Best Practice with Farm Forestry Timber Species

No. 3: REDWOODS

Ian Nicholas (Editor)

NZFFA Electronic Handbook Series


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FOREWORD

Following the success of the publication *Blackwood - a handbook for growers and end users,* several New Zealand Farm Forestry Association (NZFFA) action groups expressed an interest in the production of handbooks for other tree species.

This publication is the third in a series designed to present up-to-date information about cypresses, eucalypts, redwoods and blackwood. Support for the project has been received from the MAF Sustainable Farming Fund with additional assistance from NZFFA, Scion (FRST new species CO4X0304), Proseed NZ Ltd, Environment Bay of Plenty, Horizons Regional Council, Rarefind Timbers, the Plantation Management Cooperative and relevant NZFFA action groups.

It was agreed that an electronic format would be the most appropriate method for publication. The advantage of this format is the potential for relevant details to be updated as new research results come to hand. Management techniques for many tree species are still being evaluated and recommendations are likely to be modified over the space of a few years.

These handbooks have been independently reviewed and are offered as a summary of the best available knowledge about tree species and their suitability for forestry, shelter, and amenity planting. Information gathered from farm foresters and research scientists has been collated and presented under specific topic headings for ease of reference.

Visit the NZ Farm Forestry Association website (www.nzffa.org.nz) for the most up-to-date information available.

In 2002 Wade Cornell published “The New Zealand Redwood Growers Handbook” as part of a promotional tour for a series of workshops. This provides an excellent overview of redwood as seen by the author at that time. A comprehensive summary of redwoods in New Zealand was also published by FRI in 1993 as No. 13 in its Bulletin No 124 series. Since these publications there has been an increasing amount of activity at both the research and operational levels on redwood. This new handbook does not attempt to repeat these previous publications but endeavours to capture the new information for farm foresters and place it in a form where it can be updated as required.

For ease of reading, the colloquial name of individual species has been used throughout the handbook in preference to full scientific names:

Redwood = S*equoia sempervirens* [D. Don] Endl
Giant sequoia = *Sequoiadendron giganteum* (Lindley) J. Buchholz

Because most of the current forestry activities are based on redwood, this handbook concentrates on redwood, rather than giant sequoia.

Throughout the handbook text in boxes is used to highlight important information relevant to the chapter. At the end of each chapter, key points are used to summarise the information, along with any suggested reading. A full reference list and glossary are provided at the end of the handbook.

Grateful acknowledgement is given to the contributors who made this handbook possible, the reviewers for valuable additional input, Vivienne McLean and Margaret Richardson for editing contributions, Teresa McConchie for final formatting and Scion for web site preparation. In particular the assistance of NZ Forestry Ltd in allowing the use of website material is also appreciated.

Comments on this handbook and suggestions for revision should be sent to the NZFFA Sequoia Group (see the NZFFA web site for contact details).

Ian Nicholas

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There is a long history of planting in New Zealand with mixed success.

Redwood offers opportunity for export, especially in the Californian market.

Giant sequoia is less well known but also has several positive features, warranting more evaluation.

CHAPTER 2 - TIMBER PROPERTIES AND MARKET

Key Points

There is considerable tree-to-tree variation in redwood wood properties, in both density and durability.

Redwood has a strong market niche in California, which has moved from predominantly old crop to younger, second-growth logs.

New Zealand-grown redwood has an opportunity to market logs in California in addition to New Zealand.

Clones or seedlots with acceptable durability ratings will be a key to securing market acceptance in both New Zealand and California.

CHAPTER 3 - SITE SELECTION

Key Points

Redwood is very site sensitive.

Avoid severe out-of-season frost sites.

Avoid exposed locations.

Avoid windy coastal situations.

Redwood does best in moist valley bottom locations.

Giant sequoia can tolerate cold, dry sites, but can remain in prolonged check after planting.

CHAPTER 4 - HEALTH

Key Points

Redwood is generally a healthy species in New Zealand situations.

Dead branches and extensive bark injuries can offer entry points to borers.

Possums can cause some leader damage on young trees.

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The Kuser collection is not a true range-wide provenance sample of seed sources.

The Kuser collection has provided material for a range of trials on 64 sites throughout New Zealand from 2002-2006.

Limited redwood provenance evaluation has been carried out, on one site, established in 1981.

Giant sequoia provenance trials were established on five sites in 1977-1978.

Progeny from the Long Mile Grove redwoods and Raincliff giant sequoia trees perform poorly compared with other provenance seedlots.

Future selections of redwood and giant sequoia should be based on a wide genetic base and take account of wood properties.

CHAPTER 6 - ESTABLISHMENT

Key Points

Correct siting, robust seedlings and weed control will ensure successful establishment.

Redwood requires weed control for at least 18 months, and possibly fertiliser, to promote early growth.

Giant sequoia is a slow starter, and will often require prolonged weed control.

CHAPTER 7 - PRUNING AND THINNING

Key Points

Redwood requires pruning to produce clearwood.

Over-pruning can result in epicormic shoots.

Pruning in autumn reduces epicormic sprouting.

CHAPTER 8 - GROWTH MODEL AND REGIME EXAMPLE

Key Points

Well-sited redwood grows very well with high volume production figures.

A regime is suggested, with 800 stems/ha, up to 3 pruning lifts, one thinning to final crop stocking of 350 stems/ha for a rotation length of 35 years.

CHAPTER 9 - ECONOMIC ANALYSIS

Key Points

Analysis of redwood forestry in New Zealand shows a positive return (based on Californian prices), with an estimated Internal Rate of Return (IRR) of 9.3%.

Seek professional input before making large investment in redwood forestry

Insufficient information is available to analyse giant sequoia forestry

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New Zealand-grown redwood has been successfully utilised in New Zealand.

A sawing study currently in progress will extend knowledge on utilisation of managed redwood.

CHAPTER 11 - SUMMARY

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New Zealand redwood is a developing industry in New Zealand.

Experience suggests that redwood plantations can be well grown and utilised in New Zealand.

Little information exists to evaluate the potential of giant sequoia for plantation forestry.

As new information is obtained, key results will be updated through the Farm Forestry Association via this handbook.

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CHAPTER 1 - INTRODUCTION

Ian Brown (NZFFA), Charlie Low and Ian Nicholas (Scion),
Rob Webster (NZ Forestry)

Redwood in California

Redwood has iconic status in California, similar to that of Kauri in New Zealand. Redwood is a long-lived tree that can live over 2,000 years, and the reputation of giant sequoia being the largest trees in the world enhances the redwood image.

The image of redwood is reflected in the poem by engineer Joseph Strauss, who also designed the Golden Gate Bridge.

The Redwoods

"Here, sown by the Creator's hand
In serried ranks, the Redwoods stand:
No other clime is honored so,
No other lands their glory know.

The greatest of Earth's living forms,
Tall conquerors that laugh at storms;
Their challenge still unanswered rings,
Through fifty centuries of kings.

The nations that with them were young,
Rich empires, with their forts far-flung,
Lie buried now - their splendour gone:
But these proud monarchs still live on.

So shall they live, when ends our days,
When our crude citadels decay;
For brief the years allotted man,
But infinite perennials' span.

This is their temple, vaulted high,
And here, we pause with reverent eye,
With silent tongue and awestruck soul;
For here we sense life's proper goal:

To be like these, straight, true and fine,
to make our world like theirs, a shrine;
Sink down, Oh, traveller, on your knees,
God stands before you in these trees."

Joseph B Strauss

Figure 1: The redwood grove, Whakarewarewa Forest, Rotorua

HISTORY IN NEW ZEALAND

Early Planting

By the mid-19th century, the plant hunters had moved into the American West, collecting seeds from the spectacular forests on the Pacific seaboard. Redwood seeds were among those of many forest tree species that were introduced to the young colony from the 1860s. They were planted in private estates and gardens, and by civic authorities. The legacy of these early plantings is a scattering of trees of impressive size. The early plantings were no doubt prompted by nostalgia for the familiar, the pursuit of novelty and prestige, and a need for shelter on exposed farm sites.

By 1900, Government recognised the need for afforestation to substitute for declining native-timber resources, and a number of forest nurseries were established. Among tree species redwood was a contender – the leading contenders included Corsican pine and larch, but certainly not radiata pine at the time. Extensive areas were planted in redwood in the Rotorua district, but most failed to establish satisfactorily. The reasons are likely to have included poor site selection (too cold), poor site preparation and lack of weed control, and an absence of suitable mycorrhizae. The trees which did survive and eventually form the Long Mile Redwood Grove, New Zealand's most admired exotic forest stand, nearly succumbed to frosts. They struggled for several years until they were unexpectedly rescued when subsequently interplanted in larch, which gave them shelter.

Between 1920 and the 1940s further plantations were made by both government agencies and private companies, some run by entrepreneurs of dubious reputate. Except in a few small pockets, they all failed to get away, again through ignorance of site requirements and of establishment needs.

For some years after that time, redwood languished in the planting figures, dogged by a reputation for being difficult to establish. There were also concerns about timber quality, when the local product was compared with the timber still under harvest from the old growth forests in California. There was no corporate interest, and a lack of research funding. A number of farm foresters kept the faith, establishing small plantations, more for amenity interest than in the hope of a commercial return. With attention to site selection and weed control, most of these have thrived, and grown into impressive stands. One of the best of these stands is on the Brann's property in the Bay of Plenty.

We decided to start with a simple trial, in which members would be involved. As no research funding was available, it had to be self-funding. The aim of the trial was to examine the growth of a set of clones across a range of New Zealand sites. In 1993, Bill Libby had introduced some clonal material from the Kuser collection in California. The parent trees were unexceptional, but covered the main geographical zone occupied by redwood in California. A selection of clones were bulked up at the Fletcher Challenge tissue culture laboratory at Te Teko, and made available for the trial. Bill Libby provided a planting plan. The participants bought the trees at cost price, planted on their own property, and carried out the silvicultural work. Preliminary results are reported on page 20.

In the absence of research funding, we assumed that this would be the first of a series of small scale trials that would be conducted through the Sequoia Group. However events took a new turn when the Americans arrived.

The redwood revival

The recent renewal of interest in redwood can be clearly dated to a Farm Forestry conference in 1995. While the group sheltered under the Brann's redwood stand, Bill Libby presented a case for reconsidering the place of redwood in New Zealand. As Professor of Forestry at the University of California, Bill Libby has studied and researched redwood for many years, and had a deep knowledge of the New Zealand scene. From his observations of farm forestry plantations he was convinced that with proper site selection and management redwood could be easily established and grow well in New Zealand, and expressed the view that our conditions are probably better suited to growing redwood than anywhere else. Moreover, the quality of locally grown timber is likely to match that of the second growth currently harvested in California, and therefore likely to attract a high price in a market where demand is high and supply is dwindling.

His comments fell on fertile ground, and when a decision was made in 1999 to form a special-interest group, the Sequoia Group within Farm Forestry, there was an enthusiastic response.

The big players get involved

In 2000, a group, comprising the owners and chief foresters of the Soper-Wheeler Company, arrived in New Zealand from California to look at the potential for redwood establishment. Bill Libby was the catalyst, and much of their itinerary was arranged by members of Farm Forestry. They were impressed by our growth rates and timber quality, and keen to be free from the entanglement of regulations that govern forestry practice in California. They returned, as the New Zealand Redwood Company, and have established plantations in Canterbury, and near Hunterville in the North Island. They have an active research program, which includes growth modelling and silvicultural trials. They have introduced seed-orchard and improved clonal material from California, and have selected plus trees in New Zealand for propagation.

Significant plantations are being established by local growers, and will expand as new clonal and seed orchard stock becomes available. These will be selected for form and growth rate, and there is now growing acceptance that selection for wood properties

Figure 2: Giant sequoia, Mariposa grove

is equally important if we are to succeed in the American market.

Rob Webster and his group, the New Zealand Forestry Company, have been active in research and establishment.

Bill Libby maintains an active interest, and continues to provide support and advice.

Wade Cornell has played a major role in research and education, and has pursued a dogged campaign promoting the quality of the species' wood.

Redwood is a demanding species, and in New Zealand we are privileged to have some of the world's best sites for growing it. Redwood forestry is on a roll, and has a momentum that will result in substantial forests. These have the potential to transform much of the rural landscape, and provide a strong economic resource. The next challenge is to prepare for the future markets. This requires us to capture the genetic variability in redwood, and deliver timber of high and consistent quality.

Giant Sequoia

The world's largest tree has a patchy distribution along the western flanks of the Sierra Nevada Range in California. Not surprisingly, it is well suited to the high country of the South Island. Giant sequoia was introduced in about 1860, and has been planted mainly as an ornamental species on large South Island estates and parks. Limited trials were planted on five South Island sites in 1977.

Its timber has traditionally been regarded as inferior to that of coast redwood but is in fact similar, and accepted in the Californian markets. Trials in California and New Zealand have shown very respectable growth rates. It is likely to be more widely planted in the South Island.

Giant sequoia is highly tolerant of gale force winds, an advantage worth bearing in mind as we enter a period when extreme weather events will become more common.

Notable tree, Waikato

Giant sequoia, Rotorua Boys' High School

Giant sequoia planted by Charles Haines at Camp Hill between Glenorchy and Paradise, Otago

Notable tree, Waikato

Figure 3: Notable trees planted in New Zealand

Key Points

- Redwood is of increasing interest to the New Zealand forest industry as a potential plantation tree.
- There is a long history of planting in New Zealand, but with mixed success.
- Redwood offers opportunities for export to the Californian market.
- Giant sequoia is less well known but also has several positive features warranting further evaluation.

Suggested reading:

Brown 2007

Cornell 2002

Knowles and Miller 1993

Libby 1999

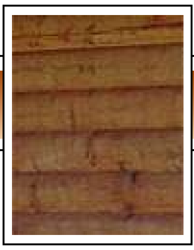
Mortimer and Mortimer 1984

NZ Tree Grower 27 (1) 2007

Poole 2007

Webster 2008

Weston 1957



CHAPTER 2 - TIMBER PROPERTIES and MARKETS

Mark Dean (Ernslaw One), Charlie Low, Russell McKinley and Dave Page (Scion), Rob Webster (NZ Forestry)

The redwood market in California has changed drastically over the last thirty years. As more old crop forest has been placed in reserves, increasing volumes of second generation forests are now being logged. There is little segregation of logs by grade from natural forests other than by small end diameter. Most clear grades come from large old growth logs, which are now in very short supply, with the result that clear lumber grades have virtually priced themselves off the market. This means there is considerable potential for pruning in New Zealand planted forests to produce clearwood. The dimension of logs produced from Californian second growth stands is similar to those of radiata pine logs produced in New Zealand.

The following chart (Figure 4) shows the change in markets for redwood lumber over the past three decades. Although cyclical, the overall trend in total production is relatively static. However, the volume available for export sales or to eastern states of the USA has steadily diminished. Now, virtually all utilisation is within California, with only small amounts in other western States.

New Zealand has a small domestic market, mostly because of the lack of New Zealand-grown material rather than lack of demand. Trial shipments of New Zealand material have been well received in the Californian market.

New Zealand experience

Redwood timber imported from California has a good (and well-deserved) reputation for exterior use and for high-quality joinery. In contrast, New Zealand-grown redwood timber has shown acceptable performance as exterior cladding and interior sarking, but its low density, low hardness, and low-to-moderate durability restrict its range of uses. There has also been considerable tree-to-tree variation in some wood characteristics.

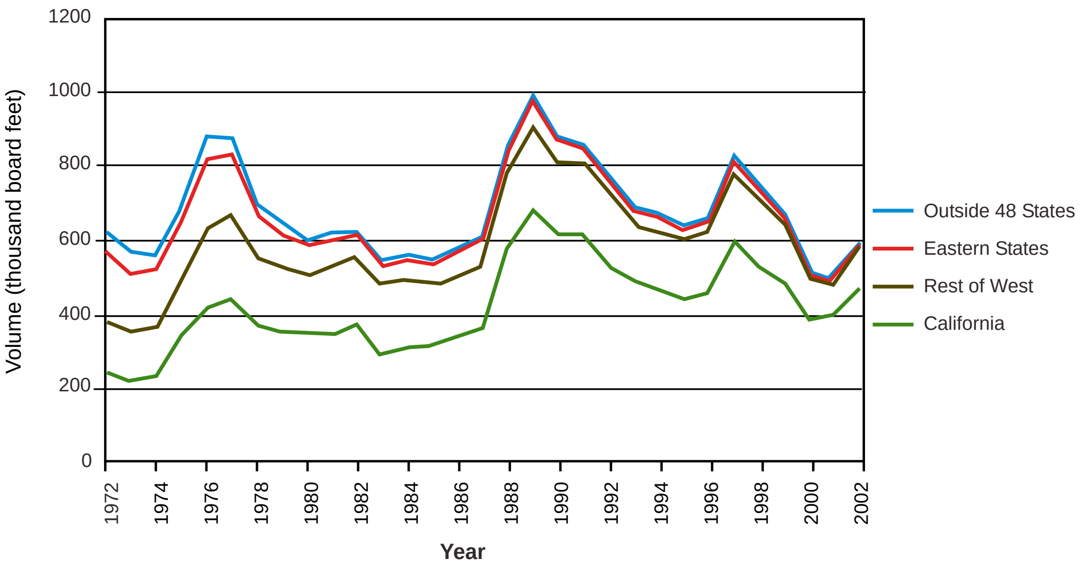


Figure 4: Destination of Redwood Lumber 1972 - 2002

Table 1: Comparison of wood properties of New Zealand-grown redwood and radiata pine (from Knowles and Miller 1993)

Property	Description	Redwood*	Radiata pine#
Density kg/m^3	Basic	335	420
	Air-dry	380	500
	Green	910	955
Shrinkage air-dry %	Volume	4.8	7.0
	Tangential	3.2	4.7
	Radial	1.5	2.2
	Longitudinal	0.02	0.10
Modulus of rupture (MPa)	Green	56	40
	Dry	63	90
Modulus of elasticity (GPa)	Green	6.4	5.8
	Dry	6.6	9.0
Maximum crushing (MPa)	Green	24	16
	Dry	36	38
Hardness (kN)	Green	1.8	2.5
	Dry	1.9	4.2

* Mean values typifying 50 year old trees

Mean values typifying 35 year old trees

Density

Variation in wood density among mature redwood trees is large. A tree evaluated at one New Zealand site was 256 kg/m^3 while the mean of trees from three other sites were 310, 356 and 385 kg/m^3. Estimated wood density from increment cores of 92 trees from nine seedlots at age 20 years in the Bay of Plenty had a mean of 314 but tree-to-tree variation ranged from a minimum of 252 kg/m^3 to a maximum of 415 kg/m^3. In this assessment tree diameter had a larger bearing on density than seed source, with larger trees lower in density. More testing of different redwood seedlots is required so selections for consistent wood properties can be undertaken.

Durability

One of the main market strengths of redwood is the natural durability of its heartwood (the sapwood is not durable). Trials have been undertaken to assess the durability of New Zealand-grown redwood (Table 2). Tests by FRI in 1962 placed New Zealand-grown redwood in natural durability Class 3 (moderately durable). A second test with wood from the same source, some 30 years later, indicated that redwood should be in Class 2 (durable). However, with a further testing of new material, a third set of stakes was less durable than the first and supported the initial classification of Class 3.

Overall, New Zealand-grown redwood has shown quite variable durability. Even though stakes from 80-year old trees appear to be more durable on average than the other sets tested, the first failures occurred in that group after only 2-3 years. Based on the tests done so far, redwood could show durability variation in situations of moderately high decay hazard or in exposed situations where a long service life is required e.g. exposed exterior structural situations.

A series of new tests established in 2007 with 70 and 40-year-old South Island material is currently being evaluated using above-ground lap-joint samples and in-ground stakes. These will provide more information on redwood durability. Laboratory testing of redwood clones has also identified clonal variation in durability.

Table 2: Summary of New Zealand durability tests

Date tests established	Tested material	Location tested	Approx age of material (yrs)	Class
1962	18-19 mm stakes	Rotorua	50	3
1988/1989	20 x 20 mm stakes	Rotorua	80	2
1988/1989	20 x 20 mm stakes	Waitarere	80	2
2001	20 x 20 mm stakes	Rotorua	35	2
2001	20 x 20 mm stakes	Waitarere	35	2
1987	Weatherboards*	Rotorua	N/A	3
1987	Weatherboards*	Devonport	N/A	3

* ex 150 mm rusticated
N/A: Not available

The reasons for the high variability are not clear although this is not unusual in species with a Class 3 durability classification.

In a Californian study it was found that decay resistance also varied amongst trees and also within the heartwood of individual trees. It was found that decay resistance decreased from outer to inner heartwood.

In low decay hazard situations such as weatherboards, New Zealand-grown redwood should meet the requirements of NZS 3602:2003 (NZ Standard for Timber and Wood-Based Products for Use in Building). The service life of uncoated boards is likely to be limited by erosion and distortion but could be improved with well-maintained surface coatings.

Use in Decking

Some New Zealand-grown redwood is too soft for exposed decking. Its low strength means that it would need to be either supported by joists at closer spacing or be thicker than radiata pine decking. Surface erosion on decking is likely to be worse than on uncoated weatherboards and would produce a very rough surface on lower density boards within five years. Its variable durability would also make it marginal for use as decking because a few failures in less than 15 years (the minimum requirement in NZS 3602) could be expected in exposed situations and in areas where there is a higher decay hazard e.g. poorly ventilated or constantly damp areas.

Giant sequoia has a reputation of producing similar timber to redwood, although it is reported to be brittle and requires different drying schedules. Commercial production in California is very small compared to redwood production. New Zealand-grown giant sequoia has not been fully evaluated.

The US decking market

The US residential deck market is large, 6.5 million new decks are constructed each year, with growth of 8.1% per year (1991-1999). Redwood was used in 12% of US residential decks in 1987 and 11.1% of decks in 1998 . The small decline in market share was possibly due to the higher price for redwood, reducing demand. Using the approximate average size of constructed decks gives an estimate of the demand for redwood deck material in the US. This equates to approximately 3.6 million m^3/yr. As an indication, this demand is approximately 80% of New Zealand's total sawn wood production in 2003. These figures are indicative only, as a greater proportion of decks in the western US use redwood, compared with the rest of the US. Also, decks in the south-western US tend to be larger on average than elsewhere.

California Redwood Association website.

Log Prices

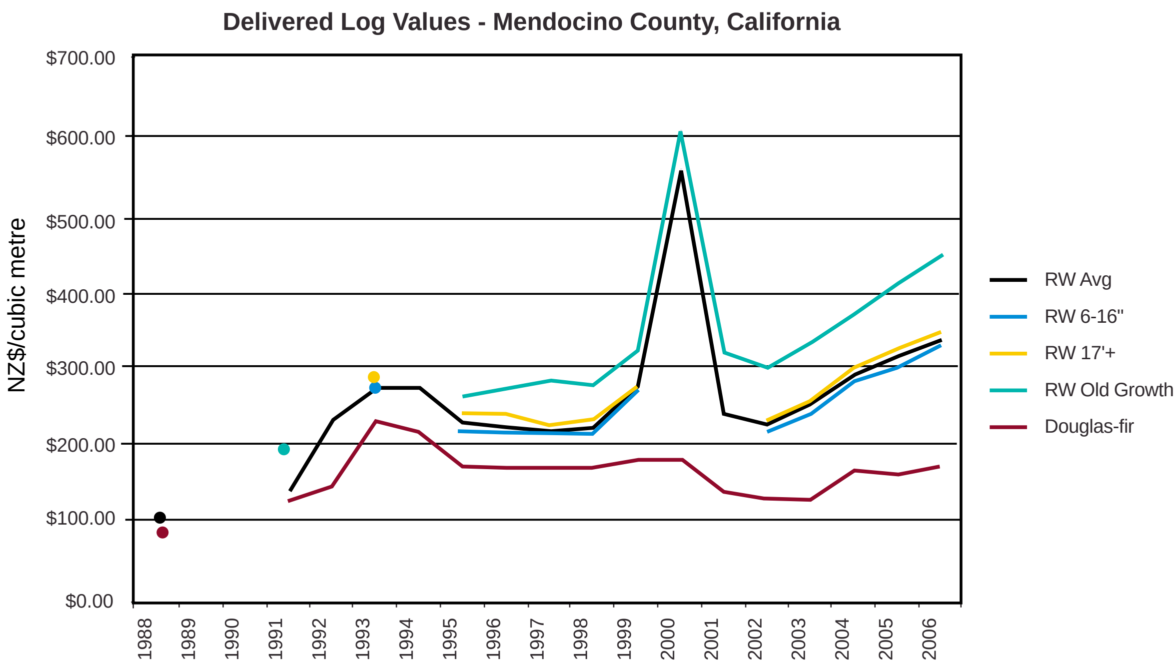


Figure 5: Redwood markets in USA

Most redwood logs exported from New Zealand have been marketed to Asian countries, such as Korea and Taiwan. Sources in this market have suggested that they would purchase all the lumber New Zealand could produce and match US prices.

Rob Webster

Figure 6: Debarked redwood logs at the Palco sawmill at Scotia, Humboldt County.

Nick Kent

Figure 7: Weatherboards on building, Coromandel Peninsula

Key Points

- There is considerable between tree variation in redwood wood properties, in both density and durability.
- Redwood has a strong market niche in California, which has moved from predominantly old crop to younger second crop logs.
- New Zealand growers have an opportunity to market redwood logs in California as well as locally.
- Clones or seedlots with acceptable durability ratings will be a key to market acceptance in both New Zealand and California.

Suggested reading:

Bier and Britton 1999

Clark and Scheffer 1983

Clifton 1994

Cornell 2002

Cown 2008

Di Maio 1997

Knowles and Miller 1993

Nicholas and Garner 2007

Webb 2007

CHAPTER 3 - SITE SELECTION

Ian Brown (NZFFA), Charlie Low (Scion), Ruth McConnochie (Nelson), Ian Nicholas (Scion), Rob Webster (NZ Forestry)

In its natural habitat, redwood grows from sea level to 900 metres altitude but prefers altitudes lower than 750 m. It prefers mild climates, although in many parts of its natural range it experiences winter snow and frosts of up to –10°C. The presence of well performing stands near Winton, Southland; North Canterbury; and Hamurana Springs. Whakarewarewa and Waiotapu near Rotorua, attest to the species' ability to do well in some cold sites in New Zealand. However, it is vulnerable to out-of-season frosts, perhaps the reason for the much publicised early establishment failure of various stands in the Central North Island during the 1920s and 1930s.

Assessment of the performance of redwood on a wide range of New Zealand sites over the last ten years has shown that the species has a wider range of site tolerances than previously thought. However, redwood performs best on soils of moderate to high fertility in areas with reasonable year-round rainfall. Avoid planting redwood on terraced sites where deep sediment deposits can lead to anaerobic conditions unfavourable to redwood growth. Redwood is intolerant of strong prevailing winds, but is surprisingly resistant to toppling and breakage from periodic storms. (Note that despite its common name coast redwood, derived from its natural range being close to the coast, redwood is *not* tolerant of salt-laden coastal winds!).

Sequoia Action Group Research Packs

During the winter of 2002, the Sequoia Action Group, of the New Zealand Farm Forestry Association, arranged for individuals to plant small plots with up to eight representatives of eight clones of redwood on a range of sites throughout New Zealand. The trial was designed by Prof. Bill Libby. Spacing was 5 m x 5 m, and plants were in groups of four identical clones.

The trials were assessed by farm foresters in 2006. In all 34 replies from the 53 sites were returned (64%), seven sites were abandoned, three failed because of frost, two because of soil erosion and or slips, and one had problems with chemical control.

This left 27 sets of data for analysis. Preliminary results are presented below. This shows a huge variation in growth with over 4 m difference between the best and poorest-performing sites. Considerable variation also occurred between plantings within regions. In Northland alone there was nearly 4 m difference between the best and worst site. The mean of the 19 North Island sites was 2.53 m, while the mean of the eight South Island sites was 1.5 m.

While the trial layout was the same and the clones were repeated on each site, it is difficult to interpret the main reasons for the difference in growth performances, as individual owners managed site preparation and weed control in different ways. Differences are likely to be at least in part due to microsite differences in both soil and site. More time and soil sampling is needed to determine this.

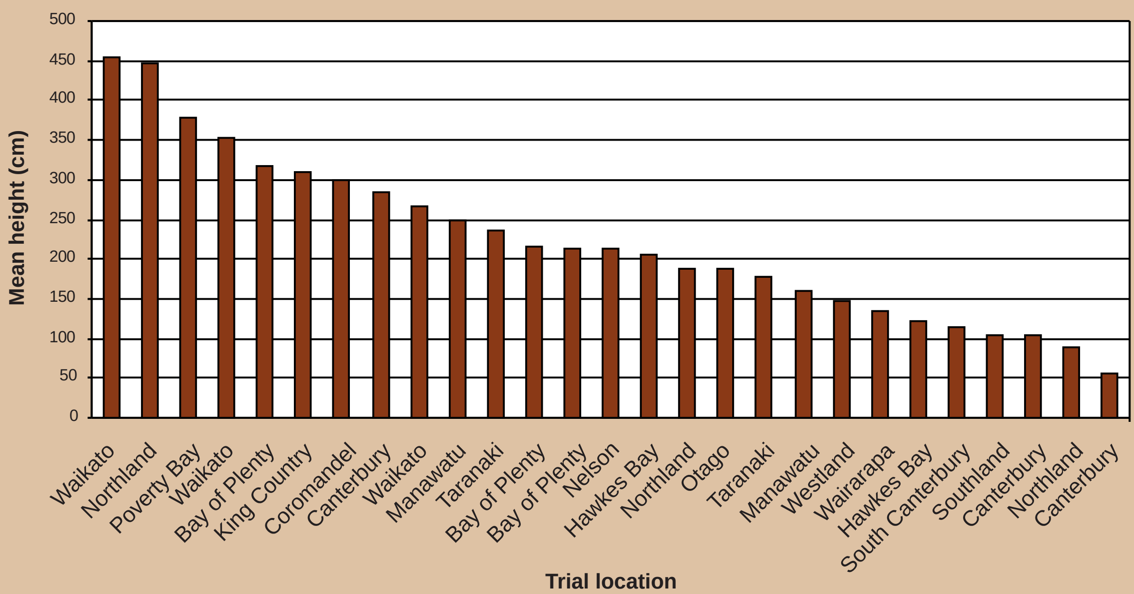


Figure 8: Average trial height at age 4 years

Giant sequoia has not had the plantation history of redwood to help guide siting recommendations. However the successful plantings in parks around the country, in particular, in cold and dry inland South Island locations, supports the impression that giant sequoia can tolerate colder and drier conditions than redwood, although a study of trees surviving droughts in the early 1990s identified giant sequoia as susceptible to drought.

Key Points

- Redwood is very site sensitive
- Avoid severe out of season frost sites
- Avoid exposed locations
- Avoid coastal situations
- Redwood does best in moist valley bottom locations
- Giant sequoia can tolerate cold dry sites as a specimen tree, but its site requirements as a plantation crop remain unclear.

Suggested reading:

Knowles and Miller 1993

Snowdon 2003

Webster 2008

Marden 1993

CHAPTER 4 - HEALTH

John Bain and Ian Nicholas (Scion)

Redwood and giant sequoia have a justified reputation for being healthy species, with no major insect or disease problems.

There has been some anecdotal evidence that pruning can allow entry of a native longhorn borer or huhu beetles, *Prionoplus reticularis*, whose tunnels severely down-grade the value of the sawn timber. Attack from these insects is only in the heartwood, with entry gained through dead branch stubs and/or stem damage which exposes heartwood. The incidence of attack is unknown, but expected to be sporadic rather than constant. This problem has been more commonly reported from warmer areas (Northland, Bay of Plenty) but the extent of this risk has not been objectively quantified.

The New Zealand drywood termite, *Kaoltermes brouni*, are secondary colonisers, obtaining entry to the dry heartwood through the bore holes of other insects. Dead branch stubs/bark encased knots provide access past the sapwood band for the lovers of the dryer heartwood. Significant damage to the heartwood can result from the termite colony and associated infection and rot. Stand management which minimises dead branches could be expected to reduce the risk of such attack.

Growing tips of redwood have suffered some leaf-roller damage, but this has not been of major concern.

A canker fungus, *Botryosphaeria* has been reported to cause minor damage on both redwood and giant sequoia. It has been reported that seedlings in nurseries can have problems with botrytis. Cypress canker has been recorded on giant sequoia, but its impact is unknown.

Possums can create damage to leaders in some locations and it is prudent to control populations if establishing redwood plantations. Cattle can also cause bark damage in young stands.

Key Points

- Redwood is generally a healthy species in New Zealand situations.
- Dead branches can offer entry points to borers.
- Possums can cause some leader damage on young trees.

Suggested reading:

Cornell, 2002

Knowles and Miller 1993

Visit www.nzffa.org.nz for the most up-to-date information available.

CHAPTER 5 - SEED SOURCE and BREEDING

Charlie Low (Scion), Ruth McConnochie (Nelson), Harry Saunders (NZ Forestry) and Toby Stovold (Scion)

The natural distribution of redwood in both latitude and altitude offers the opportunity to select seed sources that could do well in New Zealand but very little formal breeding has been undertaken in New Zealand to date. There has been more emphasis on using existing collections as a starting point rather than developing a broad genetic base for long-term tree improvement programmes. However, the ability to grow redwood as cuttings allows growers to reproduce elite material. This provides opportunities for selection and clonal propagation of elite material. Those planting forests should ensure they have the best genetic material available that has a proven track record in New Zealand.

Provenance Trial

The first full test of redwood seedlots was a trial established in Rotoehu Forest in 1981. This compared nine seedlots - eight from the natural range and one from the Redwood Grove at Rotorua. The poorest performer was the Redwood Grove source.

Redwood provenance trial

The 1981 Rotoehu trial was assessed for diameter and stem form in January 2001.

There were noticeable differences in tree size across the site with trees on the lower slopes being larger than those on the higher ground. Stem diameter of the individual trees was extremely variable and this tended to obscure any differences between seedlots.

However the measurements suggested that seedlots from the Korbel area of California performed well for growth and that the Whakarewarewa Long Mile seedlot was the slowest growing. If past damage caused by possums is discounted then most seedlots had acceptable stem form.

The trial was planted at 950 trees per hectare and had an effective stocking rate of around 660 trees per hectare. The overall average diameter on this site at age 20 years from planting was 320 mm compared with 280 mm for the Whakarewarewa seedlot. A few of the largest trees in the trial were over 600 mm in diameter.

Source: Vincent 2001

Kuser clonal provenance trials in New Zealand

Background

These trials derive their name from Professor John Kuser, a long-time redwood scholar of Rutgers University, who in 1983 initiated a collection of seedlings from 98 different stands in locations throughout the natural range of redwood to evaluate provenance variation in this species.

The intention was to compare the impact of various environmental conditions on the relative performance of material from throughout the natural range of redwood at a number of sites. This would provide information as to the best part of the natural range for selecting plant material.

Note that this was not a provenance trial in the traditional sense, in that the collection focused on just two random seedlings from each part of the range.

The reason for using vegetative propagation rather than seed was the difficulty of collecting seed from all populations because redwood has relatively few good seed crop years in California. The collection comprised of 198 genotypes, mostly young seedlings but occasionally cuttings from sprouts or older seedlings. During 1984 Dr Kuser delivered all his plants to the Simpson Timber Company nursery at Korbel for rooting. The Korbel stool beds were replicated at the University of California (Berkeley) Russell Reservation research facility, and a Californian Division of Forestry site at Jackson State Forest. The latter site was not maintained and only the two sites now exist in California. Replicate stool beds now exist in France and Spain.

New Zealand Trials

Recent redwood trials in New Zealand began back in 1990. Bill Libby was working at the then Fletcher Challenge facility at Te Teko in the Bay of Plenty, and encouraged the importation and evaluation of some of the Kuser collection. Fletcher Challenge Forests established a small number of tissue-cultured plants in a few trials in the late 1990s. A number of the clones from the above importations have been used in two series of clonal trials established by the NZ Farm Forestry Association on sites provided by members throughout the country. These trials provide an opportunity to compare sites throughout New Zealand.

A number of other clones were imported at a later date. Wade Cornell of Diversified Forests imported more clones from the Russell Reservation site in late 2000 along with other selections from redwood's natural range.

Sequoia Action Group research packs (2002)

During the winter of 2002 the Sequoia Action Group of the New Zealand Farm Forestry Association established small trial plantings of 64 trees (up to eight representatives of eight clones) on 53 sites throughout the country (see Chapter 3).

Kuser Trial Establishment (2003-2006)

During 2001, the Soper-Wheeler Company with their then New Zealand subsidiary "JPS", now The New Zealand Redwood Company (NZRC), imported to New Zealand 182 clones of the original 198 in the Kuser collection. Jim Rydelius, the Manager of NZRC at the time, was involved in the initial selection and propagation of the Kuser Clones and in the Simpson Redwood breeding programme undertaken during his time with the Simpson Timber Company at Korbel, California.

Stool beds were established at the Southern Woods Nursery in Canterbury. The Kuser clones were multiplied by cuttings and in 2003; 174 clones were established in clonal trials at three New Zealand sites. A further eight trials were established in 2004-2006 with 136-160 clones on each site. The objectives of these trials were to establish long term field tests that would quantify variation in growth, form and wood properties. To help to achieve this, trial sites have been distributed throughout New Zealand so that site variability in terms of altitude, latitude, soils type and climate will allow the evaluation of the clones for site x genotype interaction. Sites range from 40 m above sea level to 595 m. Each trial site has been planted with 8 replicates of each clone set out in six blocks of 36 trees at 3 m x 3 m spacing. Seedlings of a single seedlot are included as a control. The trial design, establishment and monitoring has been coordinated by Scion-Genetics and NZ Forestry Ltd.

Giant sequoia trials

In the early 1970s, Lauren Fins, as a PhD student of Bill Libby's at University of California, Berkeley, undertook a seed collection of up to 50 trees in each of 34 of the scattered natural stands. Most of the seed was extracted from cones harvested by squirrels. The study was quite extensive, looking for differences in seed and isozymes at the individual-tree and provenance levels. When the study was completed much seed had been used, but there was enough to make up 16 seedlots comprising seed from at least five trees per grove (or provenance), which was sent to New Zealand.

This seed was sown in a glasshouse at Rangiora nursery in December 1975 and seedlings were pricked out into PB3 containers. The seedlings were planted out on three sites, Hanmer (Canterbury), Craigieburn, (Canterbury), and Beaumont, (Otago), in winter 1977 and cuttings were planted on a further two sites in 1978, Rai Valley (Nelson), and Kakahu, (South Canterbury). A further planting of 112 unidentified cuttings was planted out adjacent to the seedling trial at Beaumont, the best planting site chosen.

The trial stocking is unusual, with the giant sequoia planted at 6 m x 5 m, then interplanted with larch to provide a spacing for the mixed stand of 3 m x 2.5 m. The initial stand composition featured larch (*Larix decidua)*, at 1,000 stems/ha and giant sequoia at 333 stems/ha. The nurse species planted at Craigieburn was birch (*Betula verrucosa*), rather than larch.

The giant sequoia were fertilised and released with Caragard, to control weeds. The spray damaged a number of trees at Kakahu. Half of the larch were removed at Hanmer and Beaumont in 1986. Early growth was painfully slow, in spite of the fertilising and releasing from weeds.

The Rai Valley site was assessed in 1981, when the cuttings were then aged three years. All other sites were assessed in 1983, when the seedlings at Hanmer, Beaumont and Craigieburn were six years old and the cuttings at Kakahu were five years old.

Best provenances reached only two metres in height at the best site, Beaumont, six years after planting. Average height at the other sites was around one metre, although survival at all sites planted with seedlings was high at 90-100%. Survival of cuttings planted at Beaumont was 98%, while Kakahu ranged from 29 to 92% and Rai Valley from 50 to 100%. Possible explanations for the lower survivals of cuttings are that Kakahu and Rai Valley were harder sites and the spray damage at Kakahu.

The Beaumont trial was measured in 1987, 1989 and 2002. The rate of height growth improved considerably at Beaumont after age 6, with the trees trebling their height to around six metres by age 12. Height growth for each seedlot was graphed against time for the Beaumont data (Figure 9) and the slope of the line becomes much steeper after age six. One seedlot shows slightly faster height growth between ages 10 and 12 but for most the rate of growth is constant from age 6 to age 12.

The 1978-planted cuttings appeared to be growing at least as well as the seedlings at this site, with the 30 cm difference in height in 1983 roughly equal to one year of early height growth for the seedlings, planted a year earlier. Form assessment showed that malformation is negligible at this site, with three trees being forked and four trees possessing ramicorn branches. The largest tree at age 12 was 9.5 m in height and 330 mm in diameter and had grown 2.7 m in height in two years.

The New Zealand seedlot from Raincliff was notable for its poor performance relative to the Californian seedlots. This is very different from the usual story in New Zealand conifer plantations, in which the neighbourhood inbreeding of natural stands is typically broken down, and some natural and silvicultural selection can occur for adaptation to local conditions, to produce more vigorous seed than natural stands in the country of origin. The poor performance is most likely due to deleterious effects of inbreeding, and caution must always be taken when collecting from sources of unknown origin. At age 25 the best seedlot was over 17 m tall and the poorest 13.5 m tall. Most of the seedlots had similar heights to each other at age 25 years, but progeny from the New Zealand Raincliff stand was significantly shorter.

The best tree from each seedlot had scion material taken in 1989 and the resultant grafts are growing at Proseed's Amberley Seed Orchard since 1990.

Figure 9: Seedlot mean height and diameter at Beaumont, 1983, 1987, 1989 and 2002

Figure 10: Beaumont Trial at age 27 years

The trial at Hanmer was assessed in 2002, when tree heights had improved from an average of 1.4 metres at age six years to around 12 m at age 25. The largest tree was 18 m tall and 700 mm in diameter. Provenance means from the 2002 assessment are shown in Figure 12. An average-sized tree of 300 mm diameter and 14.6 m in height from the North Calaveras provenance is shown in the photo below.

Figure 11: Giant sequoia at Hanmer, aged 25 years

The Hanmer trial had more seedlots tested than Beaumont. The best-performing seedlot at Beaumont was not the best at Hanmer, but progeny from the Raincliff stand averaged the poorest on both sites. Inbreeding depression is a very plausible explanation for fhe poor performance of the Raincliff seedlot. The seedlot register reveals that there were only four trees in the parent “stand”. All four trees could well have come from a single seed parent, so the seed would result from brother/sister mating. Conceivably, all four trees could have grown from cuttings taken from a single tree, so that all seed would be selfed, therefore highly inbred. Whatever the case, no further seed should be collected from this stand. Regrettably, there have been a number of seed collections from Raincliff over the years, and this may explain some of the failures of this species in New Zealand.

At Hanmer, only two trees had kinked stems, which appeared to have been caused by weed competition. Only one tree was forked. Branching was fine, with no branches larger than 2 cm. The 25-year-old trees could be pruned with light secateurs.

Once giant sequoias are fully established, from a slow start their growth rate improves considerably. Height growth in excess of one metre per year can be attained, along with diameter growth of over 25 mm per year on trees over 10 years old, on good sites. The Beaumont site, benefiting from extra water nutrients by being at the foot of a slope, with a deep river terrace soil, is evidently an ideal site for this species.

Vegetative propagation of giant sequoia

Difficulties in obtaining seed, poor seed germination, and some high levels of inbreeding, make vegetative propagation of known superior genetic sources an attractive option for the species. Rangiora nurserymen found the species easy to propagate from 18-month-old seedlings and it is a species which can produce coppice growth when felled. Ideally, plants should be grown from outcrossed seed produced in the Amberley orchard and multiplied vegetatively, or cuttings harvested from the coppice of superior mature trees. Care must be taken to avoid maturation of select material.

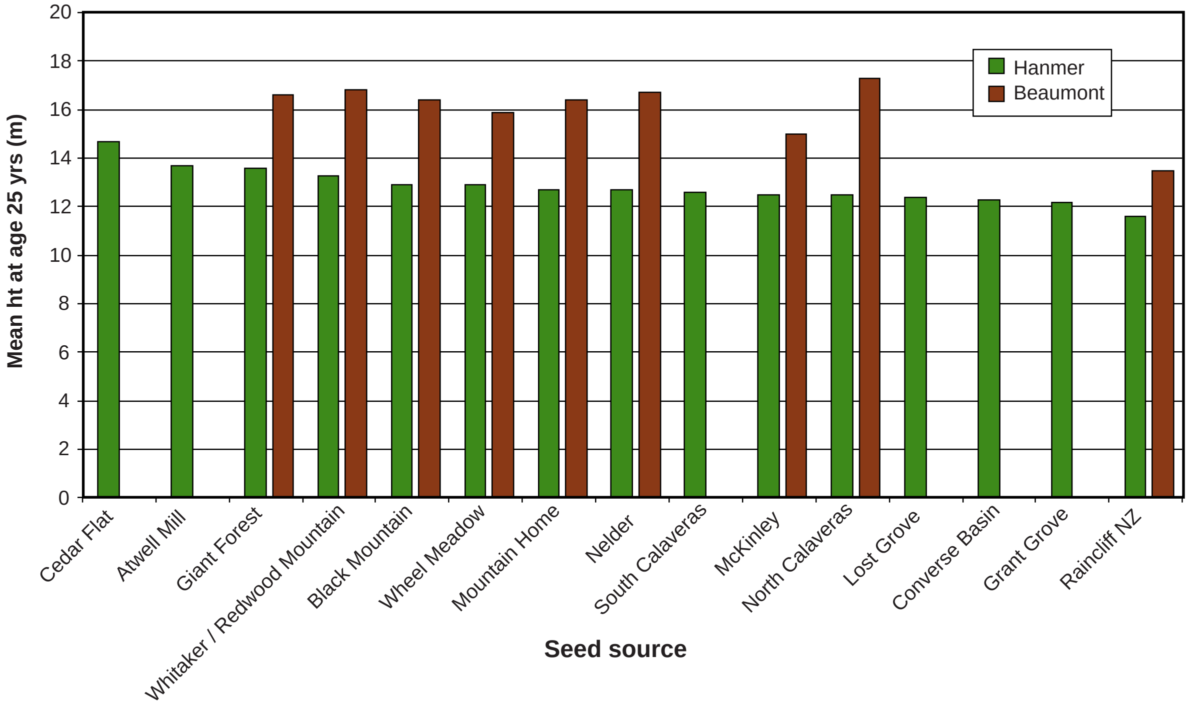


Figure 12: Mean provenance height for Hanmer and Beaumont sites at age 25 years

Key Points

- The Kuser collection, while representing a geographic spread, is not a true provenance-wide selection of seed sources.
- The Kuser collection has provided material for a range of trials on 64 sites throughout New Zealand from 2002-2006
- Limited redwood provenance evaluation has been carried out on one site, established in 1981.
- Giant sequoia provenance trials were established on five sites in 1977-1978.
- Progeny from the Long Mile Grove redwoods and Raincliff giant sequoia trees perform poorly compared with other provenance seedlots.
- Future selections of redwood and giant sequoia should be based on a wide genetic base and with regard to wood properties.
- There has been no breeding for redwood in New Zealand, but there is potential for significant improvement of redwood performance for both growth and wood properties.

Suggested reading:

Fins and Libby 1982

Knowles and Miller 1993

Libby 1993

Saunders and McConnochie 2007

Vincent 2001

CHAPTER 6 - ESTABLISHMENT

Ian Nicholas (Scion) and Simon Rapley (NZRC)

To create a successful plantation redwood must be well sited, robust planting stock used and key establishment measures taken. Apart from one trial, little published research has been conducted on establishment techniques in New Zealand. However with over 1,000 ha established in the last few years, plenty of operational experience is accumulating.

The key to successful establishment is weed control, especially over the first two growing seasons after planting. Fertiliser may also be required, depending on location.

A standard establishment regime could be:

- Pre-planting spray (Roundup or Gallant)
- Planting 800 stems/ha. A seedling clonal row by row planting pattern is suggested to provide thinning options to favour either row in the future.
- Fertilisation (if required)
- Release immediately after planting to control weed germination if required
- A second release at 18 months (or earlier if required). Generally no chemical should be sprayed over the top of seedlings, but a shield can be used in combination with a single fan nozzle.

Alternately, establish 500 stems/ha of elite clones (that have been formally tested) to achieve a final crop of up to 400 stems/ha. Elite clones selected for fine branching and stem form (among other characteristics) do not need higher initial stocking to control branch size or encourage form. Because redwoods coppice vigorously once felled, thinning must be delayed to prevent the coppice competing with the final crop. Delaying thinning to control coppice is likely to suppress the growth of the crop trees.

An establishment trial in the East Coast region showed that the best growth was achieved by applying a combination of fertiliser and weed control. Of the two treatments on that site fertiliser was the most important (Table 3).

Table 3: Growth of Coast Redwood, initial 3 years (from Bowles, 1980)

Treatment	Mean height increment (cm)			End 3rd year diameter (mm) at ground level
	1st year	2nd year	3rd year	
Fertiliser, grass controlled	42	67	89	68
No fertiliser, grass controlled	30	49	75	49
No fertiliser, no weed control	14	24	58	31

Although they grow to a magnificent size, and can make very high current stem-volume increment, giant sequoia is slow to become fully established, and will require excellent weed control to hasten the process.

Key Points

- Correct siting, robust seedlings and weed control will ensure successful establishment.
- Redwood requires weed control for at least 18 months and possibly fertiliser to promote early growth.
- Giant sequoia is a slow starter and will require prolonged weed control.

Suggested reading:

Bowles, 1980

Cornell, 2002

CHAPTER 7 -PRUNING and THINNING

Mark Dean (Ernslaw One), Mark Kimberley (Scion), Paul Silcock (Scion) and Rob Webster (NZ Forestry)

Figure 13: 29 year old untended redwood, East Coast

Introduction

Redwood has proved to grow well in New Zealand when correct siting and establishment practices are attended to. With mean annual increments in excess of 30 m^3/ha/year on good quality sites (warm, sheltered and with regular rainfall e.g Taranaki or Bay of Plenty), growth rates can equal or better those of radiata pine. Redwood is more shade tolerant than most conifer species so will survive in very low light situations. However it does require full sunlight to grow rapidly. Perhaps because of these attributes redwood readily grows from coppice and stump or root sprouts. These physiological attributes potentially allow some innovative regimes not commonly practiced with more light demanding conifer species.

Redwood enjoys a strong market demand in USA (Chapter 2), where restricted access to natural stands enhances the potential for an export market to develop for New Zealand-grown redwood. However, the Redwood lumber market differs from the radiata pine model we are used to. In California, clear heart grades attract a large premium over those with sapwood content and unpruned 'tight knot' grades, which in turn are more valued than timber with bark-encased knots. This grade and price differential, based on branch condition as well as size, provide an important distinction from the radiata pine lumber market, which most New Zealand forest growers are used to, and will provide some challenges in managing redwood silviculture.

Current Issues

While New Zealand growth rates allow for rotation lengths of around 35 years, careful attention will need to be paid to designing regimes that will capture most of the potential value with such rotations. The target will be to achieve large pruned butt logs with upper unpruned logs with green or moribund branches less than 50 mm diameter. Although there have been several hundred hectares of redwood grown and harvested in New Zealand, most have not been intensively managed so the effect of various pruning, thinning and initial/final crop stocking combinations has not yet been quantified.

However, over the past few years Scion, with assistance from NZ Forestry Ltd, The NZ Redwood Company and the Plantation Management Cooperative, has initiated a number of silviculture trials to study some of these interactions. A series of final crop stocking trials have been installed in existing stands located in the Central North Island, East Coast, Hawkes Bay and Otago. Within four or five years there will be sufficient data to formulate a thinning-response function to augment the basic growth functions implemented in the NZ Forestry/NZ Redwood Company growth model. This will allow managers to predict the outcome of various thinning and final crop stocking regimes in terms of tree growth.

Given the high value of clearwood and the premium for heartwood over sapwood combined with the uniform wood properties from pith to bark, pruning to achieve these classes of end-product is certainly a favoured option. It may be worth pruning redwoods to a small DOS as has been done with cypresses in some instances.

Figure 14: Epicormic shoots sprouting from the branch collar and cambium of a young pruned tree.

Operationally speaking, pruning redwood is not difficult. The wood is relatively soft and branches in plantation grown trees are generally small and well-spaced. Although redwood bark is thick and fibrous on mature trees, young trees have bark that is easily damaged so care must be taken to not damage the bark and cambium around branch collars when pruning.

Two pruning trials, at Tutira and Gisborne, have been installed by the Plantation Management Cooperative in partnership with The New Zealand Redwood Company. Although still in progress, interim results indicate that both stocking and pruning severity affect tree growth.

Of much greater interest is the impact of pruning severity on the incidence of epicormic shoots. These originate from buds in the cambium and are stimulated by the combination of stress induced by removing the green crown (live branches) and light on the stem. When early severe pruning treatments are applied the stems can be clothed with epicormic shoots which negates the pruning effort. However, by delaying pruning until the bark is thicker, pruning in autumn and leaving more green crown, much of this problem may be avoided.

Another silvicultural challenge is to maintain live or only recentl dead branches in the lower unpruned logs, typically from 6-15 metres height on mature stems. Currently our understanding of crown height recession with increasing stocking and age is fairly basic. There is a need to better quantify this and also to understand the time delay between branches dying and the formation of bark-encased 'loose knots'. As for managing redwood stands to minimise the incidence of bark-encased knots in sawlogs, there are a number of possible strategies which, to the authors' knowledge, have yet to be tried. For example, regimes involving multiple thinnings or possibly ultra high pruning may serve the desired goal.

There have recently been sales of small logs (down to 20 cm SED) which can be sawn for utility uses. This may make it possible to carry out production thinning on some sites. Alternatively, pruning dead branches to facilitate higher recovery of more valuable 'tight knot' grades of lumber may be warranted.

As stated earlier, log quality is of paramount importance in order to maximise the returns from redwood. To date very little is understood about the timber grade and hence value recovery from various log types arising from regime options. The sawing study currently being carried out by Scion and Interpine with funding through FIDA and the redwood theme within Future Forests Research Ltd should significantly improve baseline knowledge and provide for realistic economic analyses to attract investors and set fair market values for logs.

Figure 15: Left unmanaged epicormic shoots can quickly undo the pruning investment. The epicormic growth on the lower portion of these trees is just 12 months old.

Figure 16: Insect attack, possibly pin hole borer on an 8 year old pruned redwood. This attack may have been aborted once through the bark.

Silvicultural research

In recent years Scion, with industry support, has established more than 60 permanent sample plots in stands throughout New Zealand. In response to interest from clients (The New Zealand Redwood Company, NZ Forestry Ltd), Scion has collected retrospective growth data and developed a preliminary New Zealand Redwood Growth Model to predict yield. It is intended that as more data become available the model will be improved and mortality, pruning and thinning response functions will be added.

With funding from the Plantation Management Cooperative a series of trials designed to quantify growth response to final crop stocking and to investigate the effects of pruning severity and timing on growth and log quality has been installed (Table 4).

Table 4: Replicated silviculture response trials.

Location	Plant year	Trial type	Date Installed
Waiotapu (CNI)	1982	Final crop stocking	July 2004
Otago Coast (Otago)	1986	Final crop stocking	August 2004
Mangatu (East Coast)	1978	Final crop stocking	April 2004
Tutira (Hawkes Bay)	1998	Pruning, final crop stocking	Dec 2003

Case Study: Waiotapu Redwood Final Crop Stocking Trial

Coppice growth two years after thinning

Redwood is among the few conifers capable of producing true epicormic shoots ('sprouts'). Sprouts arise from dormant buds found along stems and, branches, and among burl tissues at the base of the tree/root collar, and can therefore coppice from stumps. Buds can be released from dormancy when sources of inhibiting hormones are eliminated and environmental conditions are favourable. Two opposing processes affect the vigour of a sprout clump: the decline in carbohydrate and mineral-nutrient reserves in the stump, and the accumulation of reserves by the sprout clump. The sprout-clump vigour is therefore a function of both the reserves at the time of cutting and the light environment following cutting.

The initial 2-year measurement of coppice growth in this trial provided data on the frequency, recruitment and vigour of sprout growth on thinned redwood stumps under three final-crop stockings. Over time this data will be useful in evaluating silvicultural regimes where coppicing may be desired (continuous-cover forestry) or not (when thinning to a final crop). The stand was planted in 1982 with an initial stocking of 1200 stems/ha. It was thinned in 2004 to four stockings: 350, 500, 650 and 1000 stems/ha.

A simple survey carried out in spring of 2005 and 2006 measuring number and height of coppice at each thinning stump shows the effect of light on coppice incidence and vigour. Figure 17 shows a higher incidence of stumps coppicing in the lower final crop stocking whereas Figure 18 shows a much higher number of shoots per stump occurring in the 500 stems/ha treatment.

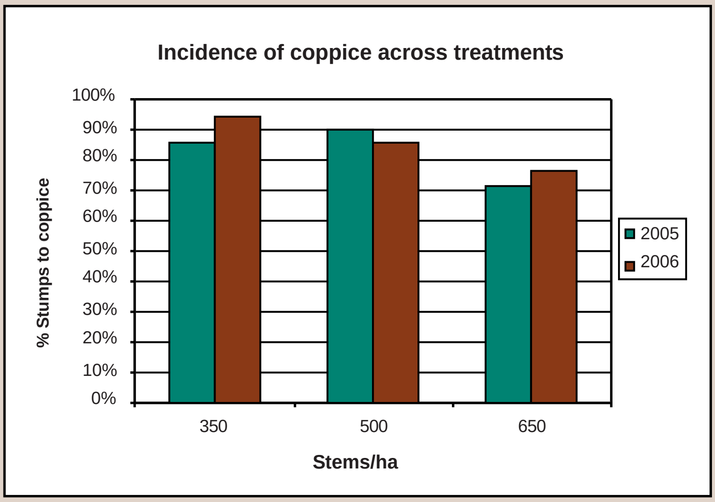


Figure 17: Incidence of coppicing stumps across three different final crop stocking thinning treatments in Waiotapu forest in 2005 and 2006

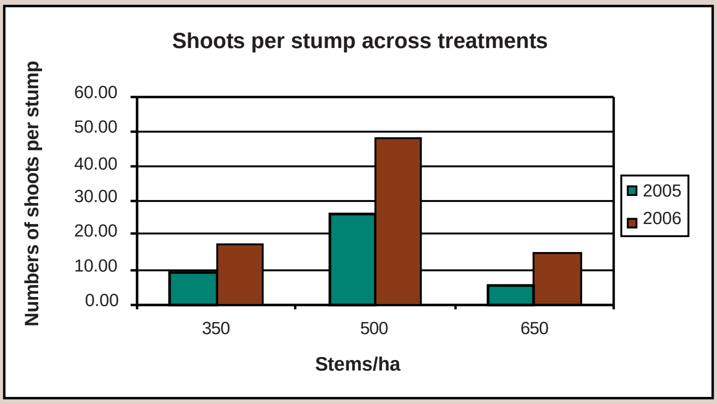


Figure 18: Vigour of stump coppice as shown by number of shoots per stump across three different final crop stocking thinning treatments in Waiotapu forest in 2005 and 2006

Case Study: Epicormic Shoots

Although there is considerable interest in growing and intensively managing redwood in New Zealand, little is understood about how it responds to the intensive silviculture commonly practiced with radiata pine in this country.

One such response is that of epicormic shoots developing up the length of the trunk after pruning. The shoots arise from buds that otherwise remain suppressed by the concentrations of auxin and carbohydrates in the phloem. Rapid changes in the light levels, temperature, nutrients or moisture can also induce a similar response.

Epicormic shoots are not true branches and do not have a knot that goes right back to the pith like a normal branch. If removed within the first season they may not cause any serious loss in clearwood recovery. However if left growing, they could cause serious downgrade to the target pruned clearwood.

In 2004 a replicated randomised block design pruning trial for redwood was installed at Tutira in Hawkes Bay. Silviculture treatments covered a range of three pruning intensities and three stocking levels. In the Wairengaokuri step- out trial, two replicates of one treatment have been established, with half the trees in each plot being pruned in spring and the other half pruned in autumn to test if season of pruning has any impact on development of epicormic shoots.

An assessment of epicormic response across the different treatments was carried out in November 2005 and December 2006, 22 and 35 months after pruning.

At the two trial sites intensive pruning resulted in sufficient numbers of epicormic shoots of significant size as to severely compromise clearwood yield. The incidence and size of epicormic shoots proved to be dependent on the severity and season of the pruning treatment. Most (and the largest) epicormic shoots appear on those stems pruned in spring, with the most severe treatment (5.5cm calliper), on the portion of the stem exposed to the most sunlight (1.2 m).

The effect of season on shoot numbers reduces over time, with no difference between spring and autumn two years after pruning. However those shoots that remain are significantly larger on the stems pruned in spring. Therefore it may be advantageous to delay pruning until the trees have thicker bark and a greater degree of canopy closure and retain a number of follower stems to provide shade to the stem. Scheduling more lifts of less severity during the autumn months should reduce epicormic incidence and size.

Key Points

- Redwood requires pruning to produce clearwood
- Overpruning can result in epicormic shoots
- Pruning in autumn reduces epicormic shoot development

Suggested reading:

Dean, 2007

CHAPTER 8 - GROWTH MODEL and REGIME EXAMPLE

Ian Nicholas, Paul Silcock (Scion),
and Rob Webster (NZ Forestry)

The increasing popularity of redwood forestry in New Zealand means an escalating need for predicting growth and yield, to provide greater confidence for those investing in redwood. First-generation models have been developed.

NZ Forestry in association with the New Zealand Redwood Company has been instrumental in initiating the development of a Redwood Growth Model and new volume and taper equations for redwood in New Zealand. The growth model predicts basal area (BA) and mean top height (MTH) for redwood grown in New Zealand. The model was developed using data from stem analysis (felling trees, cutting into discs and reconstructing growth by growth-ring analysis) of trees from eight stands supplemented with data from 32 PSPs (Permanent Sample Plots). Most of the PSPs have only recently been established and they therefore only provide an estimate of yield at a single point in time. Stem-analysis data were therefore used to characterise growth trajectories and determine appropriate model equation forms, while the PSP data were used to calibrate this model to actual-plot measurement data representative of the species and covering a reasonable range of New Zealand sites.

The Site Index for New Zealand redwood is defined as MTH at age 40 years. Basal area productivity is based on a “400 Index” measure (BA40/400) defined as BA at DBH at age 40 years and a stocking of 400 stems/ha. The models, along with a stem volume function, have been implemented in a Microsoft Excel spreadsheet-based application.

Performance within New Zealand

The New Zealand Redwood Growth Model has been derived from stands established with genetically unimproved seed. Hence predictions for stands now being established from imported seed orchard material or select clones are likely to be under-predicted.

Table 5 presents data from a number of sites within New Zealand. The table presents estimated site index and BA40/400 for each site and growth model predictions at age 35 years for the specified targets of final crop stocking.

Table 5: Growth model estimations in growth of selected stands.

Location	Site Index m@ 40 yrs	BA m^2/ha	Target stocking stems/ha	Predicted DBH cm	Predicted BA m^2/ha	Predicted Volume m^3/ha	Predicted MAI vol m^3/ha/yr
Bay of Plenty	47	213	450	73.5	184.2	1871	53
East Coast	43	202	400	71.4	154.6	1445	41
Hawkes Bay	49	132	350	59.5	93.9	975	28
Taranaki	40	154	350	64.9	115.8	1036	30
East Coast	40	150	350	64	112.8	1008	29
Taranaki	39	128	325	59.6	87.5	754	22
Rotorua	35	145	350	62.3	103.2	808	23
King Country	40	118	325	57.2	80.8	712	20
Taranaki	36	110	325	55.2	75.2	604	17
Wellington	29	145	350	62.3	103.2	682	19
Wanganui	35	110	325	55.2	75.2	590	17
Otago Coast	32	120	325	57.7	82	598	17
Reporoa	37	101	300	53.9	66.1	542	15
Mean	**39**	**141**	**348**	**61**	**103**	**894**	**26**

It is clear from these estimations of yield that redwood on good sites is capable of at least matching the average yield of radiata pine on many sites.

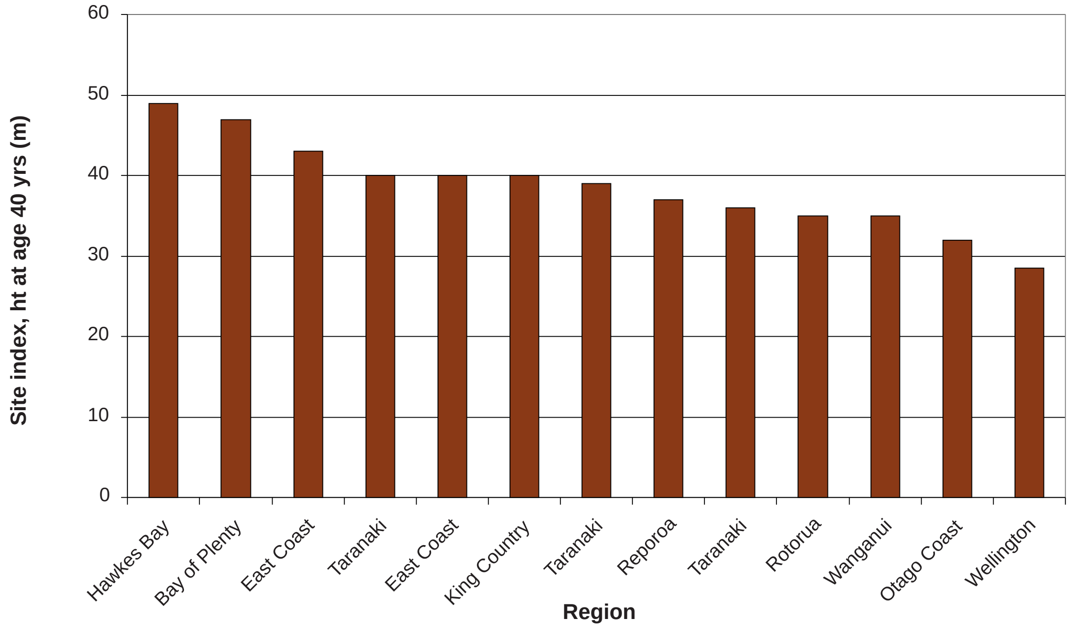


Figure 19: Site Index of cross section of New Zealand stands

Rotorua's Long Mile Redwood Grove in Whakarewarewa Forest

In Whakarewarewa Forest planting began in 1899. With 170 tree species planted, it was one of the first large experimental forests to help guide the afforestation of New Zealand. The most famous remnant of these early plantings is the Redwood Grove.

The stand when planted in 1901 originally covered 32 ha. Apart from scattered trees surrounding the grove the area is now about 6 ha. A feature of the stand is the many mature tree ferns and other native flora present throughout the Grove.

The Grove has been formally dedicated as a memorial to those who lost their lives in the two World Wars.

Apart from being Rotorua's most popular walking and running track the Redwood Grove has also been used for many unique activities ranging from wedding party photos, dawn church services (NZ Forest Service reunion), orchestral music (FRI 50-year jubilee) to the resting place of the ashes of Mr Bob Burstall (the father of notable trees in New Zealand).

The Grove is recognised as a historic tree site by the Royal NZ Institute of Horticulture, and is protected under the Rotorua District Scheme.

Since 1948, a 0.4 ha sample plot has been measured regularly (see measurements below).

Table 6: Growth measurements from Redwood Grove Permanent Sample plot

Age yrs	**MTD** cm	**MTH** m	**Volume** m^3/ha	**BA** m^2/ha	*MTD in*	*MTH ft*	*Volume ft/ac*	*BA* ft^2*/acre*
54	97	41.8	879	85.1	*31.8*	*137.1*	*2883.9*	*370.7*
57	100	45.9	1014.8	90.7	*32.8*	*150.6*	*3329.4*	*395.1*
65	107.1	48.3	1214.2	104.4	*35.1*	*158.5*	*3983.6*	*454.8*
68	109.6	49.2	1291.3	109.4	*36.0*	*161.4*	*4236.5*	*476.5*
71	111.3	51.8	1397.5	113.2	*36.5*	*169.9*	*4585.0*	*493.1*
78	115.3	52.5	1524.3	122.4	*37.8*	*172.2*	*5001.0*	*533.2*
82	117.8	55.1	1658.3	127.9	*38.6*	*180.8*	*5440.6*	*557.1*
86	120.4	57.4	1795.5	133.8	*39.5*	*188.3*	*5890.7*	*582.8*
90	123.5	57.9	1890.8	140.8	*40.5*	*190.0*	*6203.4*	*613.3*
95	126.2	60.1	2048.7	147.3	*41.4*	*197.2*	*6721.5*	*641.6*
99	128.3	59.7	2103.0	152.6	*42.1*	*195.9*	*6899.6*	*664.7*
100	128.8	59.4	2109.0	153.5	*42.3*	*194.9*	*6919.3*	*668.6*

Comparison with growth in the United States

Height growth in forest stands is measured by Site Index (the expected height of trees at a given age). For redwoods in the United States, the Site Index is quoted as expected height in feet at 100 years. Measurements from the Redwood Grove show that the stand has a Site Index of 200 feet. This is double the lowest Site Index used in US site tables of 100 feet, but less than the two best Site Indices used of 240 and 220 feet.

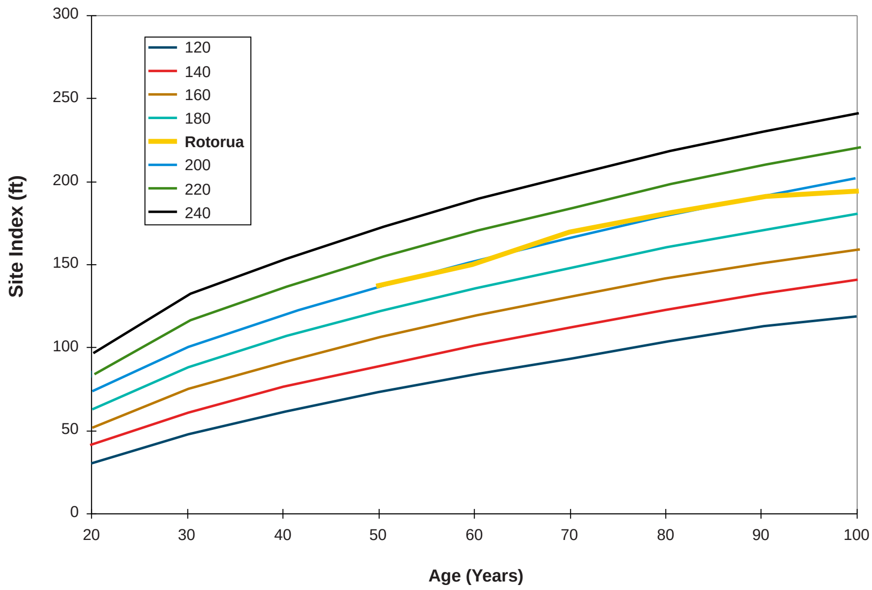


Figure 20: American Site Indices with Redwood Grove data highlighted

Suggested Regimes

Regimes for redwood are in their infancy, with many theories as to the best options. The following reflects the current thinking on potential regimes (Table 7). This can be expected to change as more data and experience is gained. (Check for updates via this electronic handbook).

Table 7: Suggested regime for redwood sawlogs

Operation	Age (yrs)	Comment
Pre-plant weed control		
Establish 800 stems/ha	0	Alternate rows of clones and seedlings
Release	0-1	Fertilise if required
Prune 420 stems/ha 0-2.5m	6	Calliper prune to 12 cm diam in August
Prune 385 stems/ha 2.5-4.5	7.5	Calliper prune to 12 cm diam in August
Prune 350 stems/ha 4.5-6.5 m	9	Calliper prune to 12 cm diam in August
Thin 800-350	11	August
Clearfell	35	Target DBH 60 cm or greater

Prune in 2 or 3 lifts (depending on site productivity) with a 12 cm calliper to 6 metres in autumn. This should result in a DOS of 12-15 cm and will reduce the incidence of epicormic shoots. Timing of thinning will depend on the incidence of epicormic shoots in the crop, exposure and green crown condition.

Key Points

- Well sited redwood grows very well with high volume production figures.
- A regime is suggested, with 800 stems/ha, up to 3 pruning lifts, one thinning to final crop of 350 stems/ha for a rotation length of 35 years

Suggested reading:

Berrill and O'Hara 2007

Dean 2007

Knowles and Miller 1993

Nicholas 2007

Tombleson 2004

CHAPTER 9 - ECONOMIC ANALYSES

Ian Nicholas, Paul Silcock (Scion), and Rob Webster (NZ Forestry)

The economics of growing redwoods are uncertain because of many unknown figures in costings (Table 8), yields and returns. As more data are gathered and models become more refined, confidence in economic predictions will increase.

In a recent comparison of alternative species it has been estimated, based on certain assumptions, that redwood plantations could return an IRR of 10.5%. This was higher than any of the other species assessed (radiata pine, Douglas-fir, eucalypts and blackwood). However it was stressed that this required good growing sites, and assumed that durability issues would not impinge on the market price. The redwood prices used in this study were based on Californian prices costed back to New Zealand dollars.

The average MAI of 13 sites based on growth model predictions gives a mean volume MAI of 26 m^3/ha/yr with a range of 15-53 m^3/ha/yr. Based on the mean volume MAI of 26 m^3/ha/yr and a rotation length of 35 years, this represents a total volume of 910 m^3/ha. Assuming that 95% is recoverable logs a total of 865 m^3/ha of recoverable logs is used in these assumptions.

It is estimated that 39% is pruned material, 34% large diameter unpruned and that 27% is smaller diameter unpruned logs.

Table 8: Costs and operations used for base case analysis

Operation	Stand age	Cost($/ha)
Land cost	-	0
Land prep	0	648
Tree stocks	0	1360
Planting	0	320
Fertilising	0	252
Releasing	0	240
Releasing	1	250
First prune	6	800
Second prune	8	840
Third prune	10	780
Thin	10	380
Annual costs		60

Management fee (15% of costs) Roading, log and load ($50/$m^3$)

The revenue is based on figures quoted by Piers Maclaren who used a New Zealand value of $184/m^3$ at mill door. This was derived from calculations by Wade Cornell working back from Californian prices at the time (2003) to a stumpage value back in New Zealand of $144/m^3$. This was converted back to a mill door value of $184/m^3$.

This provides a base case with an IRR of 9.3% (not including land costs). If land costs of $4,000/ha are included, IRR drops to 6.7%.

If plant costs are halved to $720, IRR increases to 8.9%. Using Cornell's stumpage of $144 across all log grades gives an IRR of 9.2%.

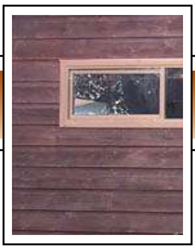
N.B. As the figures used in this analysis are of a general nature only, more detailed site specific analysis evaluated by professional advisers should be used on a case by case basis before investing in redwood forestry.

Key Points

- Analysis of redwood forestry shows a positive return (based on Californian prices), with an estimated IRR of 9.3%.
- Seek professional input before any large investment in redwood forestry.
- Insufficient information is available to analyse giant sequoia forestry.

Suggested reading:

Maclaren, 2005

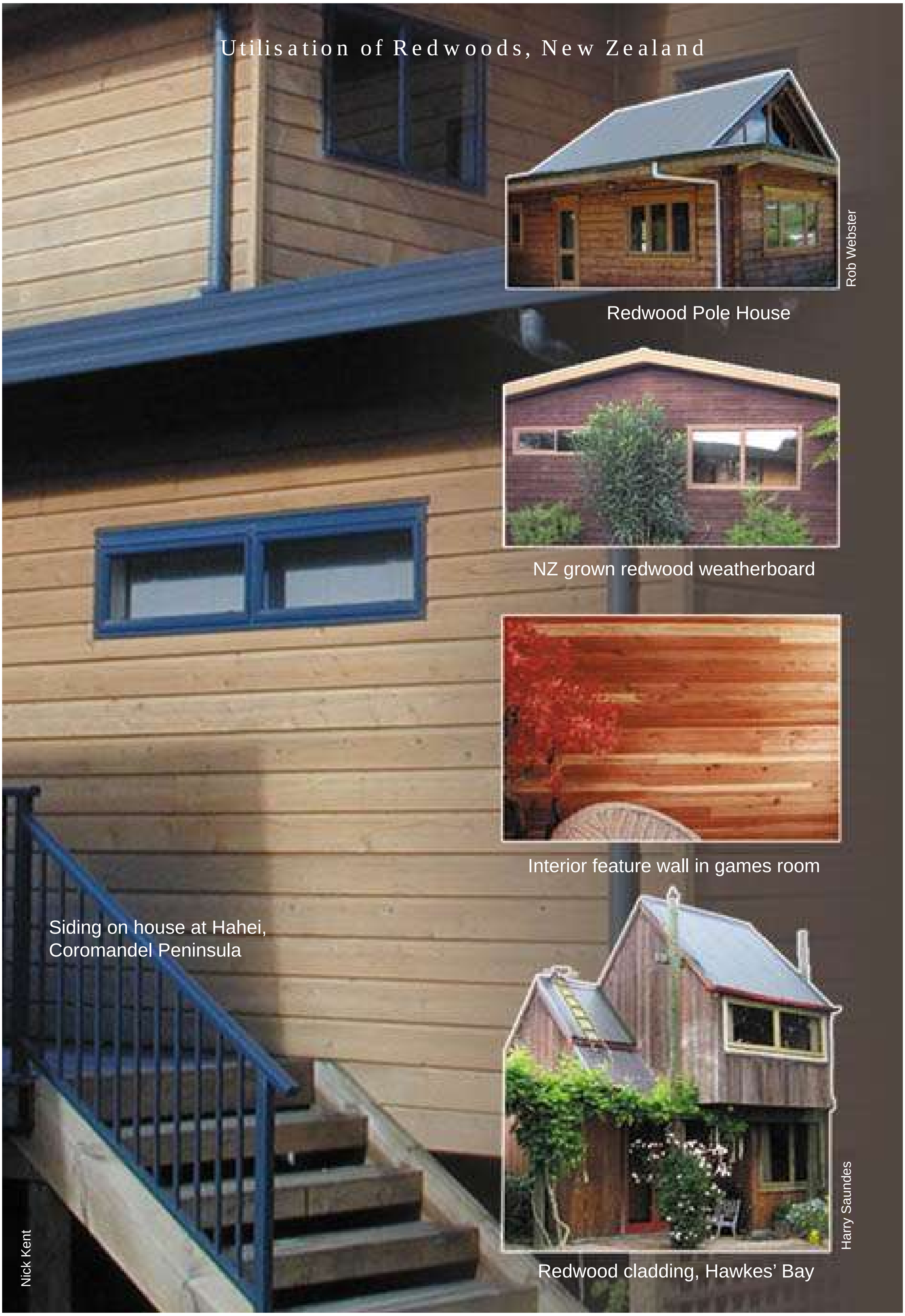


CHAPTER10 - UTILISATION

Ian Nicholas (Scion) and Rob Webster (NZ Forestry)

Both New Zealand-grown redwood and imported timber is being utilised in New Zealand, predominantly for weatherboards. Minimal problems have been reported by those sawing redwoods and the sawing of large trees from the Scion campus (for example) was conducted without any major problems.

New Zealand-grown redwood has performed well in most situations but weathering of early wood has been an issue in some exposed situations. The recently completed sawing study of a tended 38 year old stand from Mangatu will provide a wealth of data on conversion rates and timber grades from a managed redwood plantation. The issue of heartwood percentage and reliable durability will be the key aspects of successful utilisation of future redwood plantations.



Rob Webster

Redwood Pole House

NZ grown redwood weatherboard

Interior feature wall in games room

Harry Saundes

Redwood cladding, Hawkes' Bay

Siding on house at Hahei,
Coromandel Peninsula

Nick Kent

Utilisation of Redwoods, USA

Rob Webster

New House, Tahoe

Rob Webster

House, Fort Bragg

Fencing products

California Redwood Association website.

Gazebo

Decking


Rob Webster

Home at LakeTahoe, USA

Key Points

- New Zealand grown redwood has been successfully utilised in New Zealand.
- A sawing study will extend knowledge on utilisation of managed redwood.

Suggested reading:

Tombleson 2007

CHAPTER 11 - SUMMARY

Ian Nicholas (Scion)

Interest in redwoods for commercial plantations has been revived in New Zealand. This has developed for two main reasons, the performance of second-growth redwood on the Californian market which is lower quality than old-growth-timber, and recent overseas investment in New Zealand redwood forestry. Furthermore, the formation of a Sequoia Action Group within the NZFFA has seen a focus on redwood by farm forestry members and specialist consultants. Also, a Redwood Group has been formed under the Diverse Species sub-theme within The Future Forests Research Ltd. These factors have combined to produce a redwood forest resurgence, creating interest and activity within the New Zealand forest industry. The move from amenity tree to plantation tree has generated research activities to provide confidence to those establishing redwood plantations. Information gained on siting and management will help ensure plantations are successfully established and well managed. Economic assessments, based on a range of assumptions, suggest that redwood plantations can be grown profitably. However, the variation in wood properties, especially durability, must be overcome to produce a product that meets the expectations of both New Zealand and Californian markets.

Apart from some provenance trials, very little information is available for giant sequoia, despite it having potential for forestry on sites where traditional forest species are less well suited.

Growing redwoods is still a small portion of the New Zealand forestry scene. Further investment is required to know and grow improved stock, understand wood durability in New Zealand-grown timber.

However it appears redwood can perform very competitively with main-stream forestry species if it is sited and grown competitively.

As more information becomes available on redwood forestry topics this electronic handbook will be updated to provide the most up to date relevant information for those interested in redwood plantations.

Key Points

- Growing redwood is a developing industry in New Zealand.
- Experience suggests that redwood plantations can be well grown and utilised in New Zealand.

Little information exists to evaluate the potential of giant sequoia for plantation forestry.

As new information is obtained, key results will be updated through the NZ Farm Forestry Association via this handbook.

Suggested reading:

Nicholas *et al.* 2007

Tree Grower 2007

CHAPTER 12 - REFERENCES and WEB LINKS

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Weblinks

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- www.rarefind.co.nz
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CHAPTER 13 - GLOSSARY

Appearance grade: Grades of timber for finishing and other uses determined basically from the appearance of the better face and edge, usually clearwood.

Bare-rooted planting stock: Plants (seedlings, cuttings or other) grown in open nursery beds rather than containers and lifted and planted with much of the soil gone from their roots.

Basal Area: The cross sectional area of all tree stems in a stand, measured at breast height and usually expressed per hectare of land.

Basic Density: The average density of the wood at 0% moisture content

Breeding: Intensive selection and subsequent mating of top selections to achieve cumulative genetic gain over time.

Breeding population: The population in which breeders carry out intensive selection and genetic recombination. It comprises the selections that are inter-mated and their resulting offspring. It requires a broader genetic base than the seed production (orchard) population.

Cambium: A layer of rapidly growing cells between the bark and the wood, from which new wood and bark develop.

Clearwood: A length of timber which is free of knots due to branch removal, usually achieved by pruning.

Clearfell or **Clearcut:** Harvesting of trees in which essentially all trees are removed in one operation.

Clone: A group of genetically identical plants, which have been vegetatively propagated from a single individual.

DBH: Diameter at breast height of tree stems, at 1.4 m in New Zealand.

Family: A group of individuals directly related by descent from a common ancestor.

Followers: Unpruned trees left in the stand with pruned trees at the time of thinning.

Hardness: A property of timber that enables it to resist indentation.

Heartwood: The inner, nonliving part of a tree stem. Natural chemicals are often deposited in the heartwood, making it more durable and darker in colour than sapwood.

IRR (Internal Rate of Return): The discount rate that equates the various costs and benefits anticipated in future years of forestry (or other) operations.

Knots: A cross section of a branch that is imbedded in timber. The knots can either be live knots (branch was living when the tree was cut) or dead knots (from a dead branch) which often fall out.

MAI (Mean Annual Increment): The total increment of a stand up to a given age, divided by that age. Includes thinnings as well as standing crop.

Mean (arithmetic mean): The average value for a set of observations, obtained by dividing the sum of all observations by the total number of observations.

MoE (modulus of elasticity): A measure of stiffness in sawn timber.

MoR (modulus of rupture): A measure of bending strength in sawn timber.

Mouldings: High grade timber, usually clearwood, sawn for specific end uses e.g. skirting.

MTD: (Mean Top Diameter): The average diameter of the largest 100 stems/ha in a stand.

MTH (Mean Top Height): The average height of the largest 100 stems/ha in a stand.

Native population (syn. native provenance): A group of naturally growing trees found at a particular geographic location within the native range of the species.

Pith: The central core of a stem and roots, inside the first annual growth layer of wood

Progeny trial: Evaluation of parents by comparing the performance of their offspring, properly in a replicated field layout.

Propagation: Multiplication of plants. Can be either via sexual reproduction (seed production) or via asexual means (vegetative propagation).

Provenance: The ultimate geographic origin of seed, pollen, or trees.

Provenance test: A replicated field trial comparing the performance of trees grown from seed collected from different parts of a species' geographic range.

PSP plots (Permanent Sample Plots): permanent plots that have been set up throughout the plantation estate, to provide growth information for the national database on the plantation resource.

Resistance: The relative ability to repel or endure pests or other damaging influences. It may vary in degree from immunity, in which the attack or influence is completely without effect to absolute susceptibility, which may result in death.

Sapwood: The outer layers of a tree trunk, which represent living cells and conduct water up the tree, bounded by the cambium on the outside and heartwood in the inside. Generally lighter in colour than heartwood, and non-durable.

Sarking: Internal roof panelling.

Sawlog: A log that meets standards for diameter, length and defect, which is intended for sawing.

SED: The small-end diameter of a sawlog.

Seedlot: A collection of seeds, usually of known source.

Seed orchard: A plantation of selected trees, established and managed primarily for the early and abundant production of genetically improved seed. The seed orchard is isolated to reduce pollination from outside sources, and trees with undesirable characteristics are removed, based on ongoing evaluations.

Seed stands: A well-grown stand of trees, with good growth and form, selected and managed for abundant seed production.

Seed stratification: A treatment given to seed to break dormancy and improve germination, which usually involves a moist chilling.

Shelterbelt: A strip of trees established to shelter farm- or horticultural land from prevailing winds.

Site index: A measure of forest site quality expressed as the average height (actual or potential) in a specific stand of trees, at a specific age (40 years for redwood in New Zealand, 100 years for redwood in the USA).

Standing volume: The total volume of harvestable trees in a stand.

Stocking: The number of trees in a given area of a stand.

Tissue culture: (syn. micropropagation) Growing plantlets from small pieces of plant material on artificial media in a sterile, laboratory environment.

Tree improvement: Often equated with tree breeding, it includes species choice and provenance selection, but may also refer to breeding in combination with cultural practices, particularly propagation.

Veneer: A thin sheet of attractive wood, used to cover wood of lesser value.

Vegetative propagation: (syn. vegetative multiplication) Multiplication of plants via asexual means, i.e. without sexual reproduction. Includes tissue culture, rooted cuttings, and grafting.

Virulence: The ability of an organism to cause disease.