DIVERSIFIED SPECIES TECHNICAL NOTE

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Variation of Density and Acoustic Velocity in Douglas-fir by Site

Summary

Twenty-eight Douglas-fir (*Pseudotsuga menziesii*) plots were assessed for wood density and acoustic velocity (an indirect assessment of stiffness) across a range of growing conditions. Plot averages of velocity^2 (range 14.0 - 26.7) and wood density (range 319 – 505 kg m^{-3}) differed by around 40% across New Zealand. Wood density and velocity^2 were strongly related (R^2 = 0.91) among plots. Plots with the highest velocity^2 and density were found on warmer sites in the North Island and around Nelson. Mean annual temperature explained 63% of the site variation in wood density and 52% of the site variation in velocity^2. Soil fertility was also found to be a significant factor, as was tree age. When combined, these variables explained 82% of the variation in wood density and 73% of the variation in velocity^2.

The majority of New Zealand's Douglas-fir resource is grown on more snow-prone sites located at higher altitudes in the South Island. These same sites expressed lower density and wood stiffness than warmer plots assessed in the North Island. This work will allow growers to consider resource quality when planning new forest plantings in order to maintain Douglas-fir's good reputation for structural timber.

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Introduction

Wood stiffness is an important property of structural timber and is of particular importance to Douglas-fir, a species recognised on the world market for its superior stiffness, strength and density compared with many other commercially grown conifer species. To maintain Douglas-fir's good reputation as a structural timber it is important to retain these desirable properties.

The stiffness of the wood produced by a tree is determined by its genotype and the environment in which it is grown. Whilst silvicultural practices such as high stocking can improve the wood properties of a tree, the environmental conditions under which it is grown will also have a large influence on the quality of the timber produced. To quantify the effect of the environment upon wood density and stiffness we modelled these wood properties across a range of environments. From the results a map-based tool was produced to help growers select the optimum site for growing trees that will produce high quality construction timber, and to understand the likely quality of their planted resource.

Trial Plots and Assessment

Twenty-eight plots (Figure 1) were assessed across New Zealand for density and acoustic velocity.

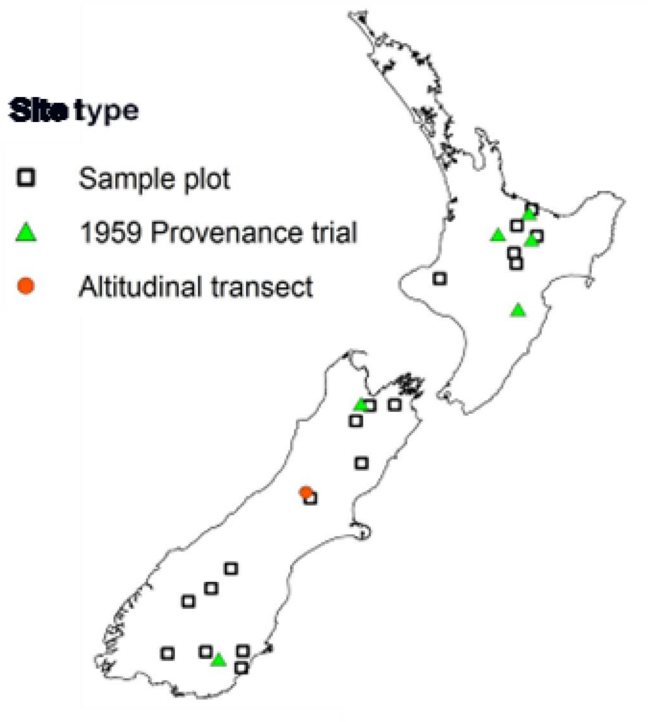

Figure 1. Location of Douglas-fir sample plots

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Plot locations spanned a wide geographic area, encompassing the large range of site variables where Douglas-fir is currently grown. All plots contained between 20 and 30 trees, were over 20 years of age and standing at a final average stocking of approximately 550 stems per hectare.

Douglas-fir planting stock across New Zealand is diverse, originating from many different provenances, as well as New Zealand landrace material collected from Ashley and Beaumont forests. This large range in origin potentially gives rise to large provenance effects, confounding the results of measured traits. For this reason, a number of plots of Fort Bragg origin, one of the better performing provenances across New Zealand, were located within the 1959 Douglas-fir provenance trials to indicate any likely provenance effect on wood density and acoustic velocity. Plots standing at a range of final stockings (250, 500, 750 and >1200 SPH) were sampled at six sites to provide information on the effect of stocking on wood density and acoustic velocity. An altitudinal transect containing four plots located between 800 and 1080m was established to see how much the wood density and acoustic velocity of Douglas-fir change with the effects of altitude.

Within each plot, outerwood density was measured on all trees from 5-cm-long cores. A pith to bark 5 mm core was extracted from ten of the trees from each plot to determine the density of individual growth rings as well as latewood to earlywood ratios and yearly growth increments. All sample trees were assessed for acoustic velocity using the ST300 (Figure 2). Acoustic velocity is related to wood stiffness by:

$$\text{Velocity}^2 = \text{Dynamic stiffness} / \text{Green density}$$

where: green density is assumed to be a constant, 1000 kg m^{-3} [1]. A strong relationship between standing tree acoustic velocity and wood stiffness has been shown [2,3]. Sample trees were also assessed for height and stem diameter, and soil cores were taken from within the plots to determine soil fertility. Based on plot locations, climatic variables were obtained from NIWA modelled climatic surfaces.

Figure 2. Assessment of acoustic velocity and core extraction to determine wood density

Results

Altitudinal Transect

Across an altitudinal transect of approximately 300 m, height, wood density and acoustic velocity significantly decreased with increasing altitude (Table 1). Decreasing tree height was correlated with the reduction in wood density and velocity^2. The marked reduction in tree height over the altitudinal transect was likely associated with increasing wind exposure.

Table 1. Altitudinal plot mean data

Altitude (m)	Height (m)	DBH (cm)	Density (kg m^{-3})	Velocity^2
800	29.8	45.6	420	21.1
850	28.0	42.3	418	20.9
960	26.9	43.9	401	18.1
1080	22.6	44.6	366	14.0

Sample Plots

The variation in wood density and acoustic velocity expressed along the altitudinal transect led to a much broader study to determine environmental variables that explained site variation in the wood properties of Douglas-fir. Twenty-eight plots were assessed (Table 2) standing at an average final stocking of around 550 SPH. Outerwood density ranged from 505 to 319 kg m^{-3} across the sites assessed, and velocity^2 from 26.7 to 14. Outer wood density and velocity^2 were strongly related among sites (R^2 = 0.91). With a few exceptions from around Nelson, the plots with the highest wood density and velocity^2 were all within the North Island and the plots with the lowest wood density and velocity^2 within the South Island (Table 2).

Table 2. Velocity^2 and outer wood density plot means. Plots in blue were located in the South Island and those in pink in the North Island.

Stand location	Density	Velocity^2	Age
Golden Downs	505	25.7	52
Rotoehu Cpt46	497	26.7	52
Te Wera	491	25.8	42
Whaka	491	23.4	27
Rotoehu Cpt88	489	24.1	39
North Bank	485	25.6	29
Wairoa	461	24.4	31
Kaingaroa Cpt1149	454	25.8	52
Kaingaroa Cpt 1236	452	18.9	19
Kinleith	444	23.1	52
Kaingaroa Cpt 656	427	22.6	27
Gwavas	426	22.3	52
Tauhara	423	18.7	22
Rankleburn	420	19.9	52
Burnt Face (800m)	420	21.1	45
Burnt Face (850m)	418	20.9	45
St Arnaud	411	20.8	28
Tokoiti	407	18.0	23
Hamner	405	18.7	26
Burnt Face (960m)	401	18.1	45
Glenfoyle	389	19.7	29
Ridbbonwood	385	16.6	27
Arrowtown	384	17.6	27
Dusky	381	16.3	26
Craigieburn	369	17.1	31
Berwick	368	14.3	29
Burnt Face (1080m)	366	14.0	43
Castledowns	319	14.7	25

Multiple regression analysis was performed to determine the variables that best explained wood density and velocity^2 (Table 3). Mean annual temperature was found to be the main determinant of wood density and velocity^2, accounting for over half of the variation observed between sites. Soil carbon to nitrogen ratio (C/N), a measure of soil fertility, was also found to be a significant factor, as was tree age. C/N ratios were adjusted by subtracting 0.014 from N before dividing C with N [4].

Table 3. Summary of statistics for the final predictive model of outer wood density and velocity^2. Parameter values and cumulative R^2 and partial R^2 values (in brackets) are shown.

Variable	Para.	Value	R^2	Sig.
Density				
Intercept	a	21.6574		
Temp	b	22.5420	0.63 (0.63)	***
Soil C/N	c	3.2825	0.80 (0.05)	***
log(age)*	d	30.4941	0.83 (0.07)	*
Velocity^2				
Intercept	a	-15.0584		
Temp	b	1.6096	0.52 (0.52)	***
log(age)*	d	4.4497	0.69 (0.17)	**
Soil C/N	c	0.1752	0.74 (0.02)	*

Note. Models for density and velocity^2 are as follows: a + b(Temp) + c(Soil C/N) + d(log(age))
* The natural logarithm was used

Thinning Trials

No marked trend was observed between stand stocking and wood density and velocity^2.

Discussion

Although the origin of planted material was unknown for the majority of stands assessed, it can be assumed that the general trends in density and velocity^2 variation hold true for the variety of Douglas-fir material currently planted in New Zealand.

The models for wood density and velocity^2 are based on predicted mean annual temperature at a given location obtained from the NIWA temperature layer. The C/N ratio was physically measured at each sample plot and used in the predictive models. The predictive maps for density and velocity^2 (Figures 3 and 4) rely upon a modelled C/N surface [4] rather than actual measurements, so errors could be greater than if using measured C/N ratios. The C/N ratio indicates soil fertility; it is assumed that the greater the soil carbon the less available soil nitrogen, as it is used up by soil microbes in the

decomposition of plant matter. Look-up tables for outer wood density and velocity^2 (Tables 4 and 5) have been created for a range of temperatures for sites with high, medium and low soil fertility.

Conclusion

This is the first time that the extent of the variability in Douglas-fir wood density and velocity^2 across New Zealand has been quantified. The main environmental drivers assessed that explained the variability in wood density and velocity^2 were mean annual temperature and soil carbon to nitrogen ratio. Modelling these two important variables is key to determining the suitability of Douglas-fir for construction and wood engineered products, and should provide a valuable tool to growers and manufacturers in quantifying the existing resource.

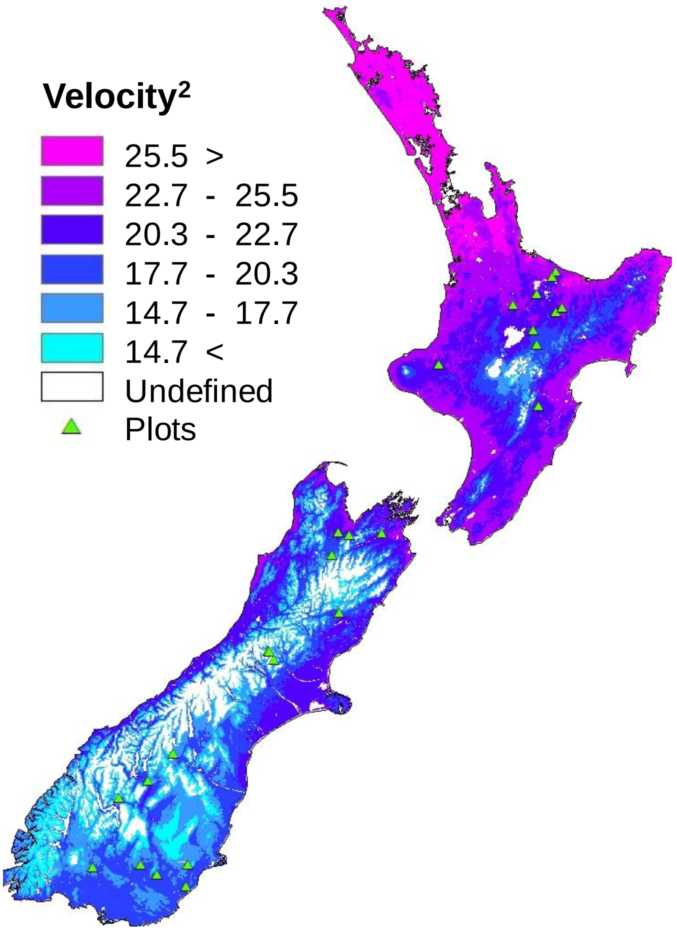

Figure 3. Modelled average outer wood velocity^2 at breast height for Douglas-fir aged 30.

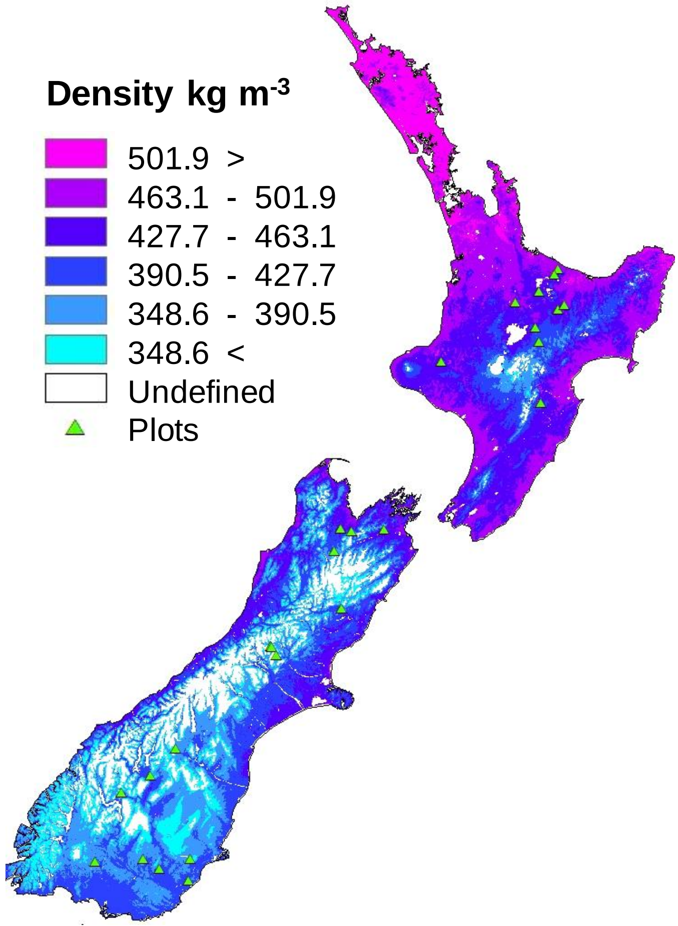

Figure 4. Modelled average outer wood density at breast height for Douglas-fir aged 30.

Table 4. Predicted outer wood density (kg m^{-3}) for a range of mean annual temperatures at high, medium and low soil fertility rates (C/N 10, 20 and 30) at age 30.

Mean annual air temperature (C°)	Soil Fertility		
	High	Medium	Low
4	248.37	281.19	314.02
5	270.91	303.73	336.56
6	293.45	326.28	359.10
7	315.99	348.82	381.64
8	338.53	371.36	404.18
9	361.08	393.90	426.73
10	383.62	416.44	449.27
11	406.16	438.99	471.81
12	428.70	461.53	494.35
13	451.24	484.07	516.89
14	473.79	506.61	539.44
15	496.33	529.15	561.98

Table 5. Predicted velocity^2 for a range of mean annual temperatures at high, medium and low soil fertility rates (C/N 10, 20 and 30) at age 30.

Mean annual air temperature (C°)	Soil Fertility		
	High	Medium	Low
4	8.27	10.02	11.77
5	9.88	11.63	13.38
6	11.49	13.24	14.99
7	13.10	14.85	16.60
8	14.71	16.46	18.21
9	16.31	18.07	19.82
10	17.92	19.68	21.43
11	19.53	21.29	23.04
12	21.14	22.90	24.65
13	22.75	24.51	26.26
14	24.36	26.12	27.87
15	25.97	27.72	29.48

Acknowledgements

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