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

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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.
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).

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), and for species specific 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).

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 CO₂ 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., Wisser, 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.
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*, *Prumnopitys 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 (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, Weimannia 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 seratina* | 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 seratina* | 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 data2, Peltzer & Payton unpublished data3, Beets et al. 2012 and unpublished data).

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.

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   |
|--------------------------|--------------|-----------|------------|--------|-------|-------|-------|
| *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 | 0.190 |       |       |
| *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 data², Beets et al. unpublished data¹). 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). 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. 26 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) 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 understory (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 coniferous species would within the same time frame potentially amass a carbon stock of $\sim$3.8 t CO$_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 $\sim$1 t CO$_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 $\sim$4 t CO$_2$ ha$^{-1}$ less, and plantings of Leptospermum scoparium $\sim$1.7 t CO$_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 $\sim$2000 stems ha$^{-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 $\sim$6.1 t CO$_2$ ha$^{-1}$ or a mixed-species planting of indigenous broadleaved and coniferous species $\sim$3.8 t CO$_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

| Abbreviation | Description |
|--------------|-------------|
| 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.

References
Allen, R.B., Partridge, T.R., Lee, W.G., Efford, M. (1992). Ecology of Kunzea ericoides (A. Rich.) J. Thompson (kānuka) in east Otago, New Zealand. New Zealand Journal of Botany, 30, 135-149. https://doi.org/10.1080/0028825X.1992.10412894

Beets, P.N., Kimberley, M.O., Oliver, G.R., Pearce, S.H., Graham, J.D., Brandon, A. (2012). Allometric equations for estimating carbon stocks in natural forest in New Zealand. Forests, 3, 818-839. https://doi.org/10.3390/f3030818

Beets, P.N., Kimberley, M.O., Paul, T.S.H., Oliver, G.R., Pearce, S.H., Buswell, J.M. (2014). The inventory of carbon stocks in New Zealand’s post-1989 natural forest for reporting under the Kyoto Protocol. Forests, 5(9), 2230-2252. https://doi.org/10.3390/f5092230

Bier, H. (1983). The strength properties of small clear specimens of New Zealand-grown timber. Forest Research Institute Bulletin 41. Rotorua, New Zealand: New Zealand Forest Research Institute/New Zealand Forest Service, 29 p.

Bier, H. & R.A.J. Britton (1999). Strength properties of small clear specimens of New Zealand-grown timbers. [Forest Research Institute Bulletin 41 (revised)]. Rotorua, New Zealand: New Zealand Forest Research Institute/New Zealand Forest Service, 27 p.

Carswell, F.E., Burrows, L.E., Hall, G.M.J., Mason, N.W.H., Allen, R.B. (2012). Carbon and plant diversity gain during 200 years of woody succession in lowland New Zealand. New Zealand Journal of Ecology, 36(2), 191-202.

Chave, J., Condit, R., Aguilar, S., Hernandez, A., Lao, S., Perez, R. (2004). Error propagation and scaling for tropical forest biomass estimates. Philosophical Transactions of the Royal Society of London Series B 359: 409-420. https://doi.org/10.1098/rstb.2003.1425

Chave, J. (2005). Measuring wood density for tropical forest trees. A field manual. 7 p. http://www.rainfor.net/upload/ManualsEnglish/wood_density_english%5B1%5D.pdf

Clifton, N.C. (1990). New Zealand timbers exotic and indigenous. The Complete Guide. Wellington, New Zealand: Government Printing Office. 170 p.

Cornelissen, J.H.C., Lavelle, S., Garnier, E., Díaz, S., Buchmann, N., Gurrich, D.E., Reich, PB., ter Steege, H., Morgan, H.D., van der Heijden, M.G.A., Pausas, J.G., Poorter, H. (2004). A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. Australian Journal of Botany, 51, 335-380. https://doi.org/10.1071/BT02124

Cown, D.J., & McConchie, D.L. (1981). Effects of thinning and fertiliser application on wood properties of Pinus radiata. New Zealand Journal of Forestry Science, 11, 79-91.

Dale, M.J. (2013). Evaluation of methods for quantifying carbon storage of urban trees in New Zealand. Auckland, New Zealand: University of Auckland. http://itreetools.org/documents/36/Evaluation_of_Methods_for_Quantifying_Carbon_Storage_of_Urban_Trees_in_New_Zealand_Dale2013.pdf

de Lange, P.J. (2014). A revision of the New Zealand Kunzea ericoides (Myrtaceae) complex. PhytoKeys, 40, 1-185. https://doi.org/10.3897/phytokeys.40.7973

Deng, X., Zhang, L., Lei, P., Xiang, W., Yan, W. (2014). Variations of wood basic density with tree age and social classes in the axial direction within Pinus massoniana stems in Southern China. Annals of Forest Science, 71, 505-516. https://doi.org/10.1007/s13595-013-0356-y

Entrican, A.R., Ward, W.C., Reid, JS. (1951). The physical and mechanical properties of the principal indigenous woods of New Zealand. Wellington: New Zealand Forest Service, Government Printer; 83 p.

Esler, A.E., Astridge, S.J. (1974). Teatree (Leptospermum) communities of the Waitakere Range, Auckland, New Zealand. New Zealand Journal of Botany, 12, 485-501. https://doi.org/10.1080/0028825X.1974.10428635
Filipescu, C.N., Lowell, E.C., Koppenaal, R., Mitchell, A.K. (2014). Modeling regional and climatic variation in wood density and ring width in intensively managed Douglas-fir. Canadian Journal of Forestry Research, 44, 3, 48-53. https://doi.org/10.1139/cjfr-2013-0275

Geological Map of New Zealand (1967). Scale 1:2 000 000. Wellington, New Zealand: New Zealand Geological Survey/Department of Scientific and Industrial Research.

Harris, J.M. (1986). Wood properties of important New Zealand commercial tree species. In H. Levack (Ed.), Forestry handbook. (pp. 112-114). Wellington, New Zealand: New Zealand Institute of Foresters (Inc).

Hayward, B.W. (1983). Sheet Q 11 Waitakere. Geological Map of New Zealand 1:50 000. Map (1 sheet) and notes (28 p). Wellington, New Zealand: New Zealand Department of Scientific and Industrial Research.

Hessell, J.W.D. (1980). The climate and weather of the Gisborne region. New Zealand Meteorological Service [Miscellaneous Publication 115(8)]. Wellington, New Zealand: Government Printer.

Hewitt, A.E. (2010). New Zealand Soil Classification. Landcare Research Science Series No. 1 (3rd ed.). Lincoln, New Zealand: Manaaki Whenua Press

Hinds, H.V., Reid, J.S. (1957). Forest trees and timbers of New Zealand. [New Zealand Forest Service Bulletin, 12]. 221 p. https://cdm20044.contentdm.oclc.org/digital_api/collection/p20044coll6/id/421/download

Holdaway, R.J., McNeill, S.J., Mason, N.W., Carswell, F.E. (2014). Propagating uncertainty in plot-based estimates of forest carbon stock and carbon stock change. Ecosystems, 17, 627-640. https://doi.org/10.1007/s10021-014-9749-5

Iida, Y., Poorter, L., Sterck, F.J., Kassim, A.R., Kubo, T., Potts, M.D., Kohyama, T.S. (2012). Wood density explains architectural differentiation across 145 co-occurring tropical tree species. Functional Ecology, 26, 274-282. https://doi.org/10.1111/j.1365-2435.2011.01921.x

Jessen, M.R., Crippen, T.F., Page, M.J., Rijkse, M.C., Harmsworth, G.R., McLeod, M. (1999). Land Use Capability classification of the Gisborne-East Coast region: A report to accompany the Second Edition New Zealand Resource Inventory. [Landcare Research Science Series 21] Lincoln, New Zealand: Manaaki Whenua Press.

Kelliher, F.M., Marden, M., Watson, A.J., Arulchelvam, I.M. (1995). Estimating the risk of landsliding using historical extreme river flood data (note). Journal of Hydrology (NZ), 33(2), 123-129.

Kimberley, M.O., McKinley, R.B., Cown, D.J., Moore, J.R. (2017). Modelling the variation in wood density of New Zealand-grown Douglas-fir. New Zealand Journal of Forestry Science, 47: 15. https://doi.org/10.1186/s40490-017-0096-0

Kingma, J.T. (1965). Geological Map of New Zealand 1:250 000 Sheet 6, East Cape (1st edition). Wellington, New Zealand: Department of Scientific and Industrial Research.

Kingma, J.T. (1967). Geological Map of New Zealand 1:250 000 Sheet 12, Wellington (1st edition). Wellington, New Zealand: Department of Scientific and Industrial Research.

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

Kohyama, T. (1987). Significance of architecture and allometry in saplings. Functional Ecology, 1, 399-404 https://doi.org/10.2307/2389797

Kohyama, T. (1993). Size-structured tree populations in gap-dynamic forest - the forest architecture hypothesis for the stable coexistence of species. Journal of Ecology, 81, 131-143. https://doi.org/10.2307/2261230

Kohyama, T. & Hotta, M. (1990). Significance of allometry in tropical saplings. Functional Ecology, 4, 515-521. https://doi.org/10.2307/2389319

Lassen, L.E., & Okkonen, E.A. (1969). Effect of rainfall and elevation on specific gravity of coast Douglas-fir. Wood and Fiber Science, 1, 227-235.

Marden, M., & Lambie, S. (2015). Plot-based growth performance of space-planted mānuka (Leptospermum scoparium) on marginal land, and vulnerability to erosion. [Ministry for Primary Industries Technical Report No: 2015/19] https://eastcoastmanuka.files.wordpress.com/2015/08/lcr-final-report-on-manuka-trials-on-erodible-bill-country.pdf

Marden, M., & Lambie, S. (2016). Plot-based growth performance of space-planted mānuka (Leptospermum scoparium) on marginal land, and vulnerability to erosion. [Ministry for Primary Industries Technical Report No: 2016/20] https://www.mpi.govt.nz/dmsdocument/13915/direct

Marden, M., Lambie, S., Phillips, C. (2018). Biomass and root attributes of eight of New Zealand’s most common indigenous evergreen conifer and broadleaved forest species during the first 5 years of establishment. New Zealand Journal of Forestry Science, 48: 9. https://doi.org/10.1186/s40490-018-0113-y

Marden, M., Lambie, S., Phillips, C. (2020). Potential effectiveness of low-density plantings of mānuka (Leptospermum scoparium) as an erosion mitigation strategy in steeplands, northern Hawke’s Bay, New Zealand New Zealand Journal of Forestry Science, 50: 10. https://doi.org/10.33494/nzjfs502020x82x
Marden, M., Rowan, D. (1993). Protective value of vegetation on Tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science*, 23(3), 255-263.

McPherson, A., & Newstrom-Lloyd, L. (2018). Handbook for manuka plantations and farms: profitable and sustainable manuka honey harvesting. 34 p. Ministry for Primary Industries, Wellington, New Zealand. [www.treesforbeesnz.org](http://www.treesforbeesnz.org)

Ministry for Primary Industries (2015a). A guide to the Afforestation Grant Scheme. Wellington: Ministry for Primary Industries [http://www.mpi.govt.nz/funding-and-programmes/forestry/afforestation-grant-scheme/](http://www.mpi.govt.nz/funding-and-programmes/forestry/afforestation-grant-scheme/) Accessed 21 May 2017.

Ministry for Primary Industries (2015b). A guide to the Permanent Forest Sink Initiative. Wellington: Ministry for Primary Industries [http://www.mpi.govt.nz/funding-and-programmes/forestry/permanent-forest-sink-initiative/afforestation](http://www.mpi.govt.nz/funding-and-programmes/forestry/permanent-forest-sink-initiative/afforestation) Accessed 2 Aug 2016.

Ministry for Primary Industries. (2015c). High performance mānuka plantations. [http://www.mpi.govt.nz/funding-and-programmes/primary-growth-partnership/primary-growth-partnership-programmes/high-performance-manuka-plantations/](http://www.mpi.govt.nz/funding-and-programmes/primary-growth-partnership/primary-growth-partnership-programmes/high-performance-manuka-plantations/) Accessed 10 June 2015.

Ministry for Primary Industries (2016). A guide to the Erosion Control Funding Programme (East Coast). Wellington: Ministry for Primary Industries [http://www.mpi.govt.nz/funding-and-programmes/forestry/erosion-control-funding-programme/](http://www.mpi.govt.nz/funding-and-programmes/forestry/erosion-control-funding-programme/) Accessed 2 Aug 2016.

Ministry for Primary Industries. (2017). A guide to carbon look-up tables for forestry in the Emissions Trading Scheme. Wellington: Ministry for Primary Industries [http://www.mpi.govt.nz/growing-and-producing/forestry/forestry-in-the-emissions-trading-scheme/emissions-returns/](http://www.mpi.govt.nz/growing-and-producing/forestry/forestry-in-the-emissions-trading-scheme/emissions-returns/) Accessed 11 Sept 2017.

Ministry for Primary Industries (2018). The One Billion Trees Programme: Our Future, our billion trees. [http://www.treesforbeesnz.org](http://www.treesforbeesnz.org)

Ministry of the Environment. (2010). The Kyoto Protocol. [http://www.mfe.govt.nz/issues/climate/international/kyoto-protocol.html](http://www.mfe.govt.nz/issues/climate/international/kyoto-protocol.html)

New Zealand Geological Survey (1972). South Island (First edition) Geological map of New Zealand 1:1 000,000. Wellington, New Zealand: Department of Scientific and Industrial Research.

New Zealand Meteorological Service. (1966). Summaries of climatological observations at New Zealand stations to 1960. New Zealand Meteorological Service Miscellaneous Publications, 122, 59 p.

New Zealand Meteorological Service. (1973). Rainfall normals for New Zealand 1941-1970. [Miscellaneous Publications, no. 145]. Wellington, New Zealand: Meteorological Service.

New Zealand Meteorological Service. (1984). Meteorological observations for 1984. [Miscellaneous Publications, no. 109]. Wellington, New Zealand: Meteorological Service.

Palmer, D.J., Kimberley, M.O., Cown, D.J., McKinley, R.B. (2013). Assessing prediction accuracy in a regression kriging surface of Pinus radiata outerwood density across New Zealand. *Forest Ecology and Management*, 308, 9-16. [https://doi.org/10.1016/j.foreco.2013.07.024](https://doi.org/10.1016/j.foreco.2013.07.024)

Scott, N.A., White, J.D., Townsend, J.A., Whitehead, D., Leathwick, J.R., Hall, G.M.J., Marden, M., Rogers, G.N.D., Watson, A.J., Whaley, P.T. (2000). Carbon and nitrogen distribution and accumulation in a New Zealand scrubland ecosystem. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere*, 30(8), 1246-1255. [https://doi.org/10.1139/x00-048](https://doi.org/10.1139/x00-048)

Schwendenmann, L., & Mitchell, N.D. (2014). Carbon accumulation by native trees and soil in an urban park, Auckland. *New Zealand Journal of Ecology*, 38(2), 213-220.

Smale, M.C. (1994). Structure and dynamics of kanuka (*Kunzea ericoides var. ericoides*) heaths on sand dunes in Bay of Plenty, New Zealand. *New Zealand Journal of Botany*, 32, 441-452. [https://doi.org/10.1080/0028825X.1994.10412931](https://doi.org/10.1080/0028825X.1994.10412931)

Tomlinson, P.R., & Leslie, D.M. (1978). Soils of Dunedin city and environs, New Zealand. [New Zealand Soil Survey Report 37]. Wellington, New Zealand: Soil Bureau.

Trotter, C., Tate, K., Scott, N., Townsend, J., Wilde, H., Lambie, S., Marden, M., Pinkney, T. (2005). Afforestation/reforestation of New Zealand marginal pasture lands by indigenous shrublands: the potential for Kyoto forest sinks. *Annals of Forestry Science*, 62, 865-871. [https://doi.org/10.1051/forest:2005077](https://doi.org/10.1051/forest:2005077)

Wardle, P. (1969). Biological flora of New Zealand: 4. *Phyllocladus alpinus* Hook F. (Podocarpaceae) mountain toatoa, celery pine. *New Zealand Journal of Botany*, 7, 76-95. [https://doi.org/10.1080/0028825X.1969.10429103](https://doi.org/10.1080/0028825X.1969.10429103)

Wardle, P. (1991). *Vegetation of New Zealand*. Cambridge UK: Cambridge University Press.

Watson, A.J., Marden M., Rowan, D. (1994). Tree species performance and slope stability. In: D.H. Barker (Ed.), *Proceedings of the Institute of Civil Engineers Conference, ‘Vegetation and slopes - stabilisation, protection and ecology’*. University Museum, Oxford, 29-30 September 1994. Pp.161-170. [https://doi.org/10.1680/vasspae.20313.0010](https://doi.org/10.1680/vasspae.20313.0010)
Watt, M.S., Zoric, B., Kimberley, M.O., Harrington, J. (2011). Influence of stocking on radial and longitudinal variation in modulus of elasticity, microfibril angle, and density in a 24-year-old Pinus radiata thinning trial. Canadian Journal of Forest Research, 41(7), 1422-1431. https://doi.org/10.1139/x11-070

Williamson, G.B, Wiemann, M.C. (2010). Measuring wood specific gravity correctly. American Journal of Botany, 97(3), 519-524. https://doi.org/10.3732/ajb.0900243
APPENDIX

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

**Site 1: Tautoro.** 8 km south of Kaitaia, Northland (173° 50’ 13 15 E, 35° 28’ 52 00 S). Regenerating *Leptospermum scoparium* (Table A4) stand on gently, southwest-facing slope 100-140 m 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 Waitamata 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.** 8 km 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 a 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).

**Sites 4–6: Tolaga Bay and site 7: Waimata Valley.** Sites 4–6 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 siltsstones 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 Tāraheru 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 11.1°C, 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°, 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 *Cuprosma 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...
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 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 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 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 16: Peggioh.** 10 km west of Ward (174° 01’ 13 67 E, 41° 51’ 31 57 S). Dense, regenerating *Kunzea ericoides* (Table A3) stand on west-facing slope 200–300 m above sea level. Bedrock consists of metamorphosed sedimentary lithologies and volcanics (New Zealand Geological Survey, 1972). Soils are classed as Brown and Melanic Soils (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 31 E, 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 data                   |
|                                   | 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                   |
| *Alectryon excelsus* (titoki)     | 622                           | Woodhill                             | Payton (pers. comm.)                                |
|                                   | 837                           | CMS plots, n=4                       | Peltzer & Payton unpublished data                   |
|                                   | 854                           |                                       | Bier & Britton (1999)                               |
| *Dacrycarpus dacrydioides* (kahikatea) | 465                           | Gray Country, 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                   |
|                                   | 440                           | Maungatautari (n=1)                  | Beets et al. unpublished data                       |
|                                   | 389                           | Whirinaki (n=20)                     | Beets et al. unpublished data                       |
|                                   | 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                   |
|                                   | 383-407                       | Whirinaki, n=14                      | Beets et al. unpublished data                       |
|                                   | 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                   |
|                                   | 470                           | Puketi Forest, Northland            | Jager et al. (2014)                                 |
|                                   | 441                           | Taranaki, n=20                       | Beets et al. unpublished data                       |
|                                   | 495                           |                                       | Bier & Britton (1999)                               |
TABLE A2: continued...

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

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

*Beets, P.N., Oliver, GR, 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.*
| Location               | Age (y) | Ht (m) | RCD (mm) | DBH (mm) | Wood Density (kg m$^{-3}$) |
|-----------------------|---------|--------|----------|----------|---------------------------|
| Riversdale            | 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      |                           |
|                       | 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      |                           |

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\(^{-3}\)) |
|-------------------|---------|--------|----------|----------|-----------------------------|
| 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      | 704      |                             |
|                   | 26      | 13.0   | 154      | 734      |                             |
|                   | 23      | 11.5   | 120      | 729      |                             |
|                   | 29      | 16.4   | 181      | 786      |                             |
|                   | 31      | 16.4   | 187      | 828      |                             |
|                   | 29      | 16.4   | 165      | 789      |                             |
|                   | 30      | 13.3   | 147      | 647      |                             |
|                   | 29      | 12.1   | 138      | 720      |                             |
|                   | 31      | 13.3   | 151      | 774      |                             |
|                   | 26      | 10.6   | 153      | 731      |                             |
|                   | 26      | 11.9   | 155      | 743      |                             |
|                   | 31      | 12.8   | 122      | 766      |                             |
|                   | 37      | 11.4   | 117      | 86       |                             |
|                   | 22      | 12.2   | 143      | 811      |                             |
|                   | 24      | 12.4   | 108      | 722      |                             |
|                   | 35      | 14.2   | 149      | 849      |                             |
|                   | 29      | 13.7   | 98       | 771      |                             |
|                   | 34      | 13.9   | 154      | 757      |                             |
| Long Gully        |         |        |          |          |                             |
|                   | 12      |        |          |          | 781                          |
|                   | 15      |        |          |          | 762                          |
|                   | 20      |        |          |          | 690                          |
|                   | 22      |        |          |          | 760                          |
|                   | 26      |        |          |          | 793                          |
|                  | *Hinewai* |      |          |          | *747*                          |
|                   |         |        |          |          | *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                          |
| 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                          |

| Location          | Age (y) | Ht (m) | RCD (mm) | DBH (mm) | Wood Density (kg m\(^{-3}\)) |
|-------------------|---------|--------|----------|----------|-----------------------------|
| Avoca Station     |         |        |          |          |                             |
|                   |         |        |          |          |                             |
|                   | 12      |        |          |          | 781                          |
|                   | 15      |        |          |          | 762                          |
|                   | 20      |        |          |          | 690                          |
|                   | 22      |        |          |          | 760                          |
|                   | 26      |        |          |          | 793                          |
|                   | *Hinewai* |      |          |          | *747*                          |
|                   |         |        |          |          | *699*                          |

**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     |        |          |          |                            |
| Nikau Valley | 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      |                            |
|              | 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    | 94       | 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                           |
| Coatbridge        | 14      | 704    | 709      |          |                               |
|                   | 11      | 710    | 710      |          |                               |
|                   | 9       | 723    | 723      |          |                               |
|                   | 8       | 684    | 684      |          |                               |
|                   | 10      | 715    | 715      |          |                               |
|                   | 14      | 719    | 719      |          |                               |
|                   | 11      | 690    | 690      |          |                               |
|                   | 14      | 743    | 743      |          |                               |
|                   | 11      | 682    | 682      |          |                               |
|                   | 14      | 742    | 742      |          |                               |
|                   | 13      | 696    | 696      |          |                               |
|                   | 13      | 734    | 734      |          |                               |
|                   | 14      | 742    | 742      |          |                               |
|                   | 10      | 624    | 624      |          |                               |
|                   | 16      | 692    | 692      |          |                               |
| Dunedin           | 10      | 4.0    | 34       | 26       | 665                           |
|                   | 11      | 4.5    | 42       | 30       | 680                           |
|                   | 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                           |
| Lake Tutira       | 15      | 704    |          |          |                               |
|                   | 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    |          |          |                               |
|                   | 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    |          |          |                               |
|                   | 17      | 666    |          |          |                               |
|                   | 17      | 704    |          |          |                               |
TABLE A4: continued

| Location | Age (y) | Ht (m) | RCD (mm) | DBH (mm) | Wood Density (kg m$^{-3}$) |
|----------|---------|--------|----------|----------|--------------------------|
| Peggioh  |         |        |          |          |                          |
|          | 724     | 756    | 645      | 669      | 666                      |
|          |         |        | 696      | 684      | 705                      |
|          |         |        | 732      | 727      | 656                      |
|          | 730     | 662    | 679      | 724      | 733                      |
|          |         |        | 729      | 607      | 610                      |
|          |         |        | 739      | 689      | 683                      |
|          |         |        |          | 660      |                          |
| Tautoro  |         |        |          |          |                          |
|          | 656     | 780    | 662      | 679      | 724                      |
|          |         |        | 733      | 729      | 607                      |
|          |         |        | 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                       |
| 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       | 220      | 143      | 543                       |
| *Weinmannia racemosa*  | Wainuiomata | 30      | 8.9        | 215      | 108      | 541                       |
| *Weinmannia racemosa*  | Wainuiomata | 51      | 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                       |
| 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                         |
| 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 ferruginea     | 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                         |