Redwood in New Zealand - an end-user perspective

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California coast redwood (***Sequoia sempervirens***) grows along the fog belt of the Pacific coast from southwest Oregon to central California where some specimens are among the tallest living plants in the world at over 100m.

"Old growth" redwood lumber has been highly prized, renowned for several unique features. The sapwood is white, but the stem consists mostly of dark red heartwood with very straight grain, high dimensional stability and resistance to warping. One of the most dimensionally stable of the western softwoods, redwood is not prone to checking and splitting, and therefore is less damaged by weathering. It has been widely used for outdoor decorative products (landscaping and cladding) as it was regarded as more durable and insect repellent in all-heartwood grades than other softwoods, yet lightweight and stable. According to reports from the USDA Forest Products Laboratory, old-growth redwood has less dimensional shrinkage than other common domestic softwoods.

The native California resource is controlled by legislation of environmental constraints, and sustainable management practices dictating that production from second- and third-crop stands is likely to continue to decrease (Stuart, 2007). The US supply of "old growth" lumber is now a small part of the market and the vast majority is from "second-growth" stands (less than 100 years old), where the wood characteristics are somewhat different. In particular, the heartwood is recognised as having only low to moderate decay resistance (USDA, 1999). The wood is mostly used for building - decks, fences, outdoor furniture, weatherboards, window sashes, doors, blinds, interior trim - where appearance and stability are major requirements.

In New Zealand, redwoods have been a feature of the landscape since the 19th century, having been established as small plantations, shelterbelts and ornamentals throughout the country (Knowles and Miller, 1993). Some iconic remnants of the early plantings remain impressive, such as the Redwood Grove in Rotorua, proving that it can grow well when correctly sited. The New Zealand Forest Service in its early days investigated many exotic temperate species, and redwood was attractive because of the high value of the Californian old growth forests. Many of the early Forest Service plantings throughout the country, however, were not successful, and the quality of the timber was disappointing compared to the US material (Brown, 2007). Unlike several other softwood species, notably radiata pine, redwood is more particular about site requirements. Libby (2007a) reaffirmed that there are impressive plantations in many parts of New Zealand, growing at very productive rates.

Experience would suggest that well managed redwood should be an excellent choice for plantations in New Zealand (Vincent, 2001), and in fact renewed interest has been shown by some companies in planting redwoods with the target of relatively short rotations (around 30 years - Knowles and Miller, 1993; Rydelius, 2007) using clonal stock. The observed variability in redwood survival and growth has lead interested individuals to establish small trials, many of them containing clonal samples from across California (Saunders and McConnochie, 2007; Rydelius, 2007). These trials are as yet too young to yield a lot of information apart from early survival. However, it is clear that redwood can grow very rapidly in New Zealand under favourable conditions. However, it is the view of the current author that to be successful as a plantation species, the most important criterion is user acceptability (wood quality), which will enable both domestic and export markets to be secured.

What About the Wood?

There are surprisingly few reports from the US on wood properties of second-growth redwood but a few studies indicate somewhat different, but still very acceptable wood properties (Schniewind, 1963; Bendtsen, 1966; Rappleyea, 1966; Libby, 2007b).

The published US data (USDA, 1999) indicate the following average properties:

Californian redwood has a well-deserved reputation for exterior and decorative products, based on old-growth

Table 1: Some Average US redwood properties

Source	Density (kg/m3) (12%)	Shrinkage (%)			Heartwood Durability
		Radial	Tangential	Volumetric	
Old-growth	400	2.6	4.4	6.8	Resistant or Very Resistant
Young growth	350	2.2	4.9	7.0	Low or Moderately Resistant

characteristics (USDA Wood Handbook, 1999). Significant quantities have been imported into New Zealand over the years for the same end uses as the US.

In the US, the harvest has dropped significantly in recent years due to regulatory legislation and replacement of some traditional products with wood/plastic composites (Burnett, 2005). Nevertheless, there are still profitable markets for redwood harvested from re-growth stands.

Redwood produces a high proportion of heartwood and the heartwood extractives make the wood resistant to fungi and insect attack. Although there is a general relationship between heartwood colour and resistance, not all dark-coloured heartwood is resistant to decay (Scheffer and Cowling, 1966; Wilcox and Piitro, 1974; USDA, 1999). Clark and Scheffer (1983) used "soil block" tests to compare the natural resistance of heartwood from old (200 to 1300 years) and young growth (24 to 100 years) in California, and found that:

1. There were large differences between both locations and individual trees and even within stems - presumably reflecting genetic differences - and even a few old growth trees were only moderately resistant.
2. Young growth trees were both less resistant and more variable.
3. The outer heartwood zone is consistently more resistant than the inner heartwood.
4. The range in recovery of "very decay resistant" timber in the outer heartwood of individual old-growth trees was 17% to 67%, indicating scope for genetic selection.

They concluded that young growth had less of the highly resistant heartwood present in old growth, and neither tree size, age or location gave a good indication of decay resistance. Individual tree variation was very significant, suggesting that genetics play a very strong role.

Where decay hazards exist, heartwood of species in the resistant or very resistant category generally gives satisfactory service, but heartwood of species in the other lower categories would require some form of preservative treatment. However, it should be noted that there is currently no market in California or anywhere else for preservative treated redwood. The continued widespread use of redwood in the US for decking and outdoor applications confirms its durability and resultant market acceptance for this purpose. However young growth is acknowledged to have somewhat poorer natural durability, and treatment could be required to ensure compliance with grade requirements.

Early reports highlighted the high variability in wood density of "old-growth" and cautioned on the interpretation of small samples (Volkert, 1925). Resch and Arganbright (1968) compared 5 old-growth trees (600+ yrs) with 6 young- growth stems (53 yrs.) and found high variation in basic density (old: 230 - 530 kg/m^3, standard deviation 40 kg/m^3; young 270 - 550 kg/m^3, standard deviation 50 kg/m^3). Within-stem trends were not pronounced and seemed to be associated with latewood development. Rappleyea, (1966) reported the wide earlywood has a tendency to erode in exposed situations.

Shrinkage characteristics are similar between old- and young-growth material. The excellent stability has been attributed to the low shrinkage and small ratio of tangential: radial shrinkage.

Schniewind (1963) compared the machining properties of old growth and young growth redwood and found them to be similar, although the young material had a greater tendency to dimensional movement. Bendtsen (1966) compared physical and mechanical properties of old- and young-growth redwood and concluded that most mechanical properties of the latter were 20-25% lower than the virgin material.

Redwood Wood properties in New Zealand

Access to natural stands of redwood in the USA is restricted, so an opportunity exists for NZ to produce highly prized lumber for local domestic use (exterior use and high quality joinery) and potentially for export. New Zealand-grown redwood could potentially capture some of the well-developed international market for western red cedar, provided the quality is similar.

Comparatively little work has been done on the wood properties and performance of New Zealand-grown redwood, and the acknowledged gaps are around characteristics such as density, stability and durability (Cooke and Satchell, 2007; Poole, 2007) which could potentially affect export markets. Experience to date suggests that the low wood density, low hardness and low-to-moderate durability could restrict end uses. Clifton (1994) notes "it is brash, brittle, and altogether "punky". It is rated moderately durable".

Cornell (2007) rightly cautioned that market requirements, both domestic and export, should be considered before a long term commitment is made to fast growing clones.

Wood Density

Wood density is a general indicator of quality, but different aspects are required for different uses. Moderate to high average density is necessary for stiffness, but uniformity is more appropriate for resistance to surface abrasion (wear) and good finishing characteristics. However, very low wood density (less than 300 kg/m^3) is highly undesirable for any uses subject to loads or wear.

The first study on New Zealand redwood (Cown, 1970) examined wood density and heartwood formation in a small number of thinnings from the Redwood Grove, Rotorua (aged about 70 years). Density levels and patterns were found to be very variable - discs averaging from 260 to 500 kg/m^3. It was noteworthy that some samples showed the highest unextracted density values to be in the first 10 rings from the pith.

Colbert and McConchie (1983) assessed the properties of five trees (age 45 years). Heartwood percentage averaged 52% (range 45 - 62%) and basic density 353 kg/m^3 (range 282 - 388 kg/m^3). An unpublished report (Young, 1983) gave density and shrinkage data from samples taken at 11 North Island sites (ages 28 - 69 yrs.) and 1 South Island site (Hokitika - 80+ yrs). Overall the wood basic density averaged 332 $kg/^3$, but the single South Island tree had an exceptionally low value at 225 kg/m^3. Data from a 22-year old stand in Rotoehu Forest (Vincent, 2001) gave average BH density values ranging from 237 to 444, averaging 321 kg/m^3 (Fig. 1). There was also an overall negative correlation between growth rate and wood density (r2 = 27% - unpublished data.). Equally important, the data showed that it is possible to find individual stems with both good growth and density.

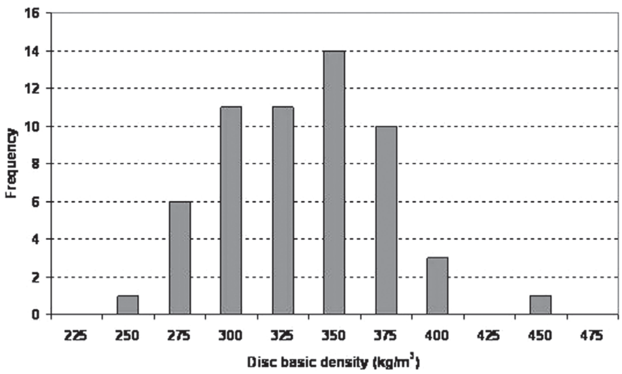

Fig. 1: Basic Density Distribution (Age 22 Years) (Courtesy Rob Webster)

The variation in density is not high within a single tree although variation between individual stems or genotypes can vary considerably. The tendency is for the inner 10 rings to have slightly higher values than rings 10 to 20 - possibly due to the deposition of heartwood extractives. Colbert and McConchie (1983) concluded that the average wood density of New Zealand-grown redwood is slightly lower than Californian. The available data suggests that in some situations, density can be exceptionally low (e.g. small samples from Taumaranui and Hokitika).

Wood densitometry can reveal the variation in wood density across growth rings. This can be important for some products in low density species as low density earlywood is very soft and can wear easily. Table 2 (see over page) and Fig. 2 give some results from redwood clones. Key points are the some low average densities (less than 200 kg/m^3); the very low latewood %; uniform latewood densities; average density only slightly higher than earlywood density; and different developmental patterns.

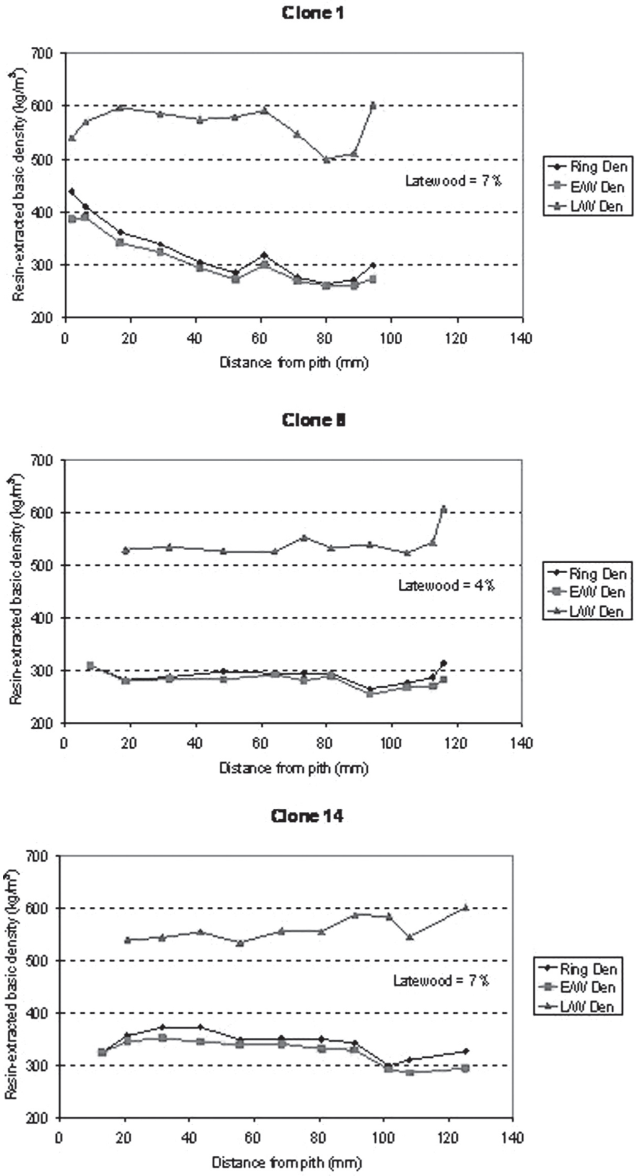

Fig. 2: Clonal Pith-to-Bark Density Trends (Age 10 - 12 years) (Courtesy Wade Cornell)

A source in the US commented that some of the low density NZ redwood processed in Californian suffered from low recovery because of crushing by hardwood fillets during drying.[2] Surface erosion at Devonport has been relatively severe in places, highlighting the extremely low density of the earlywood in some local material.

Clearly, there are rather large density between-tree wood density differences which seem to be genetic in origin and will be minimised by the use of clones.

[2] *Charlie Jourdain, California Redwood Association*

*Table 2: Clonal Densitometric Properties (Age 10 - 12 years)**

Clone	Ring Width	Latewood	Ring Density	Earlywood Density	Latewood Density	Uniformity (Latewood - Earlywood Density)
	(mm)	(%)	(Kg/m^3)			
1	9.0	7	319	303	568	258
2	9.8	6	305	287	554	267
3	10.8	11	338	309	570	261
4	8.8	2	298	292	554	272
5	10.3	8	332	309	572	271
6	11.7	8	342	323	558	235
7	11.5	7	314	297	549	252
8	11.0	4	290	279	540	260
9	10.3	11	342	313	564	251
10	8.4	7	356	340	559	219
11	11.9	5	303	287	569	281
12	10.4	11	357	326	582	256
13	13.3	8	341	322	550	227
14	11.1	7	342	327	555	225
15	13.4	15	375	345	547	202
Mean	**10.8**	**8**	**330**	**311**	**559**	**249**
Min.	**8.4**	**2**	**290**	**279**	**540**	**202**
Max.	**13.4**	**15**	**375**	**345**	**582**	**281**

Fig. 3: Biddy studio, Ongaonga (H. Saunder, NZ Forestry Ltd.)

Fig. 4: Horizontal Stained Redwood (Cown Home, Rotorua)

Shrinkage and Dimensional Stability

Stability, which is an important requirement for cladding, is not considered a problem in New Zealand grown redwood timber. Figs. 3 and 4 are examples of redwood weatherboards in use. The reports by Young (1983) and Colbert and McConchie (1983) both suggest that shrinkages (to 12% MC) were low and fairly consistent from pith to bark and between sites (radial - 1.4%, range 1.1 - 1.6%; tangential - 3.2%, range 2.8 - 3.2%). These value are lower than quoted for the US second-growth (Table 1). The ratio of Tangential:Radial is generally around 2 which is good for stability.

All indications are that NZ redwood will be a very stable timber.

Durability

Natural durability classification in New Zealand and elsewhere is often based on regional "graveyard tests" - standard samples placed in the ground and monitored over time (Page *et al.* 1997).

In the US, "old-growth" redwood has proven to be one of the most resistant species in above ground tests (Highley, 1995) and is considered Class1 in the Australian standards (AS 5604-2003). Existing evidence indicates that average second growth redwood (including NZ sources) may not be as naturally durable as North American old-growth material (Knowles and Miller, 1983). However as individual genotypes young growth redwood can also vary from highly resistant to non-resistant.

Heartwood is traditionally sought after for it's light weight, durability and appearance. Fortunately, redwood produces heartwood early. A recent study in 22-year-old material (Vincent, 2001; Charlie Low, ensis, *pers. comm.*) showed that within a range of genetic material (provenances and seedlots), heartwood % ranged from 27 - 69% with an average of 47.2%. at breast height. Even in the largest stems, sapwood only occupies the outer 25 to 50 mm.

The first 'graveyard' test of New Zealand grown redwood was installed at Rotorua in 1962 (Dave Page, ensis, *pers. comm.*). The assessment gave a predicted service life as decking of perhaps 10-15 years. More redwood has been included over the years and so far they indicate only slightly better decay resistance than the earlier test, which places NZ redwood in Class 3 (5-15 years - AS 5604, 2003), along with NZ western red cedar[3]. The point is that existing material (often of unknown genetic source and location in the tree), is highly variable in durability.

Pure Culture Decay laboratory tests have been performed on a limited number of redwood clones (Fig. 3) to determine relative resistance. In the example shown, six clones and a radiata control were exposed to a brown rot and white fungus for 8 weeks. . Loss of less than 2% weight is a guideline for indications of higher classes of durability. The limited data set indicates that some clones may be resistant to both fungi (15, 2) some to white rot (15, 2, 9, 6, 13).

The average above-ground durability of redwood is good. Trials of NZ-grown redwood timber as exterior cladding and interior sarking show some promising results (Knowles and Miller, 1993; Clifton, 1994).

Redwood takes preservative treatment well, but the redwood industry in California is trying to maintain the image of "naturally durable" as a way to be "chemical free". It would be very unwise for New Zealand to knowingly grow material which required treatment for durability, thus creating an unwanted "NZ-redwood" market distinction. Hence screening material for natural durability is strongly recommended.

Discussion and Conclusions

NZ redwood plantations (like the US second- and third-growth stands) have been highly variable in both growth and wood properties, but potentially could be significantly improved through selective breeding and identification of appropriate clones. New Zealand's faster growth rates coupled with the variability exhibited in redwood genetics indicates that plantations based upon genotypes that have not been selected for wood properties will have generally inferior wood properties to California second growth. Clearly, the main priority for clonal selection and breeding must be the selection of material which is both healthy and can survive and grow well under specified conditions. Significant improvement in general timber utility can also be achieved by screening material for basic density, stability and durability. There will probably be good continuing markets, both domestic and export, for timber with appropriate wood properties. The US love of redwood and western red cedar, combined with a reduced resource, will ensure a continuing demand for similar material.

It is anticipated that dwindling stocks of old growth western red cedar and old growth redwood will generate a market for 'clears' and other 'upper' grades. New Zealand plantations can grow these grades with good silvicultural management. Therefore, the goal of redwood management should be to ensure the sites used are suitable for healthy growth, that good genetic material is used (growth, form, health), silviculture is appropriate (spacing, thinning, pruning) and that the wood properties are acceptable (Cornell, 2002). The most important wood characteristics to achieve in NZ-grown redwood are appropriate density, stability and durability.

[3] *There is insufficient evidence to place redwood in the upper end of the range (with western red cedar) or the lower end of the range.*

The wood density of all sources of redwood has been shown to be highly variable - mostly between individual stems. In general (as with other species), there is a slight negative relationship between growth and wood density, probably related to the ratio of earlywood to latewood (see Table 2). Much of the variation in density is clearly genetic in origin, and stem differences of up to 200 kg/m^3 have been observed (Fig. 2). The only way to ensure that NZ material is at least as dense as Californian is to select suitable material from among the otherwise high performers. The goal could be to select material of uniform average density - say 340-360 kg/m^3, with Uniformity (differential between earlywood and latewood density) no more than 250 kg/m^3 - similar to the average for Californian second growth. However, there will be site effects as in other softwood species. Ideally, southern cooler sites would use material with a genetic propensity toward higher density. The very limited sampling reported by Young (1983) indicated that at least some stems can have values less than 250 kg/m^3, which would be unsuitable for most end uses. On available evidence, we can probably assume a variation in basic density of 50% around the stand mean value (for individual trees of seedling origin), and with the heritability of density in conifers being generally high, significant improvement should be attainable through selection of appropriate clones and selective breeding.

Stability is considered by the California market to be the most important characteristic of redwood. All the evidence points to the fact that stability is likely to be maintained in young redwood, as few instances have been reported of problems with distortion during drying or instability in use. On the other hand, stability is such a vital property that it needs to be monitored in clonal selection. Testing is recommended for dimensional shrinkage to confirm that the radial and tangential values are less than 2.5% and 5% respectively and the ratio of tangential:radial does not exceed 2.0.

Test results for NZ grown redwood have been variable, based on limited material, but some examples of use in service have been promising (Fig. 3, 4). More recently, limited laboratory tests have been carried out on young clonal material to document the resistance to specific pure-culture decay fungi. The results confirm US tests indicating significant differences between genotypes (Clark and Scheffer, 1983), and point to the possibility of clonal selection for improved durability (Wade Cornell, pers comm.). It is vital that future plantation stock is screened to maintain a satisfactory level of natural durability. Further study may be required to link fungal testing to graveyard service trials, and to better compare different ages of material.

The future market position will depend on the species performing well in its natural niche market areas - outdoor uses and high quality joinery. Durability and stability must be key factors in the choice of preferred clones, which can be tested for conformity to agreed standards.

In the US, old-growth redwood was considered equal to western red cedar and the two interchangeably used in some regions. The potential exists for New Zealand grown redwood clones, selected for specific wood properties, to achieve a standard that would enable replacement of western red cedar in domestic and overseas markets.

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