collected from Carbon Monitoring System (LUCAS) plots (20m x 20 m) across a wide range of well-established and pre-defined natural forest and shrubland types (Table A2) indicative of advanced succession toward indigenous forest (Hall et al. unpublished data[2], Peltzer & Payton unpublished data[3], Beets et al. 2012 and unpublished data[1]).

We did not attempt to analyse for the influence of bark thickness on basic stem wood density values (i.e. inclusive versus exclusive of bark), as for the age-range (3- to 105-years old) of the shrubland species presented in this paper, all values were expected to fall well within the range of the published data. In the absence of reliable basic stem-wood density values for individual stems, often determined for only a small sample size of trees with widely varying, or of unknown age, and variability in basic stem-wood density values, the values in this paper are presented as means (Appendix Tables A3–A5).

All statistical analyses were undertaken using Genstat (VSN International, Hemel Hempstead, UK) and were considered significant if $P<0.05$.

Results

Basic stem-wood density-allometric relationships

For >6-year-old regenerating *Kunzea* spp. basic stem-wood density was significantly, positively correlated with tree height, as was also the case for *L. scoparium* (Table 2). Of the plot-based species <6-years old, the correlation for basic stem-wood density with tree height was strongest (and positive) for *Prumnopitys ferruginea* (Table 2) but was only just statistically significant, probably due to the small sample size (n=7). Interestingly, *Dacrycarpus dacrydioides* exhibited a significant negative correlation with about 30% of the variation in basic stem-wood density explained by tree height. There were no other significant relationships between basic stem-wood density and tree height for the remaining plot-based or regenerating shrubland species. Basic stem-wood density and RCD were positively correlated for regenerating *L. scoparium* and *Kunzea* spp. >6-years old (Table 2). Root collar diameter and density values were negatively correlated for plot-based *Dacrycarpus dacrydioides* (Table 2). There were no significant correlations between basic stem-wood density and RCD for the remaining plot-based and regenerating shrubland species <6-years old.

[3]Peltzer, D.A., & Payton, I.J. (2006). Analysis of carbon monitoring system data for indigenous forests and shrublands collected in 2002/03. Landcare Research Contract Report LC0506/099. 55 p.

Basic stem-wood density and DBH were positively correlated for regenerating *L. scoparium*, *Kunzea* spp., plot-based *Dacrydium cupressinum* and *Prumnopitys ferruginea* (Table 2) with DBH explaining 17–73% of the variation in density. Basic stem-wood and DBH were negatively correlated for *Dacrycarpus dacrydioides* (Table 2). There were no significant correlations between basic stem-wood density and DBH for the remaining plot-based and regenerating species.

Basic stem-wood density was not correlated with tree age for low-density plantings of *L. scoparium* (site 10) between ages 4- and 6-years and increased with increasing tree age (data not shown). Conversely, for naturally reverting stands of *L. scoparium*, *Kunzea* spp., *Coprosma grandiflora*, *Melicytus ramiflorus* and *Weinmannia racemosa*, basic stem-wood density values of ≥6-years-old trees were not significant.

Comparisons of mean basic wood densities by age-class

Basic stem-wood density of *L. scoparium* was greater than for the remainder of the plot-based species trialled for trees <6-years of age (Fig. 2a). Basic stem-wood density was as follows for the various species in this age group: *L. scoparium* > *Alectryon excelsus* > *Dacrycarpus dacrydioides* = *Podocarpus totara* = *Prumnopitys ferruginea* = *Dacrydium cupressinum* > *Agathis australis* = *Vitex lucens*.

For naturally regenerating stands between 6–10 and 11–15 years old, *Kunzea* spp. had greater basic stem-wood density than *Melicytus ramiflorus* (Fig. 2b). Basic stem-wood density of *Kunzea* spp. was also greater than *Coprosma grandiflora* and *Melicytus ramiflorus* in the 16–20 (Fig. 2b) and 21–25-year-old age class (Fig. 2c). There was no difference in basic stem-wood density between *Coprosma grandiflora* and *Melicytus ramiflorus* between 16–20 (Fig 2b) and 21–25-year-old age classes (Fig 2c).

In the age classes 26–30, 31–35, 36–40 (Fig. 2c), and 46-50, 51–70 years (Fig. 2d) there were no differences in basic stem-wood density between *Kunzea* spp. and *L. scoparium*. However, for the oldest of the age classes their respective densities were significantly greater ($P<0.05$) than for *Weinmannia racemosa* of the same age (Fig. 2d).

Irrespective of age, the basic stem-wood density values for both *Kunzea* spp. and *L. scoparium* were not significantly different from each other but were significantly greater than that for all other species for which age-specific data was available.

Comparisons of basic stem-wood density values with published data

Basic stem-wood densities for ≥6-year-old specimen trees of *L. scoparium*, *Kunzea* spp., *Melicytus ramiflorus*, *Coprosma grandiflora*, and *Weinmannia racemosa* derived from natural stands indicative of advanced succession toward indigenous forest, fall within the range of these published values (Fig. 3a).

Conversely, the mean basic stem-wood density values for trees <6-years old were either bordered on the lower limit of published means of older trees or significantly lower than published values (Fig. 3b).

TABLE 2: Linear regressions between stem-wood density and tree height (m), root collar diameter (RCD; mm), diameter at breast height (DBH; mm) and age (years) for 12 of New Zealand's indigenous species. Regressions for both *Kunzea* spp. and *L. scoparium* included data from collective sites. Values in bold were statistically significant (*P*<0.05).

Species	Location	No. trees	Site type*	Height		RCD		DBH		Age	
				r^2	*P*	r^2	*P*	r^2	*P*	r^2	*P*
Kunzea spp.	Turangi	22	RS	**0.120**	**<0.001**	**0.201**	**<0.001**	**0.067**	**0.001**	0.004	0.392
	Waimata	32	RS								
	Tolaga Bay	13	RS								
	Dunedin	11	RS								
	Waitakere	6	RS								
	Coatbridge	3	RS								
	Long Gully	5	RS								
	Riversdale	21	RS								
	Eyrewell	2	RS								
	Nikau Valley	56	RS								
Leptospermum scoparium	Turangi	24	RS	**0.209**	**0.003**	**0.179**	**0.006**	**0.166**	**0.010**	**0.134**	**0.002**
	Dunedin	2	RS								
Alectryon excelsus	Gisborne	13	PB	0.081	0.345	0.247	0.084	0.216	0.109		
Dacrycarpus dacrydioides	Gisborne	30	PB	**0.295**	**0.002**	**0.433**	**<0.001**	**0.402**	**<0.001**		
Podocarpus totara	Gisborne	9	PB	0.026	0.676	0.379	0.077	0.3	0.127		
Agathis australis	Gisborne	8	PB	0.145	0.352	0.081	0.495	0.023	0.721		
Dacrydium cupressinum	Gisborne	14	PB	0.006	0.8	0.109	0.249	**0.426**	**0.011**		
Prumnopitys ferruginea	Gisborne	7	PB	**0.579**	**0.047**	0.271	0.231	**0.732**	**0.014**		
Vitex lucens	Gisborne	8	PB	0.446	0.071	0.301	0.159	0.278	0.179		
Coprosma grandiflora	Wellington	10	RF	0.071	0.487	0.008	0.806	0.012	0.759	0.158	0.258
Melicytus ramiflorus	Wellington	30	RF	0.006	0.688	0.009	0.615	0	0.961	0.030	0.097
Weinmannia racemosa	Wellington	10	RF	0.183	0.218	0.127	0.311	0.176	0.227	0.002	0.912

*RS = regenerating shrubland, PB = plot-based growth trial, RF = regenerating forest

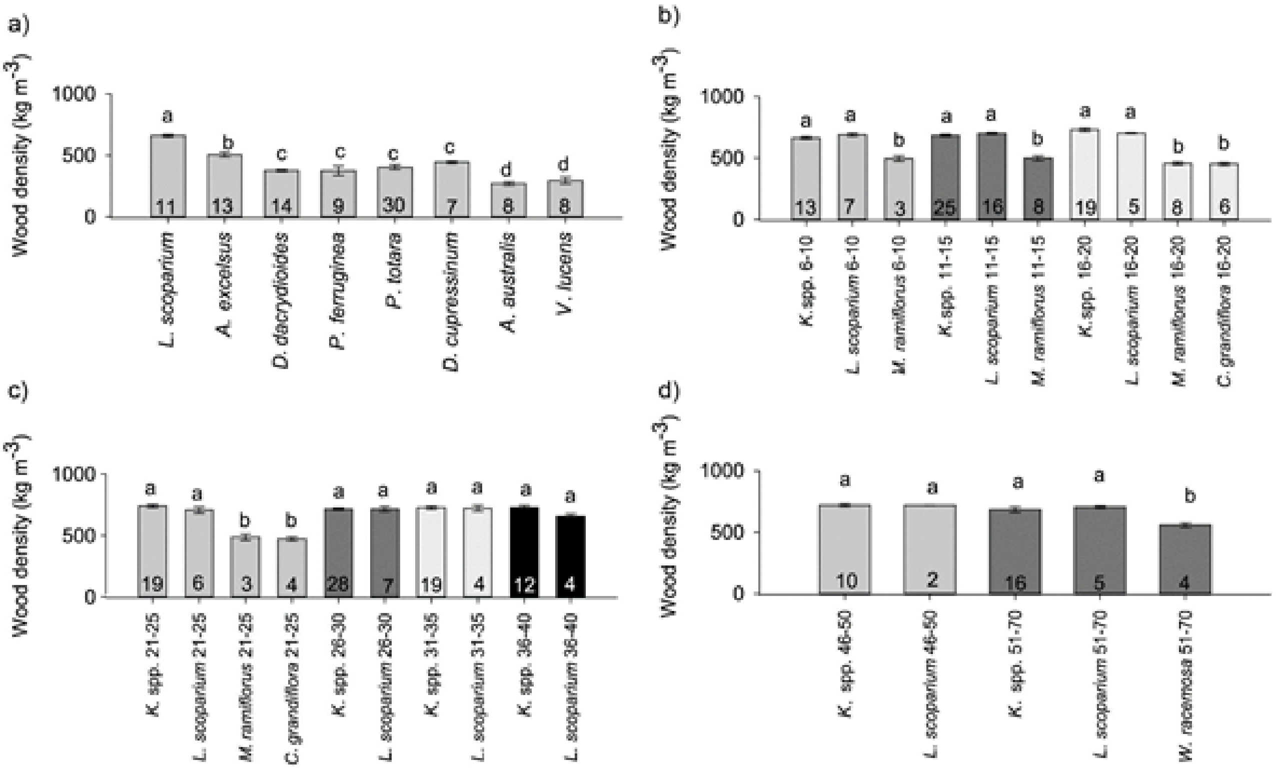

FIGURE 2: Stem-wood density values for: a) species <6-years old from plot-based growth trials; b) 6–10-year-old *Kunzea* spp. and *Leptospermum scoparium,* for 11–15-year-old *Kunzea* spp. and *Melicytus ramiflorus*, and for 16–20-year-old *Kunzea* spp., *Melicytus ramiflorus*, and *Coprosma grandiflora* older than 6-years collected from regenerating shrubland or forest; c) 21–25-year-old *Melicytus ramiflorus* and *Coprosma grandiflora*, and for 26–30-year-old, 31–35-year-old, and 36–40-year-old *Kunzea* spp. and *L. scoparium* collected from regenerating shrubland or forest ≥6-years old; and d) 46–50 and 51–70-year-old *Kunzea* spp.*, L. scoparium* and *Weinmannia racemosa* collected from ≥6-years-old regenerating shrubland or forest. Error bars represent the standard error of the mean. Sample numbers shown at base of each grey bar. Bars with different letters were significantly different (*P*<0.05).

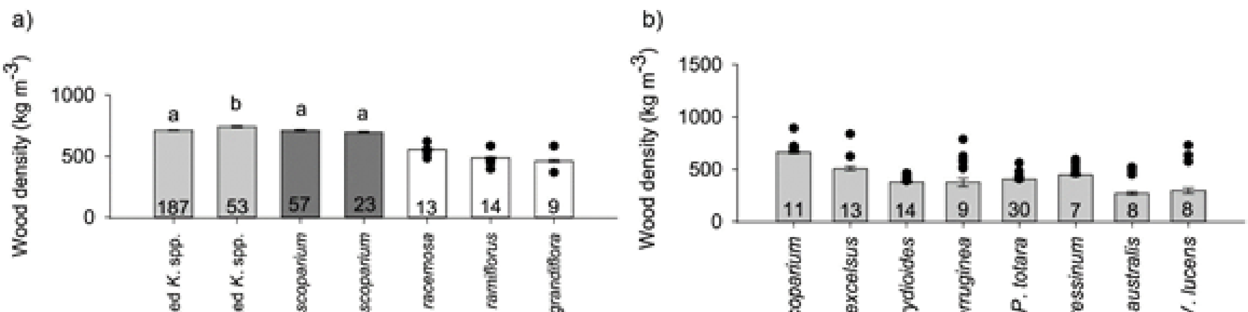

FIGURE 3: Comparison of: a) age-specific mean basic stem-wood density values for *Kunzea* spp. and *Leptospermum scoparium* ≥6-years old with densities sourced from published and unpublished literature. Density data for trees of known age was analysed separate to that for trees where age was not specified (see Table A2); and b) comparison of mean basic wood densities for trees <6-years old (grey bars) with mean densities of ≥6-year-old trees (dots) as sourced from published and unpublished literature (see Table A2). For *Melicytus ramiflorus*, *Coprosma grandiflora*, and *Weinmannia racemosa*, age-specific mean basic stem-wood density values (white bars in Fig. 3a) are compared with mean densities (dots) sourced from published and unpublished literature where age was not specified. Sample numbers shown at base of each bar. Error bars represent the standard error of the mean.

Geographic distribution in *Kunzea* spp. and *L. scoparium* basic stem-wood density

While there is considerable variation in mean basic stem-wood values within naturally regenerating stands of *Kunzea* spp. and *L. scoparium*, there is no supporting evidence that their density is significantly different between locations within either the North or South Island of New Zealand, between these islands, or between latitudes 35° to 46°S (Fig. 4). For all remaining species there was insufficient basic stem-wood density data to support a similar statistical analysis.

Discussion

Basic wood density is one of the largest sources of variation in estimates of biomass and in the calculation of carbon sequestration (Holdaway et al. 2014), yet these estimates are essential for New Zealand's international and national reporting of GHG budgets. To date, allometric functions have largely been based on limited stem-wood density data, and where species-specific and/or regional basic stem-wood density values are unavailable, congeneric values have been used instead, or, in their absence, the mean of all published values have been used (Peltzer & Payton unpublished data[3], Beets et al. unpublished data[1]). However, given that the earliest of the published values of basic stem wood density for merchantable timber trees were likely determined following the removal of the bark, a comparison with the means of all age-specific stem-wood densities, whether determined with the bark intact or after the removal of bark, might be considered invalid. Nonetheless, as has been shown in this paper, the basic stem-wood densities of ≥6-year-old trees comprising natural stands indicative of advanced succession toward indigenous forest fall well-within the range of the earlier published values. Furthermore, given the dearth of available data for many of the dominant and larger tree components of New Zealand's indigenous forests, the diversity of species, and the difficulty of accessing them in remote locations, where species-specific wood density values obtained for indigenous species harvested for timber exist, they serve as valuable reference points.

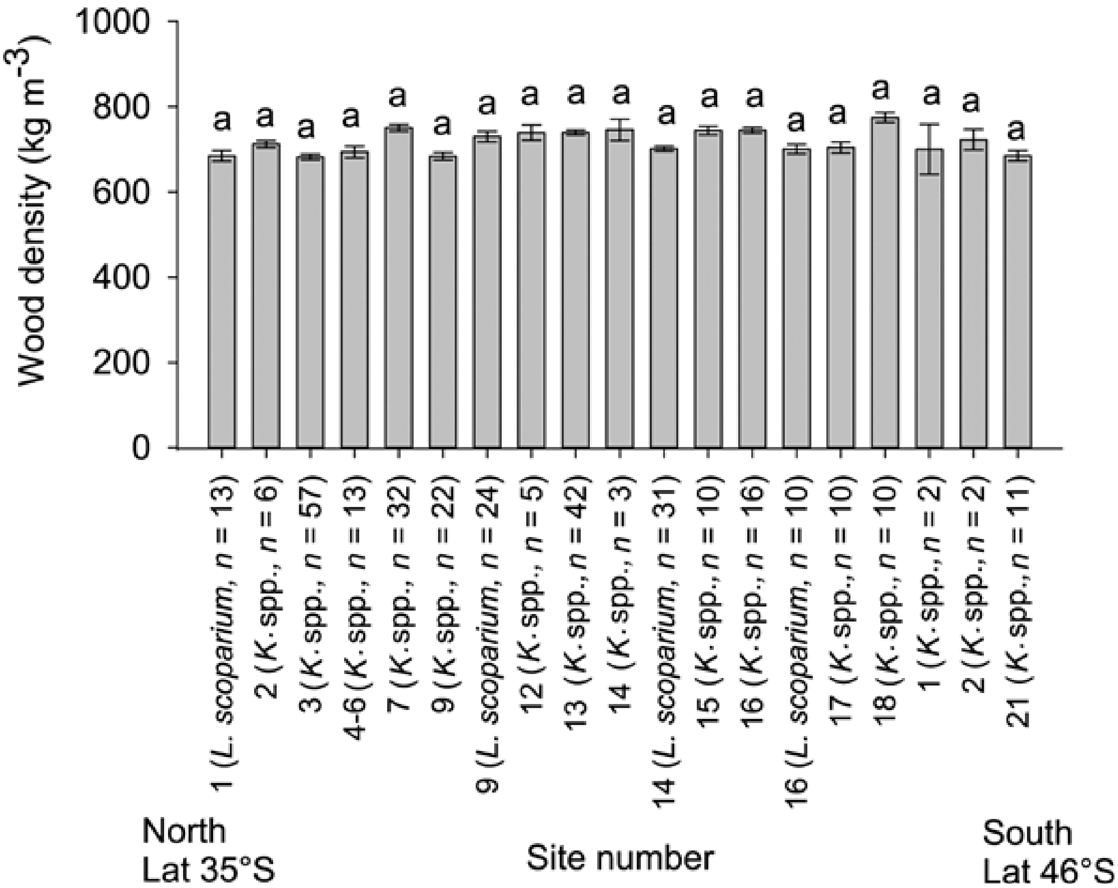

FIGURE 4: Mean basic stem-wood density values for *Kunzea* spp. (17 locations) and *Leptospermum scoparium* (4 locations) trees from naturally regenerating stands distributed throughout the North and South Islands between latitudes 35° and 46°S. Site locations are shown in Figure 1. Annotated site details are tabulated in Table 1 and presented in greater detail in Table A1. Error bars represent the standard error of the mean. Bars with different letters were significantly different (P<0.05).

At the younger end of the age spectrum, for species typically associated with the early phase of shrubland regeneration, tall statured shrubland classes, and mixed species forests, insufficient basic wood density data together with simple field measurements are a limitation to the development of appropriate allometric functions for improving estimates of biomass and carbon stocks. Furthermore, the use of different methods in the measurement of basic stem wood density (over bark versus under bark) has necessitated the development of equations that account for related variations in basic wood density in the calculation of tree biomass and changes in carbon stocks over time (Hall et al. unpublished data[2]). However, until additional basic stem-wood density data can be collected for a sufficiently diverse range of specimen trees comprising a wide range of indigenous shrubland, forest types, and ages, the continued use of the mean of all available basic stem-wood density values will likely give the best estimate of stem carbon stocks.

Although the basic stem-wood densities of *Kunzea* spp. and *L. scoparium* (both widely distributed shrubland species and a dominant component of regenerating forest on extensive areas of marginal hill country), are not significantly different from each other, they are both significantly higher than those of most of New Zealand's oldest indigenous forest and other shrubland species typically falling between 400 and 600 kg m^3 (Allen et al. 1992). Therefore, using functions based on the stem-wood density of either *Kunzea* spp. or *L. scoparium* to scale tree volume, as yield or growth, to stem biomass, and from stem biomass to total biomass for different mixed-species indigenous forest communities is likely to overestimate total biomass.

For *Kunzea* spp., while there is variation in intra-specific mean basic stem-wood density values at different sites, there is no evidence from our data that stem-wood density is significantly different between the 17 locations where this species occurs as naturally regenerating shrubland. Trends of increasing wood density values with decreased elevation (Lassen & Okkonen 1969) and increased temperature (Filipescu et al. 2014) have been reported for New Zealand-grown Douglas-fir (Kimberley et al. 2017), and for *P. radiata* basic wood density values show a gradual decrease from sea level to higher elevations, and from north to south (Clifton 1990, Palmer et al. 2013). For *Kunzea* spp., however, while the results support a correlation between decreasing basic wood densities from sea level to higher elevations, there remains little evidence in support of wood densities decreasing north to south.

Other environmental influences, including intolerance to salt (Esler & Astridge 1974), soil fertility (Cown & McConchie 1981), soil moisture retention and stress (Smale 1994), variations in genetics (de Lange 2014) and rainfall distribution, are also likely to affect growth strategies (Wardle 1969), tree form, and ultimately basic stem-wood density of many of New Zealand's indigenous shrubland and forest species. A site-by-site analysis of these factors was considered beyond the scope of this paper.

Mean basic stem-wood densities of trees <6-years old were either significantly lower, or at the lower end of published values (Fig. 3b), but that within ca. ≥6 years after establishment, basic stem-wood density values approach that of older trees, and differs little thereafter (Fig. 3a). We therefore concur with Beets et al. (unpublished data[1]) on the strength of this relationship. Differences in basic stem-wood density values between trees <6-years old and older are therefore likely to be primarily a function of their age. Deng et al. (2014) found that stem-wood density of *Pinus massoniana* stems was significantly influenced by tree age, relative heights, and social class, while Beets et al. (2012) confirmed that stem-wood density at each relative height in older trees (age unspecified) was significantly higher than that of younger trees.

Iida (2012) found that low stem-wood density was linked to the propensity of some species to select for vertical growth (tall and thin stemmed with narrow and shallow canopies) and may therefore underlie the interspecific trade-off between effective height gain and a persistent life in the understorey (Kohyama 1987, 1993; Kohyama & Hotta 1990). Furthermore, relationships between stem-wood density and tree height may be related to differences in stand density. For example, *L. scoparium* <6-years old in densely-stocked, naturally reverting stands are tall and thin-stemmed and contrast markedly with the shorter and thicker-stemmed trees that develop when planted at low densities (Marden et al. 2020). Perhaps, as has been shown in studies across a range of conifer species (Watt et al. 2011), the basic stem-wood density of *L. scoparium* would be expected to be lower in wider-spaced (planted) stands than in fully stocked stands that have reverted naturally. Unfortunately, insufficient wood density data for *L. scoparium* <6-years old from naturally reverting stands precluded such an analysis.

To reduce net greenhouse gas emissions, as required under the Kyoto Protocol (Ministry of the Environment 2010), a number of government-funded schemes (e.g. Afforestation Grant Schemes (Ministry for Primary Industries 2015a) and the Permanent Forest Sink Initiative (Ministry for Primary Industries 2015b) have been introduced to facilitate natural regeneration of shrubland, and the planting of new areas of forest (exotic and indigenous). Together with the recently announced government goal to plant one billion trees over the next 10 years (1 BT Programme) (Ministry for Primary Industries 2018), ca 1.45 million ha of steep, erosion-prone pastoral hill country considered marginal for long-term agriculture will be targeted for transitioning to a permanent indigenous shrubland or forest (Trotter et al. 2005). In such high-risk areas woody indigenous shrubland largely comprising *Kunzea* spp. and *L. scoparium* has in the past played a significant role in mitigating erosion (Marden & Rowan 1993; Ministry for Primary Industries 2015a, 2015b, 2016). Together with increasing interest in high UMF (unique mānuka factor) values associated with honey produced by *L. scoparium*, the establishment of low-density plantings averaging ca 825 to 1100 stems ha^{-1} (McPherson & Newstrom-

Lloyd 2018) is seen as an alternative and viable land management option for erosion prone steeplands (Ministry for Primary Industries 2015c).

Using linear regression analyses based on mean wood density values measured for *Leptospermum scoparium* <6-years old, new plantings at the recommended planting density, would by year 5 amass a forest carbon stock of 6.1 t CO^2 ha^{-1} (excluding coarse woody debris and fine litter on the forest floor) (Marden & Lambie 2016). Alternatively, a mixed planting of successional broadleaved and conifer species would within the same time frame potentially amass a carbon stock of ~3.8 t CO_2 ha^{-1} (Marden et al. 2018), while plantings consisting of a mix of early colonising seral species would amass a forest carbon stock of 8.8 t CO_2 ha^{-1} (unpublished). Thus, the establishment of early colonising seral species on marginal land would amass an additional ~1 t CO_2 ha^{-1} over and above the 7.8 t CO_2 ha^{-1} estimated for the 5-year period from the date of planting (Ministry for Primary Industries 2017). Conversely, the planting of mixed indigenous broadleaved and coniferous species at the same density would amass ~4 t CO_2 ha^{-1} less, and plantings of *Leptospermum scoparium* ~1.7 t CO_2 ha^{-1} less. By implication, to achieve a similar level of carbon stock for new plantings of broadleaved and conifer species within this time frame would require an increase in planting density to ~2000 stems ha^{-1} and for areas planted and managed for mānuka honey production, a planting density of 1200–1300 stems ha^{-1} would be required.

These estimates of carbon stocks are however based on only a few studies of indigenous species that comprise the many shrubland and forest communities present within New Zealand. With the pending conversion of extensive areas of former pastoral land to indigenous shrubland and forest through *passive* reversion, and by planting, therein lies an opportunity to validate and/or improve the accuracy of current estimates of biomass and carbon stocks during their early growth period, and for a wider range of species, by developing further allometric functions based on species-specific, basic stem-wood density values.

Conclusions

This study presents an analysis of a significant database of previously unpublished basic wood-density values collected for a range of New Zealand's indigenous shrubland and forest species of varying age, and from sites located throughout both North and South Islands. The findings indicate that for the most geographically widespread shrubland species, *Kunzea* spp., differences in local site factors may affect tree parameters including basic wood density to a greater extent than wide differences in latitude within the normal growing range of the species. The data do however support trends showing that basic wood density values increase with decreased elevation, and increased temperature and where local data are available its use would improve the accuracy of biomass estimates both locally and nationally. Insufficient site-specific information precludes further comment on other factors (e.g. soil fertility, plant spacing) that likely contribute to variability in basic stem-wood density values.

For each of the species <6-years old for which basic stem-wood densities were collected, their mean values were significantly lower, or at the lower end of published values for trees ≥6-years old after which basic stem-wood density values remain unchanged.

Age-specific basic stem-wood density data is scarce for shrubland communities dominated by mixed softwood species that comprise 90% of the national live tree biomass stock. Furthermore, as their stem-wood density is considerably lower than for hardwood species, additional stem-wood density data are needed for use in combination with species-abundance information from LUCAS plots to update allometric functions applicable to areas of naturally reverting shrubland and to areas of former pastoral land pending their conversion to indigenous shrubland.

As shown for the few indigenous species for which biomass and/or wood density data has been collected, at a planting density of 1000 stems ha^{-1}, early colonising seral species would within 5-years amass a higher carbon stock of 8.8 t CO_2 ha^{-1} than would plantings of *Leptospermum scoparium* ~6.1 t CO_2 ha^{-1} or a mixed-species planting of indigenous broadleaved and coniferous species ~3.8 t CO_2 ha^{-1}.

To account for the variability in densities between outer-wood (and bark) and inner-wood with tree height, estimates of the mean density of whole stems will require the collection of stem-wood data from discs at intervals along the stem, as opposed to just breast height or by coring.

List of abbreviations

DBH Diameter at Breast Height
BH Breast Height
1BT One billion Trees Programme
ETS Emission Trading Scheme
GHG Greenhouse Gas
LSD Least significant difference
RCD Root Collar Diameter
WSG Wood Specific Gravity

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MM was the primary author. SL compiled the data into spreadsheets and completed the statistical analyses. LB contributed data. All authors read and approved the manuscript.

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Availability of data and materials

Please contact the corresponding author for data requests.

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APPENDIX

TABLE A1: Location and physical characteristics of 21 sample sites throughout New Zealand.

Site 1: Tautoro. 8 km south of Kaikohe, Northland (173° 50′ 13 15 E, 35° 28′ 52 00 S). Regenerating *Leptospermum scoparium* (Table A4) stand on gently, southwest-facing slope 100-140m above sea level. Bedrock consists of greywacke argillites and sandstones (Geological Map of New Zealand, 1967). Soils are deeply weathered and classified as Altic Soils (Hewitt, 2010).

Site 2: Waitakere Range. Within the Waitakere Range (174° 35′ 14 42 E, 37° 00′ 10 17 S) stem-wood discs were collected from naturally reverting stands of well-established *Kunzea* spp. (Table A3) and *L. scoparium* (Table A4) of unknown age. At an elevation of ca. 40 m, slopes ranged between 0 and 35°. The geology comprises volcanic andesitic lava, conglomerates, and breccia of the Waitemata and Waitakere groups of early Miocene (late Otaian-middle Altonian) age. Soils comprise weathered volcanics consisting of yellow-brown granular clay grading to a compact yellow brown to brown subsoil (Hayward, 1983). The climate is relatively mild and moist with annual rainfall of ca 1250 mm increasing to over 2000 mm in the higher central parts at elevations of ca 460 m (New Zealand Meteorological Service, 1966).

Site 3: Nikau Valley. 8km south of Whakatane, Bay of Plenty (176° 58′ 23 85 E, 38° 01′ 25 27 S). Managed, dense, east-facing *Kunzea robusta* (Table A3) stands of all ages 40–100 m above sea level. Bedrock consists of undifferentiated greywacke (Geological Map of New Zealand, 1967). Pumice Soils consisting of Tarawera and Whakatane Ash overly bedrock on rolling hill country (Hewitt, 2010).

Sites 4–6: Tolaga Bay and site 7: Waimata Valley. Sites 2–4 are located approximately 8 km inland of Tolaga Bay (178˚ 12′ 19 29 E, 38˚ 20′42 58 S), and site 5 is located 15 km inland of Gisborne City (178° 03′ 13 66 E, 38˚ 28′ 33 84 S). Each site represents an even-canopied stand of naturally reverting *Kunzea robusta* (Table A3) at a different stage of development, the age of which was determined by the history of vegetation clearance, and verified by growth ring counts (Watson et al., 1994). The Tolaga Bay sites occur on slopes between 23° and 32°, have a NW (300°) to NE (60°) aspect, and are at elevations between ca 64 m and 160 m above sea level. The Waimata site is on a SW aspect at an elevation of 207 m. The underlying bedrock at these sites consists of Pliocene-age calcareous sandy siltstones with banded sandstones and thick tuffaceous horizons (Kingma, 1965). Soils are a stony colluvium varying from Orthic Recent Soils and their intergrades to Brown Soils (on well-drained sites) and Gley Soils (on poorly drained sites) typical of slopes being eroded or has received sediment mainly as a result of slope processes (Hewitt, 2010). The climate is warm temperate maritime, with moist summers and cool wet winters. Mean annual rainfall varies from about 700 mm at the coast to 2500 mm at higher elevations (New Zealand Meteorological Service, 1973). Lengthy periods of little or no rainfall are common during January to April (mid-summer to late autumn). This region has a history of extreme rainfall events (Kelliher et al., 1995), often associated with storms of tropical origin (e.g. Cyclone Bola in 1988).

Site 8: Gisborne. Five indigenous softwood (*Agathis australis, Prumnopitys ferruginea*, *Podocarpus totara*, *Dacrycarpus dacrydioides*, *Dacrydium cupressinum*) and two hardwood species (*Alectryon excelsus* and *Vitex lucens*) (Table A5) were established as a planting trial to establish their relative growth performance, above-and below-ground, over a 5-year period (Marden et al., 2018). The trial site was located on a low-lying (5 m above sea level), even-surfaced alluvial terrace adjacent to the Taraheru River, in Gisborne City (178° 00′ 16 02 E, 38° 38′ 44 82 S). The soil is a naturally fertile, free draining, Typic Sandy Brown Soil of the Te Hapara soil series (Hewitt, 2010) with no physical or chemical impediments. Temperatures over summer average 23° C and over winter 12° C and mean annual rainfall is ca 1200 mm (Hessell, 1980).

Site 9: Turangi. Stands of 25-, 35- and 55-year-old *Kunzea* spp. (Table A3) and *L. scoparium* (Table A4) were selected in Tongariro National Park near Turangi township in the central North Island (175° 47′ 11 53 E, 39° 09′ 19 20 S) at an elevation of 800 m, approaching the maximum elevation at which these species are found (Scott et al., 2000). Mean annual temperature is 11.1C°, and mean annual precipitation is ca 1610 mm. Soils derived from a series of rhyolitic and andesitic volcanic eruptions are classified as Podzolic Orthic Pumice soils of the Rangipo series (Hewitt, 2010).

Site 10: Lake Tutira. *L. scoparium* (Table A4) was planted at Lake Tutira (176° 54′ 10 44 E, 39° 14′ 00 44 S) in 2011 and 2012 at a spacing (3 m × 3 m, ca 1100 stems ha^{-1}) more typical of an exotic plantation forest. Nine permanent sample plots (20 m × 20 m) were established in 2015 (Marden & Lambie, 2015 & 2016). The terrain is 7e3 (Jessen et al., 1999) consisting of Pliocene-age mudstone, sandstone, and limestone subjected to extreme shallow landsliding during storm events. Slight tunnel gullying is also present. Slopes are predominantly west facing, between 21° and 35^0, and occur at an elevation of 200°–375 m. Soils are Typic Immature Pallic (Hewitt, 2010).

Site 11: Wainuiomata and Cannons Creek. This site consists of well-established indigenous hardwoods and lowland shrub communities dominated by mixed hardwood *Coprosma grandiflora, Weinmannia racemosa*, and *Melicytus ramiflorus* (Table A5) shrubs indicative of advanced succession progressing toward indigenous forest. Three plots were installed (174° 57′ 19 75 E, 41° 17′ 45 29 S) on slopes ranging between 17° and 28°, with a southwest aspect between 200° and 240°, and at an elevation of ca 117 m. The geology consists of complexly deformed alternating dark grey

TABLE A1 Continued...

argillite and greywacke sandstone, rare limestone and minor spilitic lava of Triassic age (Kingma, 1967). Soils are a stony colluvium derived from greywacke bedrock and vary from Orthic Recent Soils and their intergrades to Brown Soils (on well-drained sites) and Gley Soils (on poorly-drained sites) typical of slopes being eroded or has received sediment mainly as a result of slope processes (Hewitt, 2010).

Site 12: Long Gully. 6 km southwest of Wellington (174° 40´ 55 30 E, 41° 18´ 34 82 S). Regenerating wind shorn stands of *Kunzea amathicola* (Table A3) on south-facing slope 300-400 m above sea level. Bedrock consists of alternating argillite and greywacke sandstone with rare limestone and volcanics (Kingma, 1967). Soils are a stony colluvium derived from greywacke bedrock and vary from Orthic Recent Soils to Brown Soils and Gley Soils typical of slopes being eroded or has received sediment mainly as a result of slope processes (Hewitt, 2010).

Site 13: Riversdale. Near White Rock on the SE coast of Wairarapa (175° 25´ 53 49 E, 41° 30´ 57 74 S). Wide range of *Kunzea robusta* (Table A3) stands at different stages of development on mainly southwest-facing slopes 60–200m above sea level. Bedrock consists of greywacke-like dark grey muddy siltstone with minor conglomerates and spilitic lava (Kingma, 1967). Soils are a stony colluvium derived from greywacke bedrock and vary from Orthic Recent Soils to Brown Soils and Gley Soils typical of slopes being eroded or has received sediment mainly as a result of slope processes (Hewitt, 2010).

Site 14: Coatbridge. 12 km west of Renwick, Marlborough (173° 39´ 23 16 E, 41° 29´ 08 99 S) Dense regenerating *Kunzea* spp. (Table A3) and *L. scoparium* (Table A4) on moderate to steep south facing slopes 200–300m above sea level. Bedrock consists of metamorphosed sedimentary lithologies and volcanics (New Zealand Geological Survey, 1972). Soils are derived from greywacke bedrock and vary from Brown Soils to Orthic Recent and Gley Soils typical of slopes being eroded or has received sediment mainly as a result of slope processes (Hewitt, 2010).

Site 15: Long Spur. 9 km south of Tururumuri near the southeast coast of Wairarapa (175° 32´ 09´ 01 E, 41° 27´ 22 12 S). Dense regenerating stands of *Kunzea robusta* (Table A3) on slopes on a range of aspects 40–200 m above sea level. Bedrock consists of graded bedded, fine-grained, sandstone and mudstone, minor conglomerates and volcanics (Kingma, 1967). Soils are a stony colluvium derived from greywacke bedrock and vary from Orthic Recent Soils to Brown Soils and Gley Soils typical of slopes being eroded or has received sediment mainly as a result of slope processes (Hewitt, 2010).

Site 16: Peggioh. 10 km west of Ward (174° 01´ 13 67 E, 41° 51´ 31 57 S). Dense, regenerating *Kunzea robusta* (Table A3) and *L. scoparium* (Table A4) stands 200–300 m above sea level. on south-facing slopes. Bedrock consists of interbedded greywacke and argillite with minor volcanics, conglomerates, and rare limestone (New Zealand Geological Survey, 1972). Soils are a stony colluvium derived from greywacke bedrock and vary from Brown Soils to Orthic Recent and Gley Soils typical of slopes being eroded or has received sediment mainly as a result of slope processes (Hewitt, 2010).

Site 17: Shenandoah. 20 km south of Murchison, Buller (172° 15´ 05 30 E, 41° 53´ 36 00 S). Regenerating *Kunzea ericoides* (Table A3) stand on west-facing slope 200–300 m above sea level. Bedrock consists of mainly limestone and calcareous siltstone, local sandstone and coal measures (New Zealand Geological Survey, 1972). Soils are classed as Brown and Melanic Soils (Hewitt, 2010).

Site 18: Avoca Station 22 km south of Cass, Canterbury (171° 53´ 23 31E, 43° 11´ 49 51 S). Regenerating stands of *Kunzea serotina* (Table A3) on north-facing slopes 420–540 m above sea level. Bedrock consists of interbedded greywacke and argillite with minor volcanics, conglomerates, and rare limestone (New Zealand Geological Survey, 1972). Soils are a stony colluvium derived from greywacke bedrock and vary from Orthic Recent Soils to Brown Soils and Gley Soils typical of slopes being eroded or has received sediment mainly as a result of slope processes (Hewitt, 2010).

Site 19: Eyrewell. 10km south of Oxford and 6km north of Waimakariri River, Canterbury Plains (172° 11´ 41 76 E, 43° 22´ 59 35 S). Fenced remnant *Kunzea serotina* (Table A3) stand 200 m above sea level. Flat floodplain, well drained post-glacial alluvium and glacial outwash gravels (New Zealand Geological Survey, 1972). Soils are classed as Stony Brown Soils (Hewitt, 2010).

Site 20: Hinewai. 5km east of Akaroa, banks Peninsula above Otanerito Bay (173° 02´ 18 74 E, 43° 49´ 02 85 S). Wide range of *Kunzea robusta* (Table A3) stands at different stages of development on steep southeast-facing slopes 20–450 m above sea level. Bedrock consists of basalt tuff and associated intrusive rocks (New Zealand Geological Survey, 1972). Soils are classed as Melanic Soils (Hewitt, 2010).

Site 21: Dunedin. This study site consists of a ca 130 ha mosaic of 2–70 year old stands of *Kunzea robusta* (Table A3) and *L. scoparium* (Table A4) forest located on the western side of the Purakanui Inlet catchment (170° 36´ 37 14 E, 45° 45´ 11 19 S), 16 km north of Dunedin. Soils are described as brown granular loams and clays derived from loess, basalt and phonolite (Tomlinson & Leslie, 1978). Slopes are NE-E facing between 2° and 35°, and at 200–300 m elevation. Annual rainfall is about 680 mm (New Zealand Meteorological Service, 1984).

TABLE A2: Non-age specific basic mean wood density values for old growth indigenous forest and shrubland species

Tree species	Wood density (kg m^{-3})	Location/number/age	Reference
Leptospermum scoparium (mānuka)	695-714	Woodhill, CMS plot BB114	Payton (pers. comm.)
	906-1042		Kirk (1989)
	892	CMS plots, n=1573	Peltzer & Payton unpublished dataa
	720	Puketi Forest, Northland	Jager et al. (2014)
Kunzea spp. (kānuka)	671-720	Camp Creek, Woodhill	Payton (pers. comm.)
	757		Clifton (1990), Bier (1983)
	642	Akaroa, n=40, <50 years	Carswell et al. (2012)
	680	Auckland	Schwendenmann (2014)
	772	CMS plots, n=1708	Peltzer & Payton unpublished data[a]
Alectryon excelsus (titoki*)*	622	Woodhill	Payton (pers. comm.)
	837	CMS plots, n=4	Peltzer & Payton unpublished data[a]
	854		Bier & Britton (1999)
Dacrycarpus dacrydioides (kahikatea)	465	Gray County, n=5	Kirk (1889)
	410	Gray Country, 152-310 years	Entrican (1951)
	390		Hinds & Reid (1957) in Harris (1986)
	450		Clifton (1990)
	420	CMS plots, n=118	Peltzer & Payton unpublished data[a]
	440	Maungatautari (n=1)	Beets et al. unpublished data[b]
	389	Whirinaki (n=20)	Beets et al. unpublished data[b]
	410	Puketi Forest, Northland	Jager et al. (2014)
	429		Bier & Britton (1999)
Podocarpus totara (totara)	443	14-110 years	Steward (pers. comm.)
	559		Kirk (1889)
	430	Taupo County, n=5, 408-612 years	Entrican (1951)
	410		Hinds & Reid (1957) in Harris (1986)
	480	Taupo County	Clifton (1990)
	480	CMS plots, n=80	Peltzer & Payton unpublished data[a]
	383-407	Whirinaki, n-14	Beets et al. unpublished data[b]
	435		Bier & Britton (1999)
Agathis australis (kauri)	449	10-69 years	Steward (pers. comm.)
	489	126-240 years	Steward (pers. comm.)
	498-595		Kirk (1889)
	520	Waitamata county, n=5	Entrican (1951)
	480	Waitamata	Hinds and Reid (1957) in Harris (1986)
	520	CMS plots, n=1	Peltzer & Payton unpublished data[a]
	470	Puketi Forest, Northland	Jager et al. (2014)
	441	Taranaki, n=20	Beets et al. unpublished data[b]
	495		Bier & Britton (1999)

TABLE A2: continued...

Tree species	Wood density ($kg\ m^{-3}$)	Location/number/age	Reference
Dacrydium cupressinum (rimu)	575		Payton (pers. comm.)
	550-644		Kirk (1889)
	520	Raurimu, Kaitieke County, n=5, 330-443 years	Entrican (1951)
	490	Central North Island	Hinds & Reid (1957) in Harris (1986)
	560		Bier (1983)
	595		Clifton (1990)
	558	CMS plots, n=456	Peltzer & Payton unpublished data[a]
	461-466	Whirinaki, n=30	Beets et al. unpublished data[b]
	460	Puketi Forest, Northland	Jager et al. (2014)
	504		Bier & Britton (1999)
Prumnopitys ferruginea (miro)	787	Raurimu, Kaitieke County, n=5, 248-363 yrs	Kirk (1889)
	520	Kaitieke County	Entrican (1951)
	510		Hinds & Reid (1957) in Harris (1986)
	625		Clifton (1990)
	568	CMS plots, n=151	Peltzer & Payton unpublished data[a]
	592	Maungatautari, n=1	Beets et al. unpublished data[b]
	527-531	Whirinaki, n=26	Beets et al. unpublished data[b]
	510	Puketi Forest, Northland	Jager et al. (2014)
Vitex lucens (puriri)	573	Auckland	Dale (2013)
	633	CMS plots, n=8	Peltzer & Payton unpublished data[a]
	730	Puketi Forest, Northland	Jager et al. (2014)
Melicytus ramiflorus (mahoe)	396	Maungatautari, n=6	Beets et al. unpublished data[b]
	585	CMS plot, n=638	Peltzer & Payton unpublished data[a]
	445	Woodhill Forest	Payton (pers. comm.)
	464	CMS plot AU146	Payton (pers. comm.)
Weinmannia racemosa (kamahi)	484	Maungatautari, n=21	Beets et al. unpublished data[b]
	619	CMS plot, n=4175	Peltzer & Payton unpublished data[a]
	542	CMS plot AZ118	Payton (pers. comm.)
	520	CMS plot Q171	Payton (pers. comm.)
	553	CMS plot BF117	Payton (pers. comm.)
	572		Bier & Britton (1999)
Coprosma grandiflora (coprosma)	368	Maungatautari, n=1	Beets et al. unpublished data[b]
	583	CMS plot, n=208	Peltzer & Payton unpublished data[a]

* Note: Mean basic wood density values from Beets et al. unpublished data[b] are from breast height outer wood at 5–15 cm (measured from bark).

[b]Beets, P.N., Oliver, G.R, Kimberley., M.O, Pearce, S.H. (2008). Allometric functions for estimating above ground carbon in native forest trees, shrubs and ferns. Scion Report 12679 prepared for the Ministry for the Environment 63 p.

TABLE A3: Basic stem-wood densities, tree age, height, RCD and DBH of individual *Kunzea* spp. from areas of natural regeneration at: Riversdale (site 13), Turangi (site 9), Shenandoah (site 17), Eyrewell (site 19), Waimata (site 7), Long Gully (site 12), Hinewai (site 20), Tolaga Bay (sites 4-6), Dunedin (site 21), Waitakere (site 2), Avoca (site 18), Coatbridge (site 14), Peggioh (site 16), Long Spur (site 15), and Nikau Valley (site 3).

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
	53	9.5		16.0	707
	52	11.9		15.7	698
	24	5.9		7.4	706
	22	6.1		7.3	707
	22	4.9		7.0	691
	17	4.8		5.7	721
	22	4.4		6.0	792
	22	5.0		7.0	742
	31	5.9		9.0	710
	30	6.7		9.3	730
	21	5.7		7.8	742
	29	9.7		10.3	763
	43	8.2		11.6	717
	50	8.7		11.0	741
	31	5.8		8.7	737
	30	7.5		12.1	741
	31	6.9		8.9	749
	68	9.9		19.5	715
Riversdale	56	10.9		18.8	765
	45	9.6		19.2	732
	53	12.3		24.6	699
	60	12.2		20.4	772
	30	6.5		9.7	760
	29	6.6		9.3	713
	26	7.1		8.7	738
	8	2.3		1.0	687
	6	2.4		1.0	640
	32	8.2		11.2	698
	24	7.3		9.0	755
	25	8.6		10.3	725
	40	8.5		16.4	753
	41	9.1		16.2	727
	40	6.5		12.6	749
	43	10.9		23.3	759
				32.3	718
	23	4.3		5.0	796
	23	4.1		4.8	812
	20	4.4		5.1	802
	20	3.6		3.8	815
Riversdale	21	4.6		4.2	783
	70	8.8		23.3	756
					742
	53	6.6	53	43	650
	41	5.6	30	26	670
	89	101.4	113	98	650
	80	8.4	87	77	640
	76	9.1	68	58	710
	69	9.0	57	48	670
	105	12.0	186	141	680
	61	7.6	69.5	58	678
	67	9.4	100	83	765
	28	6.3	65	48	712
Turangi	34	5.4	42	37	682
	29	5.5	44	35	681
	35	7.1	97	80	711
	37	6.3	122	70	667
	63	6.6	43.5	43	622
	77	8.4	76	65	721
	27	4.0	38.5	38	658
	34	5.1	68	45	628
	28	7.0	29	26	665
	32	6.5	53	36	662
	42	9.1	82	73	748
	50	9.6	121	110	768
					661
					673
					691
					689
Shenandoah					743
					694
					676
					799
					700
					716
Eyrewell	42			11.0	759
	46			9.8	642

TABLE A3: continued

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
Waimata	15	6.5		110	710
	21	12.0		120	734
	16	10.7		113	698
	18	10.8		119	747
	20	12.0		141	777
	19	9.8		130	753
	16	9.5		142	721
	20	11.3		143	750
	18	10.2		141	806
	17	9.5		120	722
	19	8.3		108	655
	19	9.7		104	738
	16	11.0		134	805
	15	9.2		103	732
	31	9.5	136	107	704
	26	13.0	154	129	734
	23	11.5	120	108	729
	29	16.4	181	143	786
	31	16.4	187	158	828
	29	16.4	165	132	789
	30	13.3	147	111	647
	29	12.1	138	141	720
	31	13.3	151	119	774
	26	10.6	153	120	731
	26	11.9	155	142	743
	31	12.8	122	100	766
	37	11.4	117	94	86
	22	12.2	143	125	811
	24	12.4	108	96	722
	35	14.2	149	134	849
	29	13.7	98	91	771
	34	13.9	154	139	757
Long Gully	12				781
	15				762
	20				690
	22				760
	26				793
Hinewai				13.5	747
				6.5	699

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
Tolaga Bay	14	6.6	80	67	758
	13	5.7	74	61	674
	15	7.2	78	60	703
	21	7.2	100	93	790
	15	6.6	54	49	694
	6	5.7	60	50	686
	4	4.6	40	33	647
	6	6.2	60	47	652
	7	6.8	48	37	704
	8	7.4	67	57	730
	4	2.1	24	2.4	605
	3	1.9	15	1.5	660
	4	2.6	36	3.6	714
Dunedin	35	10.5	108	97	699
	45	10.5	119	101	702
	38	9.6	81	75	699
	43	11.4	150	130	730
	48	10.9	168	150	671
	29	8.6	101	84	681
	25	9.2	95	72	602
	16	7.5	44	35	619
	34	9.3	114	102	706
	27	7.5	98	76	722
	18	6.0	72	62	704
Waitakere	75	18.7	325	247	693
	59	14.7	222	177	724
	37	8.2	72	62	748
	35	8.7	1145	109	704
	42	9.1	120	97	700
	16	7.5	48	44	704
Avoca Station					748
					811
					737
					770
					834
					748
					742
					829
					778
					751

TABLE A3: continued

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
Coatbridge	15				758
	15				697
	12				782
Peggioh					764
					722
					765
					810
					711
					686
					713
					753
					735
					749
					778
					800
					779
					729
					731
					746
					744
					758
					689
					736
					764
					713
Long Spur					708
					753
					723
					768
					764
					744
					701
					783
					711
					786

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
	56	15.5		26.9	725
	43	12.6		14.3	711
	40	12.8		13.2	739
	47	11.4		13.4	734
	40	12.6		12.8	737
	39	11.6		12.1	736
	44	13.7		14.5	724
	51	11.5		20.1	673
	62	12.4		20.5	694
	13	3.7		2.7	603
	13	3.2		2.7	624
	11	3.7		2.5	662
	50	13.7		27.7	731
	26	7.8		15.5	677
	27	8.8		15.2	670
	44	12.5		15.9	696
	78	16.0		43.2	732
	46	12.5		14.2	735
Nikau Valley	48	12.6		15.5	765
	10	4.2		3.5	629
	10	3.5		4.6	687
	13	8.5		9.9	687
	14	8.2		10.0	687
	29	12.3		10.0	658
	25	11.5		9.2	592
	15	7.2		11.4	602
	31	9.6		8.8	683
	72	16.9		35.5	612
	11	3.4		2.6	608
	11	3.4		3.2	668
	9	3.5		2.6	626
	7	3.2		2.5	604
	70	14.0		31.0	703
	69	12.1		31.5	714
	70	12.6		29.5	690
	37	11.5		14.4	755
	44	13.0		15.5	673
	32	12.5		14.8	721

TABLE A3**:** continued

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
	46	11.9		20.8	709
	47	13.8		19.3	710
	42	5.8		6.0	701
	13	4.3		5.2	668
	11	1.2			661
	7	1.5			667
	9	2.3			637
	6	7.0		5.6	698
	12	6.8		5.9	682
Nikau Valley	13	7.0		6.3	653
	16	45		5.4	664
	12	4.5		5.0	629
	11	4.0		5.0	669
	40	8.2		10.5	581
	29	8.2		10.9	630
	30	8.7		10.7	706
	28	7.8		9.7	772
	36	10.9		10.4	757
	29	8.8		10.5	710

TABLE A4**:** Basic stem-wood densities, tree age, height, RCD and DBH of individual *Leptospermum scoparium* from areas of natural regeneration at Turangi (site 9), Dunedin (site 21), Coatbridge (site 14), Peggioh (site 16), Tautoro (site 1), and from planted stands at Lake Tutira (site 10)

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
Turangi	29	5.4	38	25	690
	32	5.9	38	28	770
	33	6.1	44	37	660
	39	6.4	42	33	870
	40	5.8	64	46	870
	27	5.5	31	25	720
	39	6.2	47	37	760
	47	5.6	45	37	720
	60	7.5	51	43	720
	21	4.9	36	31	721
	25	5.1	81	36	778
	26	6.3	90	52	756
	28	6.2	42	38	642
	29	5.6	55	37	682
	30	4.6	49	45	684
	31	4.0	54	40	710
	34	6.1	68	59	739
	40	6.7	36	29	672
	48	8.0	100	55	718
	51	6.7	49	44	667
	53	8.4	94	80	710
	55	7.6	96	72	712
	27	5.8	46	31	824
	68	7.8	73	59	716
Dunedin	10	4.0	34	26	665
	11	4.5	42	30	680
Lake Tutira	3	2.9	8	6	680
	3	2.1	10	6	690
	3	2.1	3	1	610
	3	2.2	3	3	650
	3	2.8	5	1	590
	3	2.5	5		700
	3	2.0	6	5	650
	4	1.8	5	4	660
	4	2.3	7	4	680
	6	4.2	15	33	697
	6	4.8	96	42	681
	6	2.9	36	7	634
	6	2.3	33	6	724

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
Coatbridge	15				709
	11				710
	9				723
	8				684
	10				715
	14				719
	11				690
	14				743
	11				682
	14				742
	13				696
	13				734
	14				742
	10				624
	16				692
	14				707
	13				694
	13				637
	14				686
	8				689
	18				704
	19				718
	20				700
	11				680
	16				744
	10				735
	23				718
	23				744
	23				611
	23				666
	17				704

TABLE A4**:** continued

Location	Age (y)	Ht (m)	RCD (mm)	DBH (mm)	Wood Density (kg m^{-3})
					724
					756
					645
					669
					666
					696
					684
					705
					732
					727
					656
Peggioh					730
					662
					679
					724
					733
					729
					607
					610
					739
					689
					683
					660
					656
					780
					662
					679
					724
					733
Tautoro					729
					607
					610
					739
					689
					683
					660

TABLE A5: Basic stem-wood densities, age, height, Root collar diameter (RCD), and Diameter at breast height (DBH) of individual hardwood species from areas of natural regeneration at Wainuiomata (site 11), and hardwood and softwood species from plot trials based at Gisborne (site 8)

Species	Location	Age (y)	Height (m)	RCD (mm)	DBH (mm)	Wood density (kg m^{-3})
Melicytus ramiflorus	Wainuiomata	12	3.7	64	34	541
Melicytus ramiflorus	Wainuiomata	14	4.7	67	55	571
Melicytus ramiflorus	Wainuiomata	18	5.3	114	68	446
Melicytus ramiflorus	Wainuiomata	12	5.3	101	47	484
Melicytus ramiflorus	Wainuiomata	10	3.9	41	28	536
Melicytus ramiflorus	Wainuiomata	13	3.6	56	37	556
Melicytus ramiflorus	Wainuiomata	16	7.2	66	62	423
Melicytus ramiflorus	Wainuiomata	18	7.0	125	106	453
Melicytus ramiflorus	Wainuiomata	11	3.3	39	24	480
Melicytus ramiflorus	Wainuiomata	9	2.9	39	26	490
Melicytus ramiflorus	Wainuiomata	18	6.5	125	51.5	529
Melicytus ramiflorus	Wainuiomata	25	5.4	103	65	533
Melicytus ramiflorus	Wainuiomata	58	9.1	350	175	496
Melicytus ramiflorus	Wainuiomata	51	8.1	258	150	476
Melicytus ramiflorus	Wainuiomata	37	8.8	154	115	513
Melicytus ramiflorus	Wainuiomata	35	7.1	133	92	509
Melicytus ramiflorus	Wainuiomata	36	7.1	178	128	495
Melicytus ramiflorus	Wainuiomata	27	6.5	198	128	519
Melicytus ramiflorus	Wainuiomata	41	7.5	135	96	521
Melicytus ramiflorus	Wainuiomata	23	6.1	137	90	480
Melicytus ramiflorus	Wainuiomata	15	6.4	84	54	429
Melicytus ramiflorus	Wainuiomata	19	5.4	143	82	467
Melicytus ramiflorus	Wainuiomata	19	1.7	92	69	474
Melicytus ramiflorus	Wainuiomata	14	4.5	117	47	430
Melicytus ramiflorus	Wainuiomata	25	5.1	154	102	444
Melicytus ramiflorus	Wainuiomata	17	—	165	65	405
Melicytus ramiflorus	Wainuiomata	17	5.0	130	64	465
Melicytus ramiflorus	Wainuiomata	5	—	47	11	457
Melicytus ramiflorus	Wainuiomata	9	4.7	77	31	464
Melicytus ramiflorus	Wainuiomata	15	4.2	70	45	495
Coprosma grandiflora	Wainuiomata	20	—	128	83	476
Coprosma grandiflora	Wainuiomata	21	6.1	130	88	433
Coprosma grandiflora	Wainuiomata	23	6.1	121	61	460
Coprosma grandiflora	Wainuiomata	17	7.2	106	40	493
Coprosma grandiflora	Wainuiomata	23	6.5	107	68	485
Coprosma grandiflora	Wainuiomata	20	6.0	124	55	465
Coprosma grandiflora	Wainuiomata	17	6.8	109	57	442
Coprosma grandiflora	Wainuiomata	23	5.8	71	53	512
Coprosma grandiflora	Wainuiomata	19	4.0	45	27	426
Coprosma grandiflora	Wainuiomata	18	6.6	92	71	412

TABLE A5: continued

Species	Location	Age (y)	Height (m)	RCD (mm)	DBH (mm)	Wood density (kg m^{-3})
Weinmannia racemosa	Wainuiomata	44	6.9	152	115	544
Weinmannia racemosa	Wainuiomata	38	7.6	120	97	576
Weinmannia racemosa	Wainuiomata	26	6.2	89	67	573
Weinmannia racemosa	Wainuiomata	69	10.2	220	143	543
Weinmannia racemosa	Wainuiomata	47	10.3	160	113	551
Weinmannia racemosa	Wainuiomata	30	7.7	107	80	548
Weinmannia racemosa	Wainuiomata	61	6.8	150	105	614
Weinmannia racemosa	Wainuiomata	51	8.9	215	108	541
Weinmannia racemosa	Wainuiomata	63	10.2	158	128	538
Weinmannia racemosa	Wainuiomata	46	7.7	159	120	509
Alectryon excelsus	Gisborne	5	2.4	34	4	391
Alectryon excelsus	Gisborne	5	2.4	34	13	426
Alectryon excelsus	Gisborne	5	1.9	36	6	429
Alectryon excelsus	Gisborne	5	2.5	50	18	464
Alectryon excelsus	Gisborne	5	2.2	44	9	533
Alectryon excelsus	Gisborne	5	2.2	44	10	478
Alectryon excelsus	Gisborne	5	2.2	43	15	590
Alectryon excelsus	Gisborne	5	2.5	36	11	556
Alectryon excelsus	Gisborne	5	2.5	36	12	467
Alectryon excelsus	Gisborne	5	2.0	28	7	500
Alectryon excelsus	Gisborne	5	2.0	28	6	529
Alectryon excelsus	Gisborne	5	2.7	52	17	618
Alectryon excelsus	Gisborne	5	2.7	52	13	605
Dacrycarpus dacrydioides	Gisborne	4	2.3	36	7	385
Dacrycarpus dacrydioides	Gisborne	4	2.3	36	8	360
Dacrycarpus dacrydioides	Gisborne	4	2.8	39	11	386
Dacrycarpus dacrydioides	Gisborne	4	2.8	39	14	413
Dacrycarpus dacrydioides	Gisborne	4	2.3	32	10	385
Dacrycarpus dacrydioides	Gisborne	4	1.9	25	4	375
Dacrycarpus dacrydioides	Gisborne	4	1.9	25	5	444
Dacrycarpus dacrydioides	Gisborne	4	2.4	31	9	394
Dacrycarpus dacrydioides	Gisborne	4	1.9	34	3	400
Dacrycarpus dacrydioides	Gisborne	4	1.9	34	5	417
Dacrycarpus dacrydioides	Gisborne	4	2.9	42	16	382
Dacrycarpus dacrydioides	Gisborne	4	2.1	34	6	417
Dacrycarpus dacrydioides	Gisborne	4	2.1	23	7	389
Dacrycarpus dacrydioides	Gisborne	4	2.7	43	13	432
Dacrycarpus dacrydioides	Gisborne	4	2.2	30	9	450
Dacrycarpus dacrydioides	Gisborne	4	2.2	30	6	444
Dacrycarpus dacrydioides	Gisborne	5	3.4	63	27	331
Dacrycarpus dacrydioides	Gisborne	5	3.0	57	22	362

TABLE A5: continued

Species	Location	Age (y)	Height (m)	RCD (mm)	DBH (mm)	Wood density (kg m^{-3})
Dacrycarpus dacrydioides	Gisborne	5	3.0	57	13	376
Dacrycarpus dacrydioides	Gisborne	5	3.1	48	18	328
Dacrycarpus dacrydioides	Gisborne	5	3.1	49	21	338
Dacrycarpus dacrydioides	Gisborne	5	1.6	47	12	375
Dacrycarpus dacrydioides	Gisborne	5	2.4	43	13	340
Dacrycarpus dacrydioides	Gisborne	5	2.9	47	15	338
Dacrycarpus dacrydioides	Gisborne	5	2.9	47	13	317
Dacrycarpus dacrydioides	Gisborne	5	2.9	47	11	366
Dacrycarpus dacrydioides	Gisborne	5	2.7	45	17	365
Dacrycarpus dacrydioides	Gisborne	5	2.6	54	18	328
Dacrycarpus dacrydioides	Gisborne	5	2.6	54	16	329
Dacrycarpus dacrydioides	Gisborne	5	2.7	32	13	361
Podocarpus totara	Gisborne	5	2.2	43	23	359
Podocarpus totara	Gisborne	5	3.0	57	27	397
Podocarpus totara	Gisborne	5	3.3	60	24	362
Podocarpus totara	Gisborne	5	3.2	64	33	345
Podocarpus totara	Gisborne	5	3.0	50	16	375
Podocarpus totara	Gisborne	5	2.6	50	18	383
Podocarpus totara	Gisborne	5	2.4	49	17	452
Podocarpus totara	Gisborne	5	2.8	41	16	526
Podocarpus totara	Gisborne	5	3.2	49	24	436
Agathis australis	Gisborne	5	1.5	24	7	318
Agathis australis	Gisborne	5	1.5	28	9	286
Agathis australis	Gisborne	5	1.6	21	8	294
Agathis australis	Gisborne	5	1.5	19	5	250
Agathis australis	Gisborne	5	1.7	20	13	210
Agathis australis	Gisborne	5	1.9	25	10	220
Agathis australis	Gisborne	5	1.6	26	10	268
Agathis australis	Gisborne	5	1.8	24	18	326
Dacrydium cupressinum	Gisborne	5	2.3	34	8	484
Dacrydium cupressinum	Gisborne	5	2.2	36	10	463
Dacrydium cupressinum	Gisborne	5	2.2	36	8	484
Dacrydium cupressinum	Gisborne	5	2.0	40	9	417
Dacrydium cupressinum	Gisborne	5	2.0	40	6	385
Dacrydium cupressinum	Gisborne	5	1.5	34	11	482
Dacrydium cupressinum	Gisborne	5	2.3	41	12	471
Dacrydium cupressinum	Gisborne	5	2.5	44	13	483
Dacrydium cupressinum	Gisborne	5	2.4	38	6	385
Dacrydium cupressinum	Gisborne	5	2.4	38	13	462
Dacrydium cupressinum	Gisborne	5	1.9	39	8	435
Dacrydium cupressinum	Gisborne	5	2.2	30	11	455

TABLE A5: continued

Species	Location	Age (y)	Height (m)	RCD (mm)	DBH (mm)	Wood density (kg m^{-3})
Dacrydium cupressinum	Gisborne	5	2.1	42	10	424
Dacrydium cupressinum	Gisborne	5	2.1	42	8	414
Prumnopitys ferruginea	Gisborne	5	1.5	11	2	333
Prumnopitys ferruginea	Gisborne	5	1.6	30	5	429
Prumnopitys ferruginea	Gisborne	5	1.7	17	3	286
Prumnopitys ferruginea	Gisborne	5	1.5	25	3	250
Prumnopitys ferruginea	Gisborne	5	1.9	28	6	500
Prumnopitys ferrugínea	Gisborne	5	1.5	15	2	333
Prumnopitys ferrugínea	Gisborne	5	1.9	24	7	500
Vitex lucens	Gisborne	4	1.9	44	8	302
Vitex lucens	Gisborne	4	1.6	45	5	145
Vitex lucens	Gisborne	5	1.8	95	8	227
Vitex lucens	Gisborne	5	2.2	95	13	354
Vitex lucens	Gisborne	5	2.2	95	10	340
Vitex lucens	Gisborne	5	2.2	95	13	324
Vitex lucens	Gisborne	5	3.3	82	34	335
Vitex lucens	Gisborne	5	3.2	84	40	348