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Sequoia sempervirens Silvicultural Practices Review and Data Analysis

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

Coast redwood (*Sequoia sempervirens*) is a promising plantation species for New Zealand. Little is known about what silvicultural practices are appropriate for managing the species in New Zealand. The objectives of this study were therefore to:

- review previous research on regime trials to determine the current knowledge of silvicultural practices in New Zealand and overseas;
- provide recommendations on silvicultural practices to FFR;
- determine if current thinning regime trial data are suitable for the development of a thinning model; and
- develop priorities for future research.

In order to assess the above objectives, a stand basal area equation that predicted growth over time was developed first. This was done to determine long term trends in basal area development with age. This equation was developed from permanent sample plots (PSPs) with the longest measurement periods. Each silvicultural trial was assessed for thinning and pruning treatment effects. The effectiveness of the Interim Redwood Growth Model was assessed with current PSP data. The results of the study were as follows:

1. Maximum productivity of coast redwood is unknown. The highest stand basal area in New Zealand is from Taumarunui - 241 m^2/ha at 86 years. However, data from more productive younger sites suggest that a higher maximum is possible.
2. There is little mortality in young or old PSPs, which suggests that current stockings are below full site occupancy.
3. For the thinning trials, there were no observed treatment effects on growth rate. A lack of a response was partially due to the low stand density of the controls and the short length of time since the treatments were applied. The high shade tolerance of a long lived species means that responses to thinning will take longer than in other plantation species.
4. The data indicated that individual-tree growing space analysis may be more sensitive to early thinning effects than stand level analysis, and may be more appropriate for this species
5. For the pruning trials at Tutira, growth rates of pruned stands were able to recover within two years of a light prune and four years of a severe prune. The data suggest that young coast redwood stands can adapt and respond quickly to crown removal at a favourable site. Pruning reduced relative basal area five years after the first lift – 10% for light pruning and 20% for heavy pruning. The benefits of pruning from a smaller diameter over stubs at harvest will likely outweigh any reduction in tree volume.
6. Comparison of PSP data with predictions from the redwood growth model indicated that the model was reasonable. Due to a lack of additional data, little will be gained by improving the model at this time.

Silvicultural Recommendations:

Although there are some promising trends, there has been insufficient time since the establishment of the trials to conclude what management practices will maximise tree growth and merchantable timber at harvest. The regime trials have yet to show clear growth responses to silvicultural treatments, except for the quick recovery from severe pruning at Tutira. Thus, thinning and pruning functions for the interim redwood growth model cannot be developed at this time. Despite the inconclusive nature of the regime trials, the following can be concluded about silvicultural practices for coast redwood:

1. *Stand density:* The results indicate that the current stocking levels used by industry (400-750 sph at establishment) are unlikely to require a thinning due to intraspecific competition

until at least 30 years. It is hypothesized that stocking on unfavourable sites will need to be less due to more intense intraspecific competition.

2. *Pruning severity:* The Tutira results suggest that on a favourable site, coast redwood can recover quickly from severe and frequent pruning. However, this may not be the case on unfavourable sites. It is recommended that pruning regimes on unfavourable sites are less severe than those applied for the heavy pruning regime at Tutira.
3. *Rotation length:* The Mangatu sawing study has shown that a 38-year-old stand on a highly productive site can produce valuable merchantable timber. It is unclear how these results can be applied to other sites due to differences in silviculture and genetics. It is reasonable to hypothesize that a rotation length of 40 years on a favourable site is likely to produce trees with high log grades.
4. *Silvicultural prescription:* Based on available data, coast redwood on a highly favourable site will likely support a final crop stocking up to 500 sph. Repeated, severe, pruning with a final prune height of at least 8 m is unlikely to have an impact on growth and survival.

Trial and PSP Recommendations

1. *Measurements of PSP network*: Further measurements of current PSPs and regime trials are required to provide evidence of the likely long-term trend in growth dynamics
2. *Expand the PSP network*: More PSPs need to be established in regions where coast redwood is most likely to be planted commercially on favourable and unfavourable sites.
3. *Improve the interim growth model in five years' time*: When more observations are collected from current and new PSPs, treatment responses from silvicultural trials may become clear enough to develop thinning/pruning functions for the growth model.
4. *Establish more pruning and thinning trials:* More pruning trials are required to understand the dynamics of pruning severity, pruning frequency to control diameter over stubs, and timber quality at harvest. More thinning trials will help researchers understand the impact of intraspecific competition throughout the rotation.

INTRODUCTION

Coast redwood (*Sequoia sempervirens*) is an alternative commercial species to radiata pine (*Pinus radiata*) [1-6] Although the wood is not used on a large scale domestically, there is a well established market in the United States. The timber, highly desired for its heartwood colour and rot resistant properties, has multiple outdoor and indoor uses [7]. Uses include house sidings, fences, outdoor decking and furnishings, interior trim and moulding, and interior shelving [7].

Research in the last 15 years has identified the potential for coast redwood as a fast growing plantation species in New Zealand [8]. With logging in California of redwood forests becoming increasingly restricted, there is an opportunity for New Zealand to become an important supplier of the timber [1]. Further, its ability to sequester carbon long after canopy closure means that coast redwood is highly suitable for long-term carbon forestry in New Zealand.

Despite the above attributes, research on this species has been limited for a number of reasons. These include forestry companies focusing on radiata pine, little interest in the wood in the domestic market, and failures of plantings in the past due to poor siting and lack of site preparation and weed control [8].

Due to limited research in New Zealand, the growth dynamics of coast redwood and responses to silviculture is not well understood. Analysis of previous and current data from regime trials, permanent sample plots (PSPs), and other sites would provide a better insight into how this species responds to different silvicultural regimes.

This study investigates whether it is feasible to make silviculture recommendations for coast redwood based on data recorded from recently established spacing and pruning trials.

The following analyses were carried out to determine whether it would be feasible to develop a model predicting response to silviculture, and to determine the adequacy of the current coast redwood model:

- A brief investigation of maximum stand basal area and tree mortality in older trials.
- An analysis of how coast redwood responds to pruning and thinning/spacing trials.
- An analysis of how well the current redwood interim growth model [9] predicts height and basal area development from new PSP data from growth and regime trials.

The results are then discussed and recommendation made for silvicultural practices and future research priorities.

Current coast redwood PSPs managed by Scion/ FFR are listed in Appendix 2, with recommendations on their usefulness for future data collection and model development.

LONG-TERM TRENDS IN STAND BASAL AREA AND MORTALITY

To be able to develop reliable growth and silvicultural models for coast redwood, it is important to know the long term trends in growth. However, coast redwood PSPs vary considerably by stand age, the age when the PSP was established, and the number of PSP measurements. Indeed, it is unclear what the long-term growth trends would be, as only a few PSPs are established in stands older than 40 years. Four PSPs were selected to determine the long-term growth trends and individual tree mortality of coast redwood (Table 1).

Table 1: List of PSPs from older stands and/or a long time sequence of measurements

PSP number	Site	Stand Est. year	Age range of observations (years)	No. Obs.	Current stocking (stems/ha)	Reduction in stems/ha due to mortality
FR 92/5 1/0	Taumarunui	1922	81 – 86	4	460	80
FR453/2 1/0	Hanmer	1930	73 – 77	3	442	0
RO 230/0 1/0	Whakarewarewa	1901	47 – 107	16	198	0
R0 2021/6 8/1	Brann	1969	31 – 41	9	363	0

Tree Mortality

An important issue that needs to be considered is the likely trend in basal area with increasing age. If there is a maximum basal area that a site can carry, one would expect to see individual tree mortality occurring when that maximum is reached.

The only older PSP with a record of tree mortality was Taumarunui (FR 92/5 1/0) (Table 1). At each re-measurement one or two of the smaller trees, in terms of diameter at breast height (dbh), were classified as dead. Interestingly, the recorded basal area/ha continued to increase slightly with increasing age. There appears to be a lack of mortality for the other PSPs. Coast redwood is a species with a high shade tolerance; thus it can tolerate high tree densities, intense competition, and low light conditions before mortality occurs. However, the complete lack of mortality in the other three PSPs appears to be unusual. This would suggest one of the following; a) stand densities are not high enough for mortality to occur; b) mortality occurs at younger ages; or c) mortality wasn't recorded. An example of the latter is Whakarewarewa (RO 230/0 1/0). There is a lack of mortality in the PSP records over a 60-year period. The stand records indicate that this area was established at 7000 stems/ha. However the area was either planted as a mixture of 416 coast redwood stems/ha and 6528 larch stems/ha [10]; or coast redwoods were planted first, but did not grow well, so was replanted with larch which then provided shelter for the coast redwood to grow (C. Low pers. comm. 2011). The area was thinned around 1975 with larch and some coast redwood being removed (C. Low pers. com. 2011). So the current stocking of 203 stems/ha was likely reached by thinning rather than natural mortality.

The Taumarunui PSP provides the best indication of coast redwood's long-term growth potential due to its age and location on a suitable site favourable for the species. The basal area at 86.2 years (the last re-measurement) was 241.5 m^2/ha and is the highest basal area/ha in all of the current PSPs. As trees are starting to die, this is the best estimate that we have of a possible maximum basal area that a site can carry. The value of 240 m^2/ha has been used as a potential maximum for comparison with simulations later in this report. However, it is possible that the maximum basal area for New Zealand may be higher, and that it may vary with site conditions.

Basal Area

Stand basal area varied between the four sites (Figure 1). Low productivity sites were Whakarewarewa and Hanmer and high productivity sites were Brann and Taumarunui (Figure 1). The trend in basal area with age was examined visually and then a simple equation was fitted to the PSPs with the highest number of measurements to predict the long term trend – high productivity Brann and low productivity Whakarewarewa (Figure 2). The equation fitted was:

$$BA = a + b \times age^{c} \qquad [1]$$

Where:

BA is the stand basal area

age is the stand age

a, b, c are the model coefficients

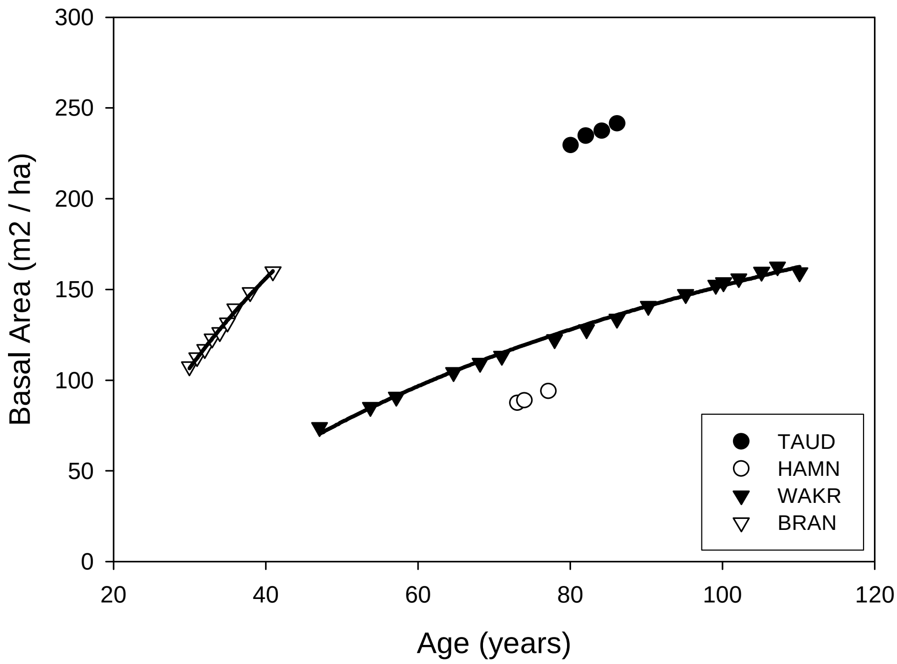

Figure 1: Measured basal area for Taumarunui (TAUD), Hanmer (HANM), Whakarewarewa (WAKR), and Brann (BRAN)

The measured and predicted trends in basal area per hectare are shown in Figure 1. For Whakarewarewa, the relationship between basal area and age is not quite linear. The predicted value coefficient *c* in Eqn. 1 was approximately 0.6 (Table 2), indicating that basal area growth is slowing down with increasing age. When Eqn. 1 was fitted to data from Brann, the coefficient c was not significantly different from zero, so a linear response was then fitted (i.e. c held equal to 1) (Table 2). However a linear trend is unlikely to continue as growth rate is likely to decrease over time as with Whakarewarewa. Stand basal area for Brann may be similar to the high productivity site of Taumarunui when it reaches 80 years, but this is unclear. As stated earlier, we will assume that Taumarunui's stand basal area at age 86 is the maximum basal area possible in New Zealand. As long term age trends are unknown, Brann's stand basal area equation should not be extrapolated beyond 50 years.

Table 2: Details of fitting equation 1 to stand data from low productivity site (Whakarewarewa) and high productivity site (Brann)

Model statistics	Whakarewarewa	Brann
Predicted a ± approx. standard error	-67.7 ± 18.1	-38.9 ± 4.5
Predicted b ± approx. standard error	14.6 ± 5.1	4.9 ± 0.1
Predicted c ± approx. standard error	0.59 ± 0.06	1.0 (fixed)
F value	12834.3	1413.7
Approx. Probability of exceeding F	< 0.0001	<0.0001

ANALYSIS OF THINNING AND SPACING TRIALS

Introduction

The high shade tolerance of coast redwood means that the species can grow at high tree densities with little mortality for a number of years. However, the growth rate and productivity of a shade tolerant species will be reduced once a certain tree density is reached. Nine thinning and spacing trials have been installed since 1999, and all trials were overlaid onto existing stands (Table 3). The trials differ in objectives, stand age, thinning intensity, replication, and the number of thins. However, the trials could answer two important questions: 1) what is the optimal stand tree density for growth rate and volume production; and 2), at what age and thinning intensity is redwood most responsive?

Table 3: List of PSPs that contain a thinning trial or can be used to assess stand tree density on growth rate.

PSP number	Site	Trial type	Plot Est. date	No. plots	Age range of observations (years)	No. Obs.
FR 475/35	Tutira	Thinning/ Pruning	2004	21	6 -14	9
FR 453/6	Otago Coast	Thinning	2003	7	17-25	6
FR 453/8	Mangatu Cpt 98	Thinning	2004	9	26-32	5
FR 453/9	Waiotapu	Thinning	2004	8	22-30	6
FR 453/3	Waerenga-O-Kuri	Thinning/ Pruning*	2003	4	5-14	13
FR 453/16	Collings	Thinning/ Spacing	2005	3	8-14	4
FR 453/20	Okota	Thinning/ Pruning	2008	4	5-8	3
RO 2021/6	Brann	Spacing	1999	3	4-13, 30-41	7-9
RO 2106/11 & FR 453/18	Brown	Spacing	2005	2	10-16, 12-16	3-5

* Waerenga-O-Kuri trialled the timing of pruning, not pruning intensity. All trees were pruned to a height of 6.5 m

Thinnning Responses at the Stand Level

To date, all thinning trials have yet to show a significant treatment effect at the stand level. For example, for the thinning trials at Otago Coast, Waiotapu, and Mangatu, the stand basal area growth rate of the thinned stands paralleled the unthinned stands for up to seven years after thinning (Appendix 1). There are a number of reasons why there is a lack of a response. One possibility is that the trials, except Tutira and Collings, were established in stands that were aged between 17 to and 25 years. At this age range, coast redwood may be able to tolerate higher tree densities than younger or older stands. Another potential reason is that the unthinned control plots were at stockings of less than 1000 stems per hectare (sph). If there is a response to thinning in these trials, it is likely to take another 5 to 10 years after the last treatment before it becomes significant. The differences in establishment year (1969, 1997, and 2000) and stand ages when the plots were measured made it difficult to determine a thinning effect in the Brann's trial (data not shown).

The growth response to thinning at the Tutira and Collings sites were more nuanced. Both trials were thinned at a young age, thus creating the best conditions for a thinning response when the stand is fast growing and dynamic. At Tutira, stand basal area was similar for all plots when the treatments were applied at age 5 (Figure 2). Then stand basal area diverged by final stocking as the thinning treatments were applied (Figure 2). When mean dbh increment between thinning treatments was examined, there were indications that increment in the plot with the highest tree densities (lightest thinning) was less than at the other two treatments at ages 9 and 11 (Figure 3). This may indicate a thinning response for treatments with a final stocking of 600 sph (medium thinning) and 350 sph (heaviest thinning). Another possibility is that unfavourable climate conditions in those years reduced growth in the stand with the highest tree density due to intense competition. Indeed, the plots with the highest tree density were located on top of the hill while the plots with the lowest tree density were located at the bottom of the hill. Whatever the cause, the growth rate of the highest density plots was able to catch up to the other two treatments by age 13.

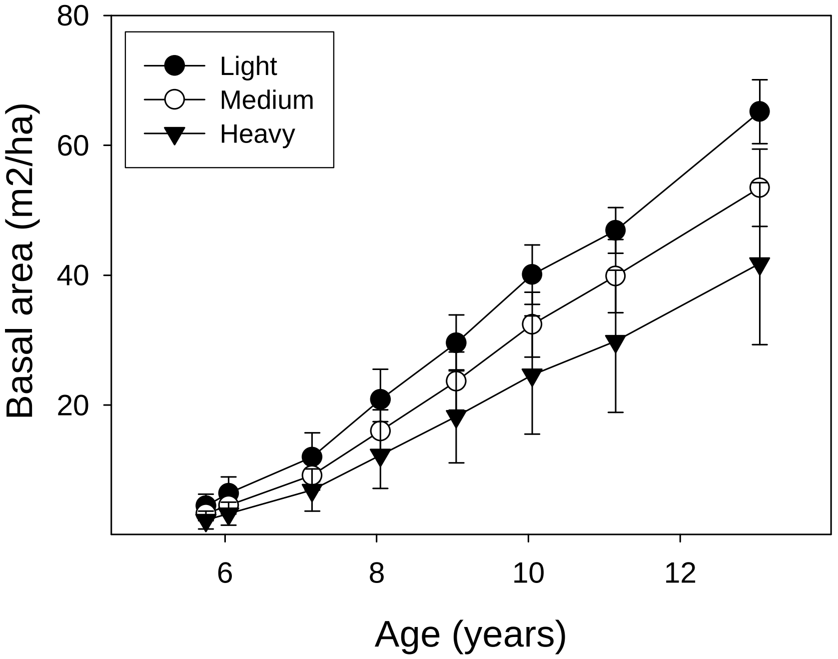

Figure 2: Tutira trial stand basal area by thinning intensity as represented by final crop tree density; light thinning (800 sph), medium thinning (600 sph), heavy thinning (350 sph). All treatments unpruned.

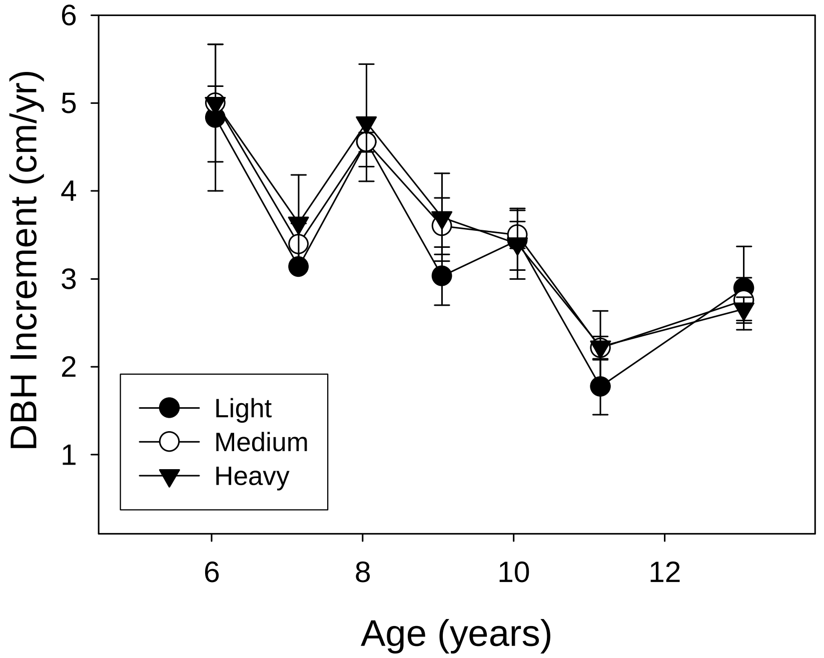

Figure 3: Tutira trial mean diameter at breast height (DBH) growth increment by thinning intensity as represented by final crop tree density; light thinning (800 sph), medium thinning (600 sph), heavy thinning (350 sph). All treatments unpruned.

For the Collings trial, there was an apparent increase in height and dbh growth for the one stand that was thinned to 480 sph before age nine (Figure 4). However, the small number of plots and limited number of measurements means it is unclear if this apparent thinning response is real and not a blip. More measurements over time are needed, the results combined with Tutira to determine what response, if any, coast redwood has to thinning. Tutira is likely to provide the best evidence of a thinning response since it is well replicated; the treatments were applied when the stand was young, and it is measured frequently. The third and final silvicultural treatment was applied at Tutira in 2011 just after the last measurement. How the trees respond when the trees are cut to the final tree (crop) densities in the next 5 years will likely provide the best indication how redwood responds to thinning at the stand level.

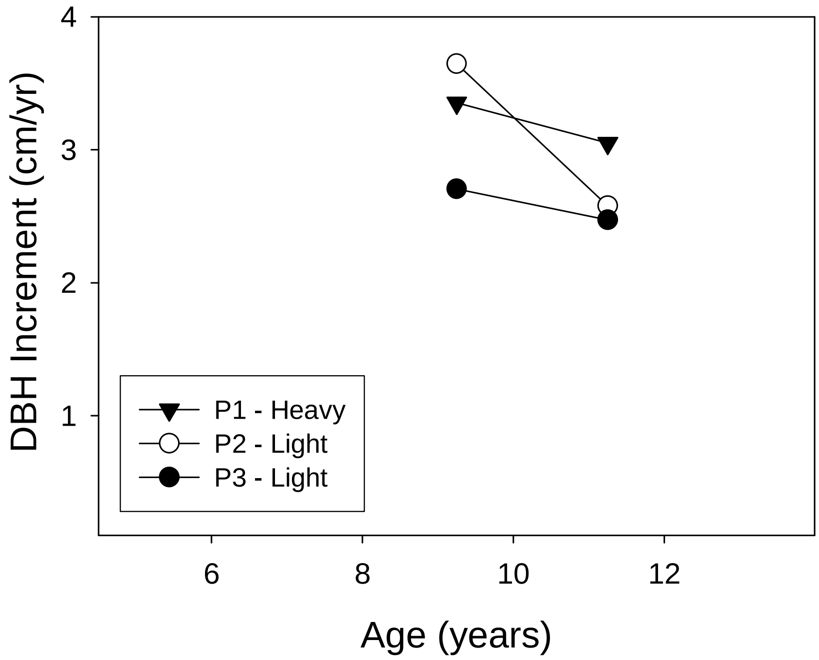

Figure 4: Collings trial diameter at breast height (dbh) growth increment by plot and final crop tree density; heavy thinning (480 sph).and light thinning (760 sph).

Thinnning Responses at the Individual Tree Level

An alternative approach to stand level equations is to predict basal area development on an individual tree basis and then sum to give basal area per hectare. Many different types of individual tree growth models have been developed. Such models may or may not consider the actual location of trees (distance-dependent versus distance-independent models), and may or may not include tree age (the latter case being an age-independent model). If the age of the trees is not known, one needs to develop age-independent growth models [11]. This approach will be particularly important in the USA where the regeneration age is unknown. An age-independent approach can also be applied where the age of the trees is known [12].

One type of distance-dependent model is the growing space index [13]. This index uses the theory that for trees at one homogenous site, trees at a lower stocking will be growing in a different environment from those at a higher stocking. In particular, trees at lower stocking should have access to more light, water and nutrients. For this study an attempt was made to derive “growing space” that would be applicable in a “distance-independent” situation. The following variable appears to incorporate the differences between plots such that one equation will be applicable for all treatments:

$$GS = \frac{dbh}{\overline{dbh}} \times \frac{10000}{sph} \qquad [2]$$

Where:
GS is the growing space
dbh is the dbh of an individual tree
$\overline{dbh}$ is the mean dbh for the plot
sph is the number of stem/ha in the plot

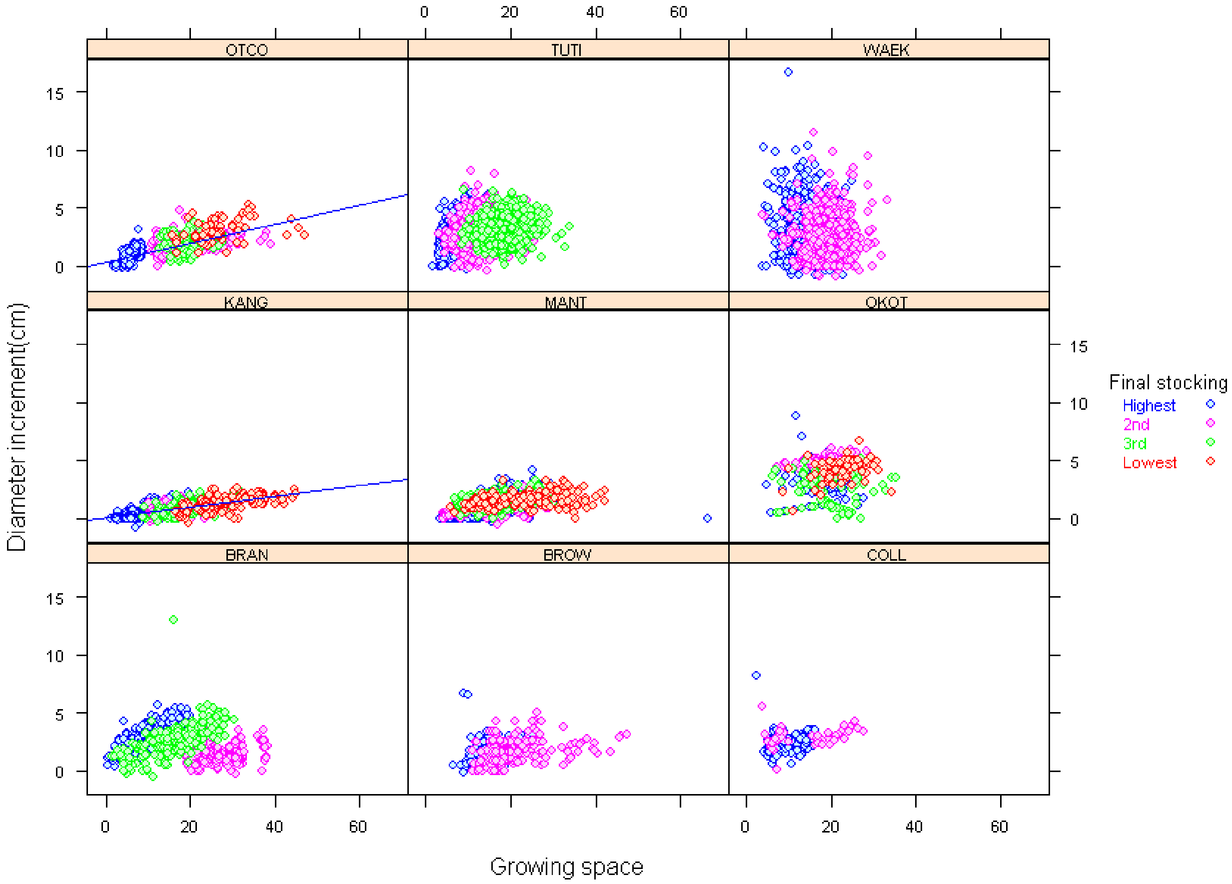

Figure 5: Relationship between individual tree growing space index and diameter increment (growth rate) by final stocking (sph) and site. Final stockings rank from highest (most number of stems per hectare) to lowest (least number of stems per hectare). Sites are Okota (OKOT), Otago Coast (OTCO), Tutira (TUTI), Waerenga-O-Kuri (WAEK), Brann (BRAN), Brown (BROW), Collings (COLL), Waiotapu (KANG), and Mangatu (MANT).

The relationship between individual tree diameter increment growth rate and growing space index varied by site (Figure 5). Tree diameter growth rate increased with increasing growing space for Otago Coast (r^2 0.53) and Waiotapu (r^2 0.47), whereby the tree diameter growth rate increased with growing space (Figure 5). It appeared that the same trend was present for Collings, but this trend was non-significant (Figure 5). There was a wide variation in diameter increment within each final stocking category for Tutira, Waerenga-O-Kuri, and Brown (Figure 5). The lack of a trend for Okota may be due to the young age of the stand and the small difference in stocking (443-583 sph). There is a possible negative trend for Brann; however that may be due to the differences in stand age between each of the three plots (Figure 5). For Mangatu, the thinning study was confounded by the selection of controls which had a lower stocking than most of the plots that were thinned. This may explain the overlapping growth rates with growing space (Figure 5). For Waiotapu, there is an apparent plateau in diameter increment with increasing growing space (Figure 5). This may indicate that a final crop stocking of 350 sph may be too low to fully utilise the site, or that coast redwood is unable to readily respond to heavy thinning at a cold site. This "plateau" effect may disappear as the trees age and more data are obtained. Until this trend is observed at other sites, this "plateau" effect must be treated as a site effect specific only to Waiotapu.

The lack of a growing space index relationship at Tutira may be due to the young age of the stand (14 years), tree density of the plots not at final stocking, and the confounding effects of pruning severity on growth. When only the unpruned stands were examined using the growing space index at Tutira, there appears to be a developing positive growth trend (Figure 6). This trend may become stronger as the stand ages and when canopy closure occurs after the final thinning.

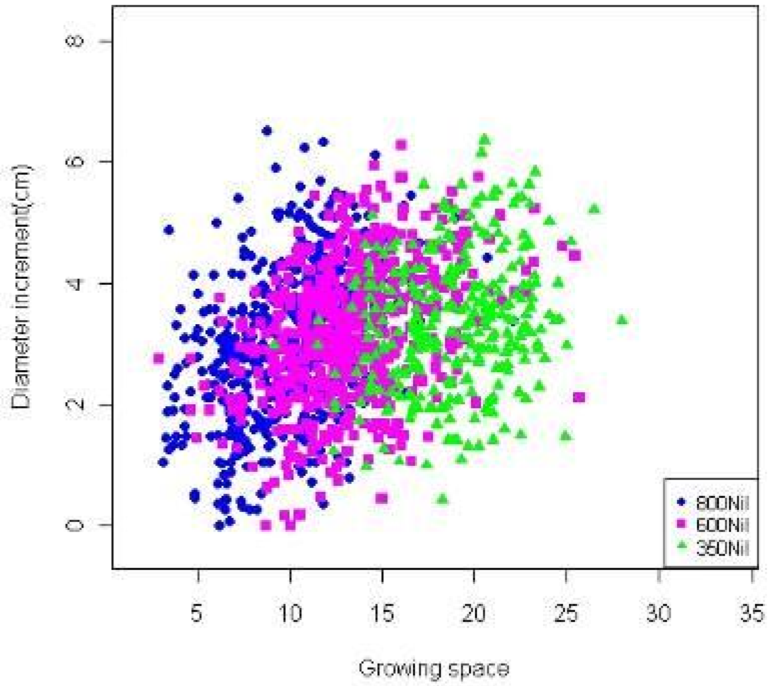

Figure 6: Relationship between annual dbh increment and growing space at Tutira for the unpruned plots by final targeted stocking (sph).

Synthesis

Coast redwood is highly shade tolerant species, so it can tolerate a high stocking for a prolonged period before competition-based mortality occurs. Few trees have died in the PSPs since they were established. This is likely due to the short length of time observations have been made, and the stocking density. The number of trees typically planted for coast redwood in New Zealand is likely well below maximum stocking density. For the thinning trials, only the Otago Coast site has a control with stand density greater than 1,000 stems/ha. The growth rate from Otago Coast shows that its growth was not impeded by a stocking at 1667 stems/ha (Appendix 1), for at least a slow growing site between stand age 17 and 23 years. We currently have insufficient information to determine what is the maximum basal area that a site can support. It is also unclear if a stand is more responsive to thinning at a certain age.

The difficulty of establishing a relationship with thinning can be attributed to the limited number of trials and short length of time since thinning occurred. However, research in the USA has also had difficulty in establishing a clear relationship between stand density and growth in secondary forest. One study found that stand growth at 60 and 80 years, as measured by basal area increment or periodic annual increment, reached a plateau when stocking was above 800 stems/ha or approximately 80 m^2/ha [14]. A similar trend was found in an earlier study for 45-50 year-old stands, with the plateau of growth when stand basal area was above 69 m^2/ha [15]. However, the "plateau" found in these studies may be due to the high variability of the data [14]. Stand stratification or differences in site quality between plots can produce the illusion that stand growth plateaus after a certain density [14]. Site effects were apparent in Oliver *et al*. [15], where periodic annual increment plateau at 69 m^2/ha for two sites while the third and most productive site declined after 85 m^2/ha. These results have led to debates about whether they supported the thinning response hypothesis (Langsaeter's theory) or the critical stocking density hypothesis (Assman's theory). The former states that stand growth rate will plateau above a given stand density, typically 50% of maximum basal area [16, 17]. The latter states that stand growth rate will increase with a light thin, but it will decrease below a critical level of the unthinned stand basal area [18]. Both theories can be supported from these studies, but the large degree of site variability could cast doubt on the validity of developing one equation to explain coast redwood stand growth dynamics.

The thinning response is also dependent on the length of time after thinning. For example, Oliver *et al.* [15] established a control and three thinning treatments (25%, 50%, and 75% of original stand density), and it was monitored over a 15-year period. For the first 5 years, the only significant response in basal area increment was a decrease for the heaviest thinning (25%) treatment. Between 5 and 10 years, the 50% thinning treatment had the fastest growth rate. Between 10 and 15 years, all treatments basal area increment were faster than the control, while growth in the heaviest thinned treatment had accelerated.

Stand level measurements may be insensitive to microsite effects and/or intraspecific competition within a stand. Individual tree models may be a more sensitive measure of site productivity and an early indicator of responses to thinning. Growing space analysis showed that individual trees at several sites were sensitive to the effects of growing space on tree growth. A strong relationship between tree leaf area (as a measure of GS) and tree growth was demonstrated in the USA [19]. This apparent sensitivity could indicate that thinning may be more important on sites that are less favourable for coast redwood, as intraspecific competition may be more intense. Future analysis of PSP data should include both types of analysis to determine which measure of productivity is more appropriate as more data become available.

ANALYSIS OF PRUNING TRIALS

Introduction

Pruning is an important management tool to maximise the value of merchantable volume at harvest. Many commercial plantings of coast redwood have been established at low stockings necessitating pruning to achieve high value logs. A sawing study from a 38-year-old stand at Mangatu demonstrated that although pruned logs represented 38% of the merchantable volume, they contributed 50% of the gross timber value [20]. The same study found that the most important determinants of log value were the small end diameter of the log, quality of the pruning, heartwood content, and branch status [20]. Three trials have been established to consider alternative pruning regimes (Table 4). Waerenga-O-Kuri was established as a step out trial of Tutira. Only Okota was established with future pruning operations planned.

Table 4: List of PSPs that contain a pruning trial

PSP number	Site	Trial type	Plot Est. date	No. plots	Age range of observations (years)	No. Obs.
FR 475/35	Tutira	Thinning/ Pruning	2004	21	6 -14	9
FR 453/3	Waerenga-O-Kuri	Thinning/ Pruning*	2003	4	5-14	12
FR 453/20	Okota	Pruning	2008	4	5-8	3

* Waerenga-O-Kuri trialled the timing of pruning, not pruning intensity. All trees were pruned to 6.5 m

Pruning Severity and Growth Dynamics

The Tutira trial investigated the impact of pruning intensities on growth and pathogen resistance. As stated in the earlier section, Tutira also investigated the impact of thinning intensities on growth. Waerenga-O-Kuri investigated the impact of the timing of pruning on pathogen resistance and the development of epicormic shoots. The results of this study showed that epicormic shoot development was less if trees were pruned in the autumn (data not shown). At Tutira, the pruning intensities were determined by a stem gauge: for the first lift in 2004, the light prune used a 9-cm stem gauge while the heavy prune used a 5.5-cm gauge. It was found that the pruning lift was too severe – some trees had 90% of the crown removed (Table 5). For the second lift in 2008, the gauge sizes were increased to 12 cm for the light prune and 9 cm for the heavy prune (Table 5). By the third lift, the trees were too tall for gauges to be used safely. Thus, a constant height pruning was used with a minimum crown percentage rule to ensure that sufficient crown remained after pruning (Table 5).

Table 5: Pruning prescription used at Tutira trial for each lift

Lift	Year	Light pruning	Heavy pruning
1st lift	2004	Prune to height where stem fits 9 cm gauge	Prune to height where stem fits 5.5 cm gauge
2nd lift	2008	Prune to height where stem fits 12 cm gauge	Prune to height where stem fits 9 cm gauge
3rd lift	2012	Constant height rule: a. Prune to 4.5 m crown height, UNLESS the height removes 70% of the green crown. If this rule is violated, then; b. Prune to leave approximately 50% of green crown.	Constant height rule: a. Prune to 7.5 m crown height (Max reach from top of pruning ladder), UNLESS the height removes 70% of the green crown. If this rule is violated, then; b. Prune to leave approximately 50% of green crown.

To determine the impact of pruning on coast redwood, dbh growth was used to measure the impact on volume productivity, and height growth was used to measure the impact on tree growth rate. The heavy prune decreased dbh growth for each thinning intensity when pruning lifts occurred in 2004 and 2008 (Figure 7). There was also a decrease in dbh growth for the light pruning for plots with a targeted final stocking of 800 sph and 350 sph (Figure 7). Between 2004 and 2009, heavy pruning reduced relative basal area growth by 21% while the light pruning decreased it by 10% (Table 6). Despite this decrease, the dbh growth rate for both pruning intensities recovered within four years after the first lift and two years after the second lift (Figure 7). The height growth rate did not vary between treatments; thus pruning intensity had no impact on its growth rate (Figure 8).

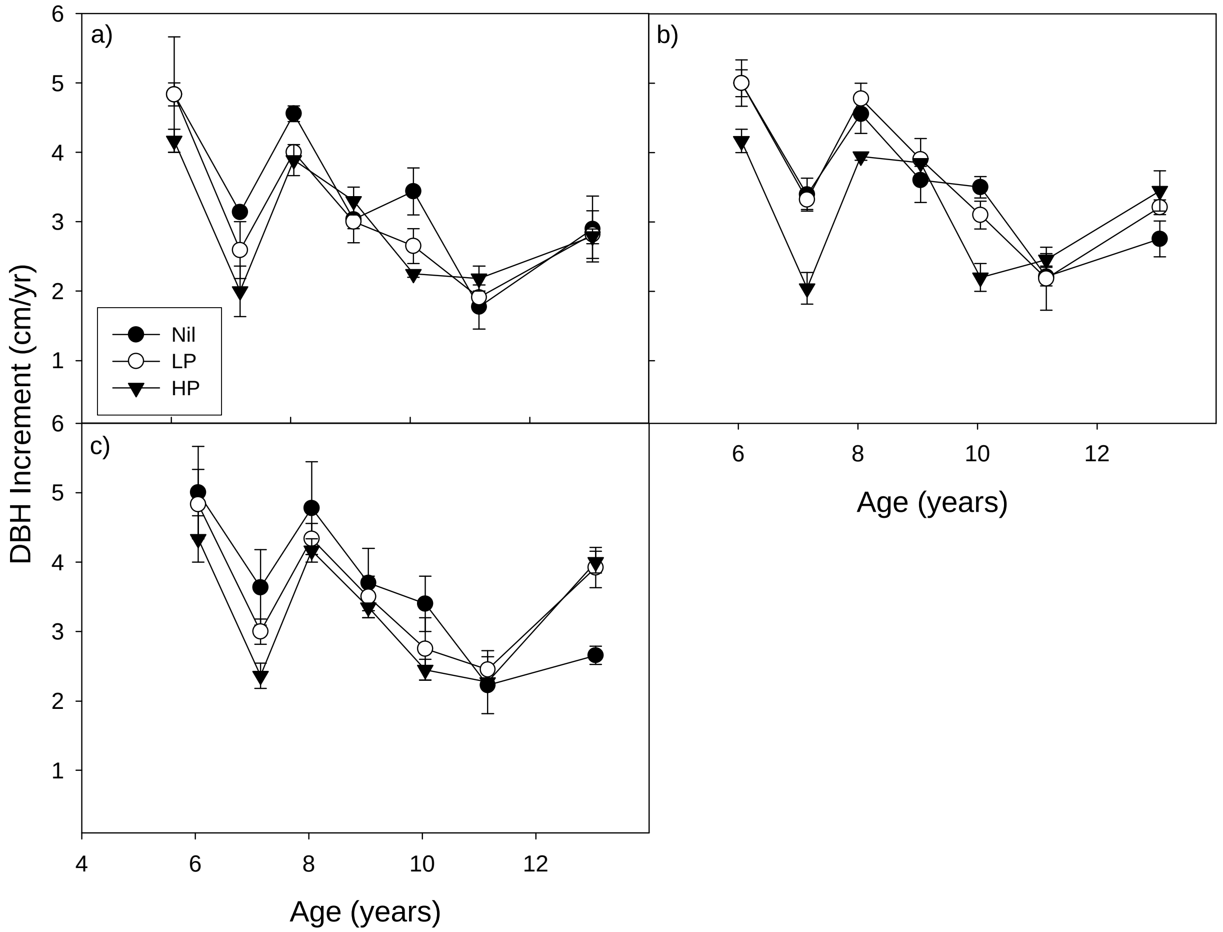

Figure 7: Tutira trial mean dbh increment by thinning pruning intensity: no pruning (Nil), light pruning (LP), and heavy pruning (HP) for three final stocking target intensities, 800 stems per hectare (a), 600 stems per hectare (b), and 350 stems per hectare (c).

Table 3: Mean relative basal area for different silvicultural treatments for Tutira at age 11 years

Pruning treatment	Mean basal area/ha	Ratio compared to no pruning
No pruning	39.91	1.0
Light pruning	35.75	0.90
Heavy pruning	31.59	0.79

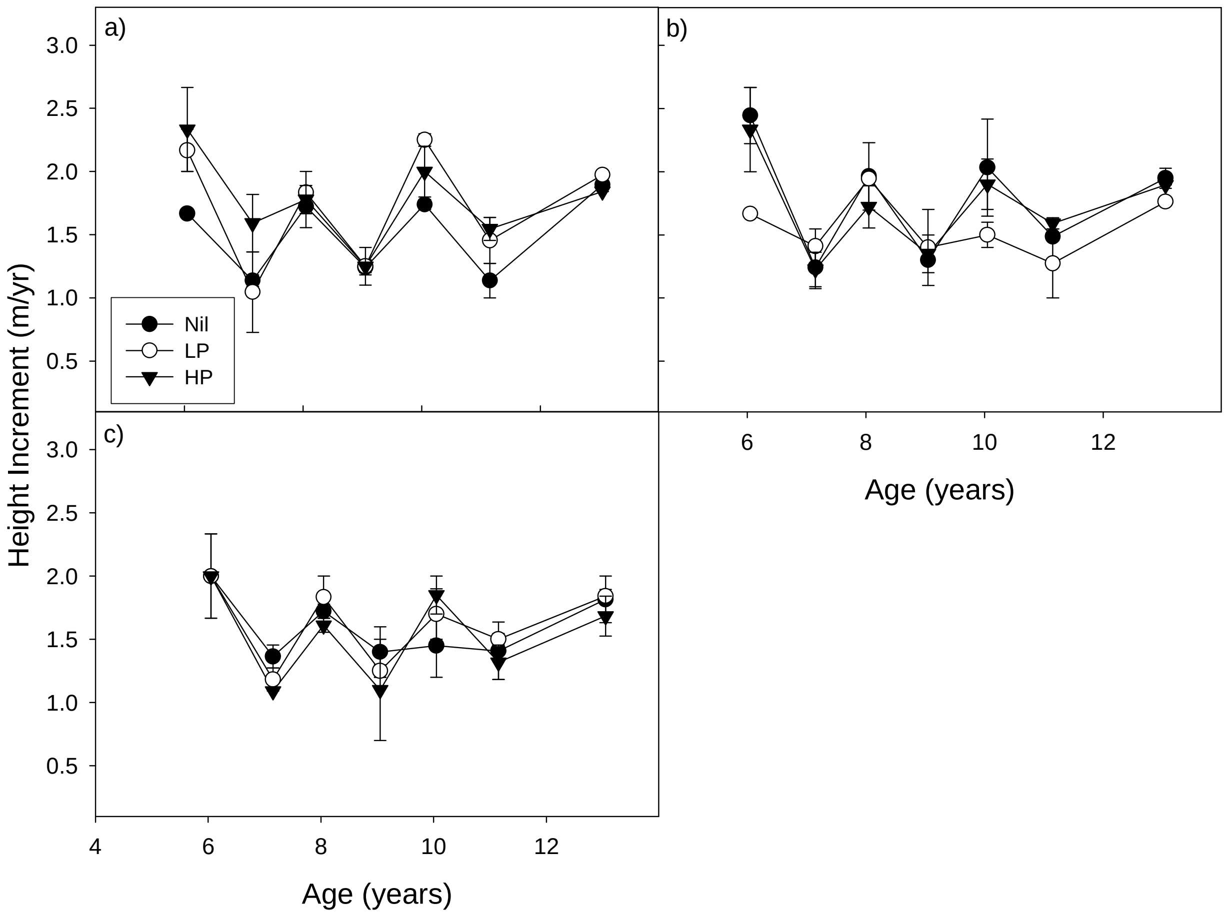

Figure 8: Tutira trial mean tree height increment by thinning pruning intensity: no pruning (Nil), light pruning (LP), and heavy pruning (HP) for three final stocking target intensities, 800 stems per hectare (a), 600 stems per hectare (b), and 350 stems per hectare (c).

Synthesis

Pruning live branches is used as a mechanism to minimise the presence and size of knots to increase the values of merchantable timber and the profitability at harvest. This is especially important for coast redwood as it is primarily graded for appearance. The Tutira trial has demonstrated that pruning has a short-term impact on productivity. This would suggest that at young ages coast redwood has a high degree of plasticity; thus it is able to recover quickly from pruning even when a large percentage of the crown is removed. Five years after the first lift, relative stand basal area was 10% and 20% less than the unpruned stands for the light and heavy pruning intensities respectively. It is unknown if the growth rate of pruned treatments will be able to recover some of this volume by the end of the rotation, or if there is another unknown impact of pruning on the stand. But from the results to date would suggest that the return from a smaller diameter over stubs should compensate for any reduction in tree volume.

Within some plots at Tutira, there was a large variance for individual tree relative growth rates which may indicate spacing and microsite effects. Thus, individual tree responses for pruning coast redwood may vary more within a stand than in other species (e.g. *Pinus radiata*). Tutira is a site that is highly favourable for coast redwood. It is unclear if coast redwood would respond so positivity to heavy pruning at sites that are less favourable. Thus, the treatment responses at Tutira should be interpreted with caution when pruning is applied for silvicultural regimes at other sites. The results from Tutira may be confirmed by more recently established pruning trials, like Okota (Hunterville).

Industry typically plants coast redwood at low tree stockings at establishment (400-800 stems per hectare). Low stocking will increase branch size at establishment and the diameter over stubs specifications of the highest value grades have made pruning a necessity. A sawing study from a 38-year-old stand at Mangatu demonstrated that although pruned logs represented 38% of the merchantable volume, they contributed 50% of the gross timber value [20]. The same study found that the most important determinants of log value were the small end diameter of the log, quality of the pruning, heartwood content, and branch status [20]. As noted above, coast redwood may not tolerate heavy pruning on less favourable sites. The Mangatu sawing study found that the quality of pruning was indicative of the log's value [20].Heartwood is the single most important factor determining log grade, but in the Mangatu study it was not possible to the determine heartwood content of a standing tree until it was sawn. Planting individual clones may reduce heartwood variability within a stand and may increase heartwood content for each tree. Research is required to determine if current clone selection techniques will produce the desired results. It is recommended that silvicultural research focuses on developing a coast redwood pruned log index so that the type of log at harvest can be predicted.

The development of epicormic shoots is of particular concern, as persistent epicormic shoots can cause major downgrade in log value, as the Mangatu sawing study demonstrated [20]. Pruning in winter drastically reduces the likelihood of persistent epicormic shoots forming (P. Silcock pers. com.). The observed variability of the number of epicormic shoots sprouting between trees at the Tutira trial would suggest genetic variability in epicormic shoot proliferation. Thus identification of provenances that do or do not minimise epicormic shoot sprouting may be possible. The potential of epicormic sprouts over a rotation remains a serious concern for low tree stocking and heavy pruning regimes.

ANALYSIS OF THE INTERIM REDWOOD GROWTH MODEL

Introduction

The interim redwood growth model [9] is a stand level model predicting mean top height and basal area at a new age from mean top height and basal area at an earlier age. The equations assume that mean top height, but not basal area, will reach a common asymptote. This analysis examines how well the model performs using the PSP data collected since the model was developed, and in particular how it would perform if post-thinning and or post-pruning data were used as input.

The earliest and latest records were selected for PSPs to avoid any thinning between records. An exception was made for a few plots in the Tutira trial where one or two trees were removed. PSPs were assigned to the following categories:

- Mixed (where trees were from different age cohorts)
- No treatment (where no treatment had been recorded)
- Pruning (PSPs that had been pruned between the two measurements)
- Thin and prune (the Tutira trial)
- Thinning (Otago Coast, Mangatu, and Waiotapu trials)

The model equations were implemented in SAS and mean top height and basal area/ha at the later age calculated. The model results were examined graphically.

Model Performance

Mean Top Height

Mean top height was poorly predicted where the age of first measurement was less than 10 years, and in particular for pruned PSPs. There was a possible trend with age above 10 years (Figure 9). Excluding the pruned PSPs, there is a possibly a slight negative trend in the error with increasing stocking at the first measurement (Figure 10). However this trend may be an artefact of site, as it is not obvious in the individual thinning trials (data not shown**Error! Reference source not found.**).

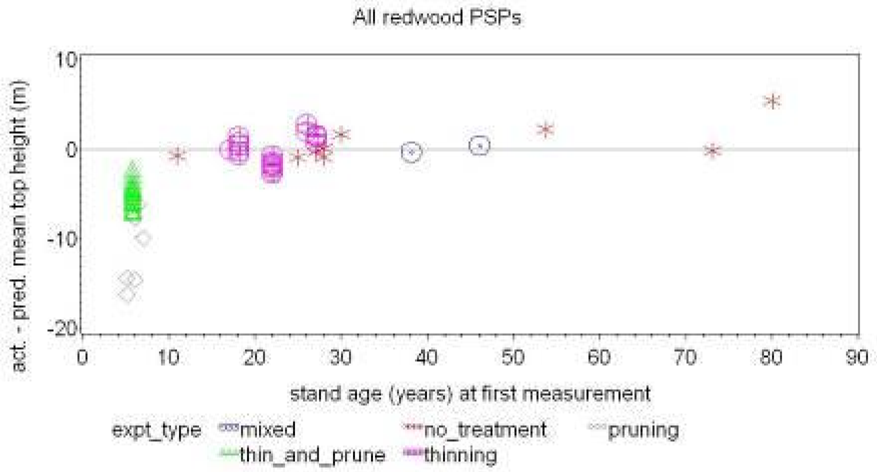

Figure 9: Actual – predicted mean top height versus stand age at 1st measurement.

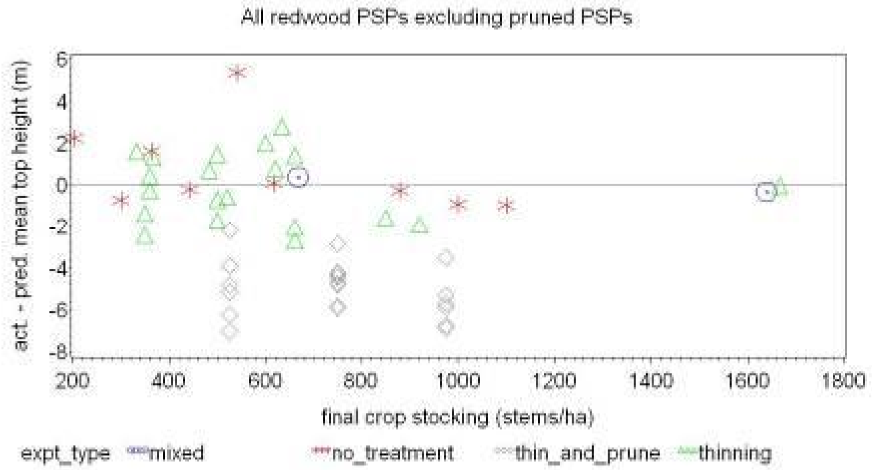

Figure 10: Actual – predicted mean top height versus stocking at 1st measurement.

Basal Area

The prediction of basal area per ha was particularly poor for the pruned PSPs where the age of first measurement was less than 10 years (Figure 11). There was a negative trend in the residuals (actual – predicted basal area) with increasing stocking at first measurement (Figure 12), which indicates that the basal area increment depends on the stocking.

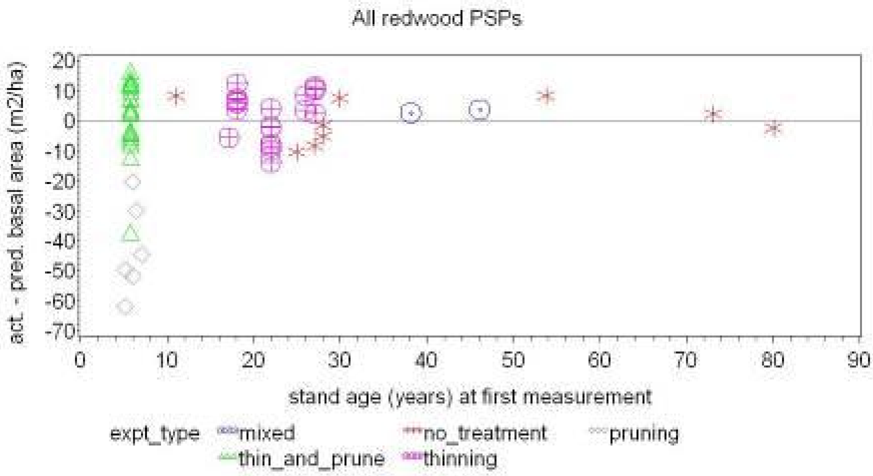

Figure 11: Actual – predicted basal area versus age at first measurement

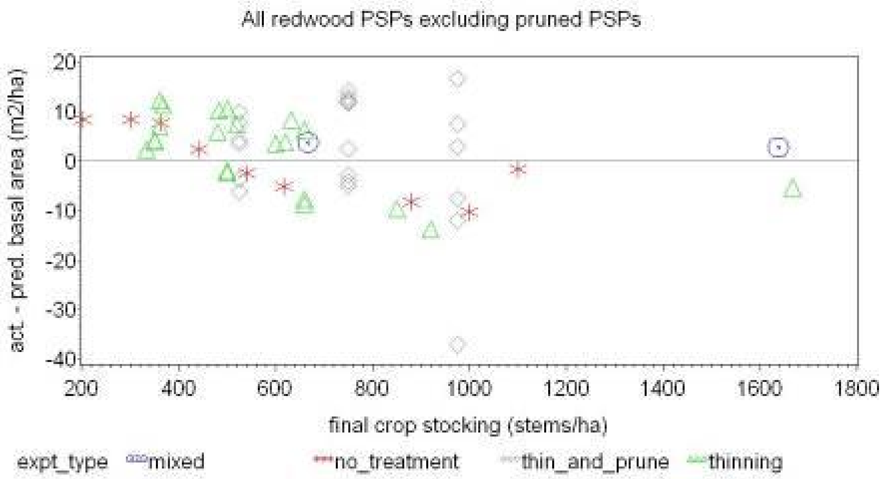

Figure 12: Actual – predicted basal area versus stocking at first measurement.

Synthesis

Given the small amount of data used to produce the original redwood model, the predictions from the interim redwood model using independent data are generally reasonable. There are trends in the model residuals, with independent variables indicating that there is room for further model development. However, as there is little additional PSP data since the model was developed in 2005, little would be gained in trying to improve the model at this time. The above results indicate that the current stand level model does not account for changes in stand structure due to silvicultural treatment particularly well. Given the paucity of data, the development of an individual tree – distance independent model may be more suitable than a stand level model. It would account for the size of the tree crown (i.e. allows for pruning) and the “growing space” available to each tree (i.e. allows for thinning).

CONCLUSIONS AND RECOMMENDATIONS

Silvicultural Recommendations

This study summarises the height and basal area growth responses from various thinning and pruning trials for coast redwood. Although there are some promising trends, there has been insufficient time since the establishment of the trials to conclude what management practices will maximise tree growth and merchantable timber at harvest. The regime trials have yet to show clear growth responses to silvicultural treatments, except for the quick recovery from severe pruning at Tutira. Thus, thinning and pruning functions for the interim redwood growth model cannot be developed at this time. Despite the inconclusive nature of the regime trials, the following can be concluded about silvicultural practices for coast redwood:

1. *Stand density:* Tree stockings less than 1,000 stems per hectare to slow stand growth rates for most of the rotation. None of the thinning trials have shown a treatment response at the stand level, which may be due to stand age or the short length of the trials. Indeed, only a handful of PSPs have recorded competition-related mortality. The results indicate that the current stocking levels used by industry (400-750 sph at establishment) are unlikely to require a thinning due to intraspecific competition until at least 30 years. It is hypothesized that stocking on unfavourable sites will need to be less due to more intense intraspecific competition.

2. *Pruning severity:* Trees under age 12 are able to adapt quite quickly (high plasticity) when a large percentage of the crown is removed – at least on favourable sites. The results from Tutira clearly showed that coast redwood is able to tolerate severe and repeated pruning. Growth rates of pruned plots were able to match the unpruned stands within two to five years. The Tutira results would suggest that it will be the cost of pruning rather than the physiological impact of pruning that will determine the severity and frequency of pruning. However, it is quite possible that coast redwood growth rates on unfavourable sites may be suppressed for a longer period. It is recommended that pruning regimes on unfavourable sites are less severe than what was applied for the heavy pruning regime at Tutira.

3. *Interim growth model:* The model performs well with the limited data that are currently available. Although it underestimates growth of stands less than 12 years, it provides a reasonable prediction of growth in older stands.

4. *Rotation length:* The Mangatu sawing study has shown that a 38-year-old stand on a highly productive site can produce valuable merchantable timber. It is unclear how these results can be applied to other sites due to differences in silviculture and genetics. Modern silvicultural practices are likely to reduce the knot size found in the sawing study. The genetics of seedlings and clones have a major influence on the percentage and quality of heartwood. Despite these caveats, it is reasonable to hypothesize that a rotation length of 40 years on a favourable site is likely to produce trees with high log grades.

Knowles and Miller[4] suggested planting to obtain a final crop stocking of 250-300 stems/ha and pruning to 8-10 m. A minimum rotation length of 50 to 80 years was suggested. Berrill and O'Hara[21] used data from the USA to suggest that the upper limit for stand densities was 360 stems/ha to achieve a mean dbh of 70 cm, 460 stems/ha for 60 cm mean dbh, and 620 stems/ha for 50 cm mean dbh. There are not enough data from the regime trials at present to make definitive silvicultural recommendations, but the data suggest that stands can grow vigorously at higher stand densities than is currently assumed. By extrapolating the results of the Mangatu sawing study for a site that is favourable for coast redwood growth, it can be hypothesized that a rotation length of 38-40 years that uses current silvicultural practices will produce valuable merchantable timber. A favourable site is likely to support a final crop stocking up to 500 sph for the entire rotation without an adverse effect on growth rate. On a highly favourable site, coast redwood will be able to tolerate repeated, severe, pruning. A final pruned height of at least 8 m that leaves 40% of the live crown is unlikely to impact growth and survival long term.

Trial and PSP Recommendations

Coast redwood is a shade tolerant and long-lived species. Thus, responses to thinning trials are likely to take longer and be more nuanced than for *P. radiata*. Experience in the United States has shown that it can be difficult to quantify redwood responses to silvicultural treatments. Without knowing what the maximum stand basal area is in New Zealand for a 30–50 year rotation, it is not possible to develop tree stocking/growth rate relationships. Even though clear relationships with growth and pruning severity were found at Tutira, it is unknown if coast redwood will recover as quickly on less favourable sites – especially sites that experience long periods of water stress. To answer these and other questions raised in this report, the following is recommended:

1. *Measurements of PSP network*: Further measurements of current PSPs and regime trials are required to provide evidence of the likely long-term trend in growth dynamics. Annual remeasurement is probably too frequent, but measurements should be made at least every three to five years to ensure a minimum of approximately 10 data points at the end of the rotation.

2. *Expand the PSP network*: The current network of 111 PSPs on 27 sites is too small to develop robust empirical models. More PSPs need to be established in regions where coast redwood is most likely to be planted commercially. Data should also be collected from sites that are not favourable for coast redwood, to determine the range of potential productivity throughout New Zealand.

3. *Improve the interim growth model in five years' time*: The interim redwood growth model should be updated in at least five years' time when new PSP data described above are collected. Stand growth and development should have advanced enough to improve the growth model significantly. Treatment responses from silvicultural trials may become clear enough to develop thinning/pruning functions for the growth model.

4. *Establish more thinning trials:* More thinning trials are required to understand the impact of intraspecific competition throughout the rotation. Control stocking should be at least 1667 sph to determine the maximum stand basal area for favourable and unfavourable sites. Individual growing space models should be investigated further to determine if such models are more appropriate for coast redwood.

5. *Establish more pruning trials*: More pruning trials are required to understand the dynamics of pruning severity and pruning frequency to control diameter over stubs and timber quality at harvest. Priority should be given to sites on unfavourable land such as hill country of the East Coast and Manawatu

ACKNOWLEDGEMENTS

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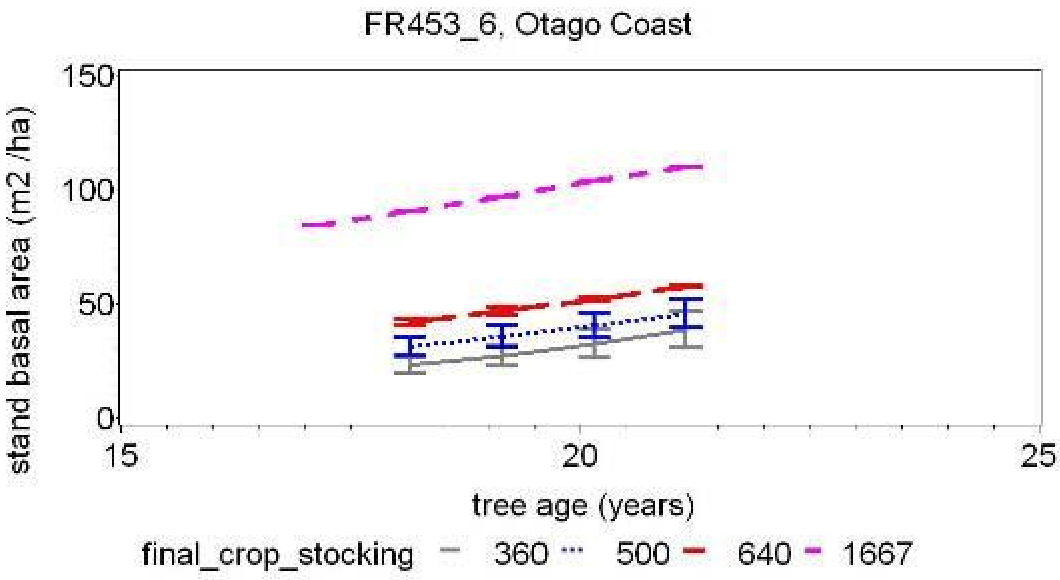
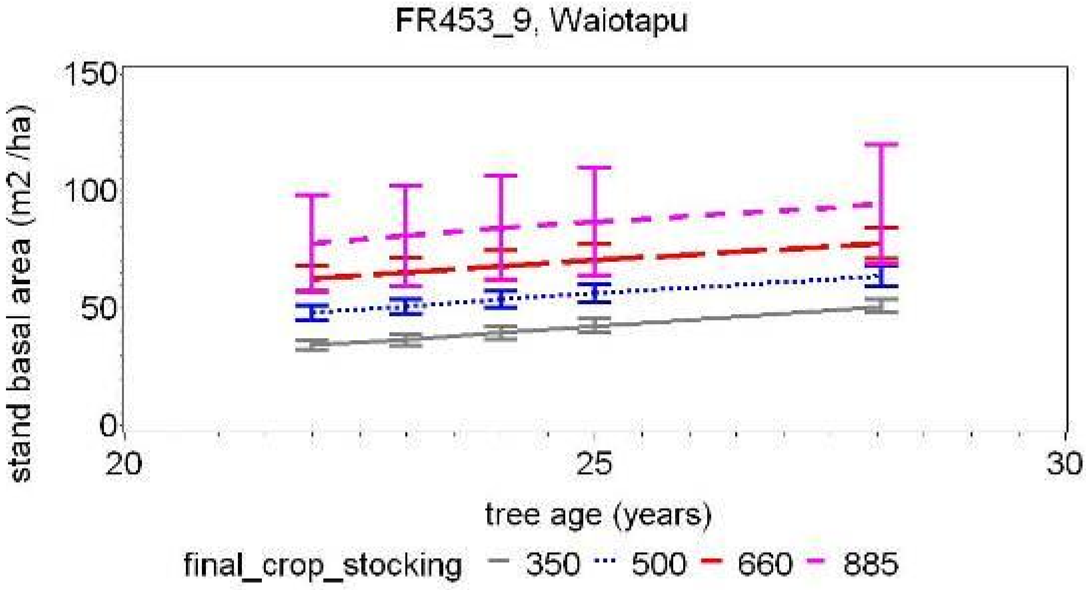
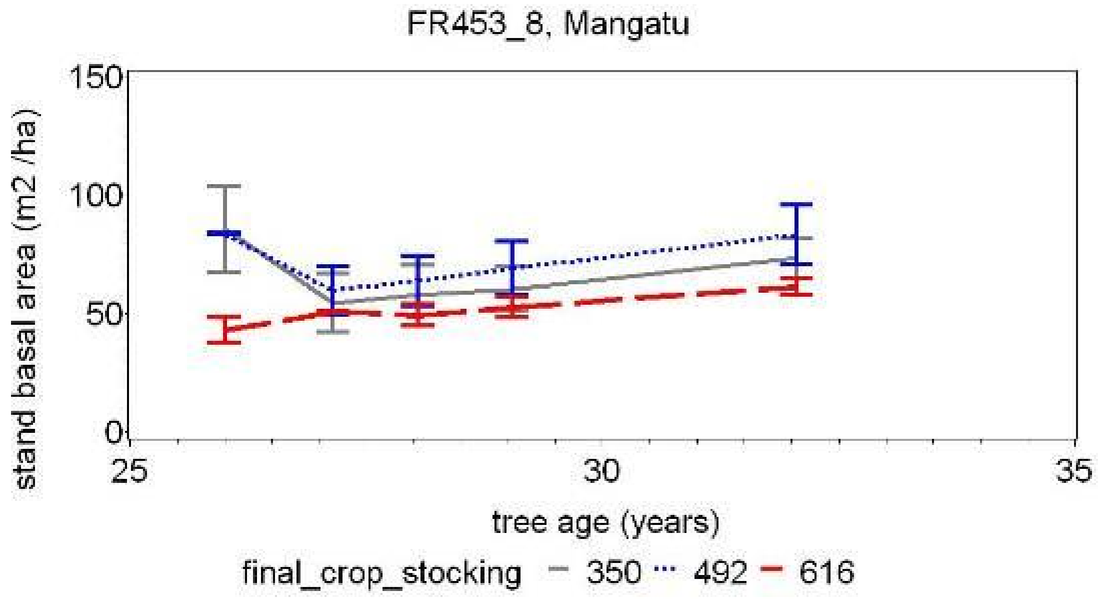
APPENDICES

Appendix 1: Stand basal area by final stocking for thinning trials at Waiotapu, Otago Coast, and Mangatu






FR453_8, Mangatu
stand basal area (m2 /ha)
150
100
50
0
25
30
35
tree age (years)
final_crop_stocking 350 492 616

Appendix 2: Summary of current redwood PSPs managed by Scion /FFR

Experiment	92
Sub-experiment	5
Plot	1
Sub-plot	0
Region	CNI
Forest	DOC, Taumaranui
Latitude	-38.898
Longitude	175.2695
Plant date	1-Jun-22
Age 1st measurement	80.05
Age last measurement	86.15
Date last measurement	25-Aug-08
Number of measurements	4
Stems/ha planted	.
Stems/ha at 1st measurement	540
Stems/ha at last measurement	460
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	80
Number of prunings	.
Maximum prune height (m)	.

This PSP should be maintained and measured at regular intervals as it exhibits individual tree mortality.

Experiment	453
Sub-experiment	1
Plot	1
Sub-plot	0
Region	East Coast
Forest	Ross Estate, Gisborne
Latitude	-38.6945
Longitude	177.8659
Plant date	1-Jun-96
Age 1st measurement	7.05
Age last measurement	13.15
Date last measurement	10-Aug-09
Number of measurements	6
Stems/ha planted	1111
Stems/ha at 1st measurement	713
Stems/ha at last measurement	713
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	3
Maximum prune height (m)	6.5

Experiment	453
Sub-experiment	2
Plot	1
Sub-plot	0
Region	Canterbury
Forest	Hanmer
Latitude	-42.5131
Longitude	172.8387
Plant date	1-Jun-30
Age 1st measurement	73.05
Age last measurement	77.15
Date last measurement	16-Aug-07
Number of measurements	3
Stems/ha planted	.
Stems/ha at 1st measurement	442
Stems/ha at last measurement	442
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	.
Maximum prune height (m)	.

This PSP is worth maintaining as it is an old stand, and will be useful for developing mortality functions.

Experiment	453	453	453	453
Sub-experiment	3	3	3	3
Plot	1	2	3	4
Sub-plot	0	0	0	0
Region	East Coast			
Forest	Waerenga-O-Kuri			
Latitude	-38.6684	38.6682	-38.6686	-38.6704
Longitude	177.8292	177.829	177.829	177.8276
Plant date	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98
Age 1st measurement	5.15	5.15	5.15	5.15
Age last measurement	11.15	11.15	11.15	11.15
Date last measurement	13-Aug-09	13-Aug-09	13-Aug-09	10-Aug-09
Number of measurements	12	11	12	11
Stems/ha planted	833	833	833	833
Stems/ha at 1st measurement	750	500	825	675
Stems/ha at last measurement	750	500	750	500
Number of recorded thinnings	1	1	1	1
Total stems/ha thinned	75	175	75	175
Stems/ha windthrown	0	0	0	0
Stems/ha dead	0	0	0	0
Number of prunings	6	6	6	6
Maximum prune height (m)	6.8	6.5	6.6	6.8

Experiment	453	453
Sub-experiment	4	4
Plot	1	1
Sub-plot	0	0
Region	Taranaki	
Forest	Te Wera	
Latitude	-39.2232	-39.2232
Longitude	174.5907	174.5907
Plant date	1-Jun-57	1-Jun-84
Age 1st measurement	46.15	19.15
Age last measurement	50.15	23.15
Date last measurement	30-Aug-07	30-Aug-07
Number of measurements	4	4
Stems/ha planted	2500	2500
Stems/ha at 1st measurement	500	167
Stems/ha at last measurement	500	133
Number of recorded thinnings	.	.
Total stems/ha thinned	.	.
Stems/ha windthrown	0	0
Stems/ha dead	0	51
Number of prunings	.	.
Maximum prune height (m)	.	.

This is a mixed-age plot. One column of data is shown for each "crop-age". The second crop is probably coppice from old stumps, rather than a completely new planting.
It will provide useful data for developing mixed-aged models and developing mortality functions

Experiment	453	453	453
Sub-experiment	5	5	5
Plot	1	1	1
Sub-plot	0	0	0
Region	Southland		
Forest	Waitane, Winton		
Latitude	-46.1763	-46.1763	-46.1763
Longitude	168.6924	168.6924	168.6924
Plant date	1-Jun-65	1-Jun-91	1-Jun-00
Age 1st measurement	38.15	12.15	3.15
Age last measurement	43.15	17.15	8.15
Date last measurement	7-Aug-08	7-Aug-08	7-Aug-08
Number of measurements	4	4	4
Stems/ha planted	1812	1812	1812
Stems/ha at 1st measurement	472	611	556
Stems/ha at last measurement	361	528	417
Number of recorded thinnings	1	1	1
Total stems/ha thinned	306	306	306
Stems/ha windthrown	0	0	0
Stems/ha dead	0	0	28
Number of prunings	.	.	.
Maximum prune height (m)	.	.	.

This is a mixed-age plot with trees at three different-aged crops. From the plot map the younger crops are obviously coppice from thinned trees. Note: Need to check calculation of trees thinned.

Experiment	453	453	453	453	453	453	453
Sub-experiment	6	6	6	6	6	6	6
Plot	1	2	3	4	5	6	7
Sub-plot	0	0	0	0	0	0	0
Region	Southland						
Forest	Otago Coast						
Latitude	-45.9496	-45.9496	-45.9496	-45.9496	-45.9496	-45.9496	-45.9496
Longitude	170.2149	170.2149	170.2149	170.2149	170.2149	170.2149	170.2149
Plant date	1-Jun-86	1-Jun-86	1-Jun-86	1-Jun-86	1-Jun-86	1-Jun-86	1-Jun-86
Age 1st measurement	17.15	18.15	18.15	18.15	18.15	18.15	18.15
Age last measurement	21.15	21.15	21.15	21.15	21.15	21.15	21.15
Date last measurement	15-Aug-07	15-Aug-07	15-Aug-07	15-Aug-07	15-Aug-07	15-Aug-07	15-Aug-07
Number of measurements	5	4	4	4	4	4	4
Stems/ha planted	2083	1666	1666	1666	1666	1666	1666
Stems/ha at 1st measurement	1667	360	660	360	520	480	620
Stems/ha at last measurement	1667	360	660	360	520	480	620
Number of recorded thinnings	.	1	1	1	1	1	1
Total stems/ha thinned	.	1100	780	1220	1180	840	920
Stems/ha windthrown	0	0	0	0	0	0	0
Stems/ha dead	67	20	20	0	20	0	0
Number of prunings	.	.	.	.	.	.	.
Maximum prune height (m)	.	.	.	.	.	.	.

All PSPs should have the same planted stems/ha. The tree spacing needs to be checked at the next re-measurement to determine the correct planted stems/ha. Previous field notes indicate that there has been some coppicing in this trial. This needs to be checked to determine whether any of the current trees have grown from coppice.

Experiment	453	453	453	453	453	453
Sub-experiment	8	8	8	8	8	8
Plot	1	2	3	4	5	6
Sub-plot	0	0	0	0	0	0
Region	East Coast					
Forest	Mangatu					
Latitude	-38.1759	-38.1761	-38.1762	-38.174	-38.1746	-38.1739
Longitude	177.9162	177.9159	177.9164	177.9173	177.9165	177.9159
Plant date	1-Jun-78	1-Jun-78	1-Jun-78	1-Jun-78	1-Jun-78	1-Jun-78
Age 1st measurement	26	26	26	26	26	26
Age last measurement	32.05	32.05	32.05	32.05	32.05	32.05
Date last measurement	16-Jul-10	16-Jul-10	16-Jul-10	16-Jul-10	16-Jul-10	16-Jul-10
Number of measurements	4	5	5	5	5	5
Stems/ha planted	1200	1200	1200	1200	1200	1200
Stems/ha at 1st measurement	633	967	983	600	1183	800
Stems/ha at last measurement	633	500	367	600	483	317
Number of recorded thinnings	.	1	1	.	1	1
Total stems/ha thinned	.	467	617	.	700	467
Stems/ha windthrown	0	0	0	0	0	17
Stems/ha dead	0	0	0	0	0	0
Number of prunings	.	.	.	.	.	.
Maximum prune height (m)	.	.	.	.	.	.

Experiment	453
Sub-experiment	8
Plot	7
Sub-plot	0
Region	East Coast
Forest	Mangatu
Latitude	.
Longitude	.
Plant date	1-Jun-78
Age 1st measurement	26
Age last measurement	26
Date last measurement	1-Apr-04
Number of measurements	1
Stems/ha planted	.
Stems/ha at 1st measurement	633
Stems/ha at last measurement	633
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	.
Maximum prune height (m)	.

Experiment	453	453
Sub-experiment	8	8
Plot	8	8
Sub-plot	0	0
Region	East Coast	
Forest	Mangatu	
Latitude	-38.1761	-38.1761
Longitude	177.9169	177.9169
Plant date	1-Jun-78	1-Jun-05
Age 1st measurement	26	0.55
Age last measurement	32.05	5.05
Date last measurement	16-Jul-10	16-Jul-10
Number of measurements	6	5
Stems/ha planted	.	.
Stems/ha at 1st measurement	633	150
Stems/ha at last measurement	633	0
Number of recorded thinnings	2	2
Total stems/ha thinned	550	550
Stems/ha windthrown	0	0
Stems/ha dead	0	0
Number of prunings	.	.
Maximum prune height (m)	.	.

This is another mixed-age plot. The initial plot data need checking. The plot description sheet is inconsistent. It says stand was thinned to 650 stems/ha but planted at 500 stems/ha. It is worth maintaining for developing mixed-aged models.

Experiment	453	453
Sub-experiment	8	8
Plot	9	9
Sub-plot	0	0
Region	East Coast	
Forest	Mangatu	
Latitude	-38.1738	-38.1738
Longitude	177.9176	177.9176
Plant date	1-Jun-78	1-Jun-05
Age 1st measurement	26	0.55
Age last measurement	32.05	5.05
Date last measurement	16-Jul-10	16-Jul-10
Number of measurements	6	5
Stems/ha planted	.	.
Stems/ha at 1st measurement	633	333
Stems/ha at last measurement	633	0
Number of recorded thinnings	2	2
Total stems/ha thinned	1099	1099
Stems/ha windthrown	0	0
Stems/ha dead	0	0
Number of prunings	.	.
Maximum prune height (m)	.	.

This is another mixed-age plot. The initial plot data need checking. The plot description sheet is inconsistent. It says stand was thinned to 650 stems/ha but planted at 500 stems/ha. It is worth maintaining for developing mixed-aged models.

Experiment	453
Sub-experiment	8
Plot	10
Sub-plot	0
Region	East Coast
Forest	Mangatu
Latitude	38.27553
Longitude	177.8525
Plant date	1-Sep-70
Age 1st measurement	38.9
Age last measurement	40
Date last measurement	15-Sep-10
Number of measurements	2
Stems/ha planted	3086
Stems/ha at 1st measurement	280
Stems/ha at last measurement	280
Number of recorded thinnings	2
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	4
Maximum prune height (m)	6

Note: Pruned stand in Mangatu.

Experiment	453
Sub-experiment	8
Plot	11
Sub-plot	0
Region	East Coast
Forest	Mangatu
Latitude	38.27533
Longitude	177.8533
Plant date	1-Sep-70
Age 1st measurement	38.9
Age last measurement	40
Date last measurement	15-Sep-10
Number of measurements	2
Stems/ha planted	3086
Stems/ha at 1st measurement	620
Stems/ha at last measurement	620
Number of recorded thinnings	2
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	4
Maximum prune height (m)	5.8

Experiment	453
Sub-experiment	12
Plot	1
Sub-plot	0
Region	East Coast
Forest	Mangatu
Latitude	-38.229
Longitude	177.8595
Plant date	1-Jun-79
Age 1st measurement	25
Age last measurement	29.05
Date last measurement	9-Jul-08
Number of measurements	3
Stems/ha planted	.
Stems/ha at 1st measurement	1000
Stems/ha at last measurement	850
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	150
Number of prunings	.
Maximum prune height (m)	.

Another PSP that would be useful for developing a mortality function.

Experiment	453	453	453	453
Sub-experiment	9	9	9	9
Plot	0	0	0	0
Sub-Plot	1	2	3	4
Region	CNI			
Forest	Kaingaroa			
Latitude	-38.3435	-38.3435	-38.2633	-38.3436
Longitude	176.3722	176.3716	176.3673	176.3713
Plant date	1-Jun-82	1-Jun-82	1-Jun-82	1-Jun-82
Age 1st measurement	22	22.05	22	22
Age last measurement	28.05	28.05	28.05	28.05
Date last measurement	1-Jul-10	1-Jul-10	2-Jul-10	2-Jul-10
Number of measurements	5	5	5	5
Stems/ha planted	1666	1666	1666	1666
Stems/ha at 1st measurement	660	850	350	500
Stems/ha at last measurement	660	817	350	500
Number of recorded thinnings	1	.	1	1
Total stems/ha thinned	220	.	767	220
Stems/ha windthrown	0	0	0	0
Stems/ha dead	0	33	0	0
Number of prunings	.	.	.	.
Maximum prune height (m)	.	.	.	.

Experiment	453	453	453	453
Sub-experiment	9	9	9	9
Plot	0	0	0	0
Sub-Plot	5	6	7	8
Region	CNI			
Forest	Kaingaroa			
Latitude	-38.3435	-38.3437	-38.3439	-38.3438
Longitude	176.3719	176.3721	176.3717	176.3714
Plant date	1-Jun-82	1-Jun-82	1-Jun-82	1-Jun-82
Age 1st measurement	22	22	22	22
Age last measurement	28.05	28.05	28.05	28.05
Date last measurement	2-Jul-10	2-Jul-10	2-Jul-10	2-Jul-10
Number of measurements	5	5	5	5
Stems/ha planted	1666	1666	1666	1666
Stems/ha at 1st measurement	660	500	350	920
Stems/ha at last measurement	660	500	350	900
Number of recorded thinnings	1	1	1	.
Total stems/ha thinned	440	460	350	.
Stems/ha windthrown	0	0	0	0
Stems/ha dead	0	0	0	20
Number of prunings	.	.	.	.
Maximum prune height (m)	.	.	.	.

Experiment	453	453
Sub-experiment	10	10
Plot	1	2
Sub-plot	0	0
Region	East Coast	
Forest	Ruatoria	
Latitude	-37.7288	-37.7286
Longitude	178.2666	178.2643
Plant date	1-Jun-76	1-Jun-76
Age 1st measurement	28	28
Age last measurement	31.05	31.05
Date last measurement	16-Jul-07	16-Jul-07
Number of measurements	3	3
Stems/ha planted	.	.
Stems/ha at 1st measurement	1100	617
Stems/ha at last measurement	1067	617
Number of recorded thinnings	.	.
Total stems/ha thinned	.	.
Stems/ha windthrown	0	0
Stems/ha dead	33	0
Number of prunings	.	.
Maximum prune height (m)	.	.

Two PSPs on East Coast with different stockings. These are worth re-measuring as trees have started to die in the higher stocked plot.

Experiment	453
Sub-experiment	11
Plot	1
Sub-plot	0
Region	Hawkes Bay
Forest	Patunamu
Latitude	-38.8839
Longitude	177.2555
Plant date	1-Jun-77
Age 1st measurement	27
Age last measurement	30.05
Date last measurement	18-Jul-07
Number of measurements	3
Stems/ha planted	.
Stems/ha at 1st measurement	880
Stems/ha at last measurement	840
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	40
Number of prunings	.
Maximum prune height (m)	.

Experiment	453
Sub-experiment	13
Plot	1
Sub-plot	0
Region	CNI
Forest	Chavasse Holt, Paengaroa
Latitude	-37.834323
Longitude	176.49557
Plant date	1-Jun-93
Age 1st measurement	11
Age last measurement	15
Date last measurement	26-May-08
Number of measurements	5
Stems/ha planted	357
Stems/ha at 1st measurement	300
Stems/ha at last measurement	230
Number of recorded thinnings	1
Total stems/ha thinned	70
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	.
Maximum prune height (m)	.

No urgency for re-measurement as at a low stocking and unlikely to be any mortality

Experiment	453
Sub-experiment	14
Plot	1
Sub-plot	0
Region	CNI
Forest	Heather, Paradise Valley, Rotorua
Latitude	-38.1006
Longitude	176.1566
Plant date	1-Jun-80
Age 1st measurement	24.65
Age last measurement	27.15
Date last measurement	20-Aug-07
Number of measurements	3
Stems/ha planted	650
Stems/ha at 1st measurement	425
Stems/ha at last measurement	425
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	.
Maximum prune height (m)	.

No urgency for re-measurement as at quite a low stocking and unlikely to be any mortality

Experiment	453	453
Sub-experiment	15	15
Plot	1	1
Sub-plot	0	0
Region	CNI	
Forest	Green Lake, Whakarewarewa	
Latitude	38.21606	38.21606
Longitude	176.2972	176.2972
Plant date	1-Jun-1910	1-Feb-84
Age 1st measurement	99.25	25.4
Age last measurement	99.25	25.4
Date last measurement	17-Sep-09	17-Sep-09
Number of measurements	1	1
Stems/ha planted	2000	2000
Stems/ha at 1st measurement	144	1648
Stems/ha at last measurement	144	1648
Number of recorded thinnings	1	1
Total stems/ha thinned	.	.
Stems/ha windthrown	0	0
Stems/ha dead	0	0
Number of prunings	.	.
Maximum prune height (m)	.	.

This PSP will be useful for developing mixed-aged models

Experiment	453	453	453
Sub-experiment	16	16	16
Plot	1	2	3
Sub-plot	0	0	0
Region	CNI		
Forest	Collings, Ohakuri		
Latitude	-38.3748	-38.3751	-38.3721
Longitude	176.0987	176.0913	176.1078
Plant date	1-Jun-98	1-Jun-98	1-Jun-98
Age 1st measurement	7.55	7.55	7.55
Age last measurement	11.25	11.15	11.15
Date last measurement	16-Sep-09	28-Aug-09	28-Aug-09
Number of measurements	3	3	3
Stems/ha planted	1400	1500	1500
Stems/ha at 1st measurement	1480	1480	1420
Stems/ha at last measurement	480	760	760
Number of recorded thinnings	2	2	2
Total stems/ha thinned	1000	740	700
Stems/ha windthrown	0	0	0
Stems/ha dead	0	0	0
Number of prunings	2	1	1
Maximum prune height (m)	6.1	6.1	6.2

Note: Planted stems/ha for plot 1 is less than actual stocking.

Experiment	453
Sub-experiment	17
Plot	1
Sub-plot	0
Region	CNI
Forest	Manutahi, SF118
Latitude	37.90287
Longitude	178.3363
Plant date	1-Jun-77
Age 1st measurement	29.15
Age last measurement	31.05
Date last measurement	8-Jul-08
Number of measurements	2
Stems/ha planted	.
Stems/ha at 1st measurement	320
Stems/ha at last measurement	320
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	.
Maximum prune height (m)	.

No urgency for re-measurement as is at a low stocking so unlikely to be any individual tree mortality in the foreseeable future

Experiment	453	2106
Sub-experiment	18	11
Plot	1	6
Sub-plot	0	0
Region	CNI	CNI
Forest	I. Brown, Pinongia	I. Brown, Pinongia
Latitude	-38.0468	.
Longitude	175.1216	.
Plant date	1-Jun-95	1-Jul-95
Age 1st measurement	12.15	10.1
Age last measurement	14.05	14
Date last measurement	15-Jul-09	15-Jul-09
Number of measurements	2	4
Stems/ha planted	850	510
Stems/ha at 1st measurement	850	510
Stems/ha at last measurement	525	280
Number of recorded thinnings	1	1
Total stems/ha thinned	325	230
Stems/ha windthrown	0	0
Stems/ha dead	0	0
Number of prunings	2	2
Maximum prune height (m)	3	3.8

Two PSPs with the same private owner, but with different planting stockings .

Experiment	453
Sub-experiment	19
Plot	1
Sub-plot	0
Region	Canterbury
Forest	Hundalee
Latitude	-42.733
Longitude	173.2493
Plant date	9-Sep-02
Age 1st measurement	6.15
Age last measurement	6.15
Date last measurement	1-Oct-08
Number of measurements	1
Stems/ha planted	600
Stems/ha at 1st measurement	620
Stems/ha at last measurement	620
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	.
Maximum prune height (m)	.

Contains different redwood clones.

Experiment	453	453	453	453
Sub-experiment	20	20	20	20
Plot	1	2	3	4
Sub-plot	0	0	0	0
Region	Manawatu			
Forest	Okota			
Latitude	39.87286	39.87316	39.87338	39.87266
Longitude	175.562	175.5622	175.562	175.5617
Plant date	1-Jun-03	1-Jun-03	1-Jun-03	1-Jun-03
Age 1st measurement	5.4	5.4	5.4	6.25
Age last measurement	6.25	6.25	6.25	6.25
Date last measurement	18-Sep-09	18-Sep-09	18-Sep-09	18-Sep-09
Number of measurements	2	2	2	1
Stems/ha planted	500	500	500	500
Stems/ha at 1st measurement	433	533	483	517
Stems/ha at last measurement	433	533	483	517
Number of recorded thinnings	.	.	.	.
Total stems/ha thinned	.	.	.	.
Stems/ha windthrown	0	0	0	0
Stems/ha dead	0	0	0	0
Number of prunings	.	1	1	.
Maximum prune height (m)	.	1	2.5	.

This is a pruning trial established by New Zealand Redwood Company.

Experiment	453
Sub-experiment	21
Plot	1
Sub-plot	0
Region	
Forest	Wilsons, Otorohanga
Latitude	38.30831
Longitude	175.3282
Plant date	1-Jun-62
Age 1st measurement	47
Age last measurement	47
Date last measurement	23-Apr-09
Number of measurements	1
Stems/ha planted	750
Stems/ha at 1st measurement	750
Stems/ha at last measurement	750
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	.
Maximum prune height (m)	.

PSPs Plot description states that this PSP has remained unthinned since establishment and mortality has just started. Worth maintaining to develop mortality function.

Experiment	475	475	475	475	475	475
Sub-experiment	35	35	35	35	35	35
Plot	0	0	9	9	55	55
Sub-plot	6	10	1	12	13	20
Region	Hawkes Bay					
Forest	Tutira					
Latitude	-39.2384	-39.2389	-39.239	-39.2386	-39.2385	-39.2385
Longitude	176.8889	176.8877	176.8886	176.8879	176.8881	176.8874
Plant date	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98
Age 1st measurement	5.75	5.75	5.75	5.75	5.75	5.75
Age last measurement	11.15	11.15	11.15	11.15	11.15	11.15
Date last measurement	25-Aug-09	26-Aug-09	24-Aug-09	25-Aug-09	25-Aug-09	25-Aug-09
Number of measurements	7	7	7	7	7	7
Stems/ha planted	1333	1333	1333	1333	1333	1333
Stems/ha at 1st measurement	525	525	525	525	525	525
Stems/ha at last measurement	525	525	525	525	525	525
Number of recorded thinnings	.	.	.	.	.	.
Total stems/ha thinned	.	.	.	.	.	.
Stems/ha windthrown	0	0	0	0	0	0
Stems/ha dead	0	0	0	0	0	0
Number of prunings	.	.	1	1	1	1
Maximum prune height (m)	.	.	3.9	4.8	5.6	4.1

Experiment	475	475	475
Sub-experiment	50	50	50
Plot	0	0	0
Sub-plot	7	8	9
Region	Hawkes Bay		
Forest	Tutira		
Latitude	-39.2385	-39.2386	-39.2389
Longitude	176.8887	176.8882	176.888
Plant date	1-Jun-98	1-Jun-98	1-Jun-98
Age 1st measurement	5.75	5.75	5.75
Age last measurement	11.15	11.15	11.15
Date last measurement	25-Aug-09	25-Aug-09	25-Aug-09
Number of measurements	7	7	7
Stems/ha planted	1333	1333	1333
Stems/ha at 1st measurement	750	750	750
Stems/ha at last measurement	750	725	725
Number of recorded thinnings	.	1	1
Total stems/ha thinned	.	50	25
Stems/ha windthrown	0	0	0
Stems/ha dead	0	0	0
Number of prunings	.	.	.
Maximum prune height (m)	.	.	.

Experiment	475	475	475	475	475	475
Sub-experiment	50	50	50	50	50	50
Plot	9	9	9	55	55	55
Sub-plot	2	11	17	3	14	21
Region	Hawkes Bay					
Forest	Tutira					
Latitude	-39.2389	-39.2387	-39.238	-39.2387	-39.2383	-39.2377
Longitude	176.8889	176.8875	176.8882	176.8892	176.8884	176.8882
Plant date	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98
Age 1st measurement	5.75	5.75	5.75	5.75	5.75	5.75
Age last measurement	11.15	11.15	11.15	11.15	11.15	11.15
Date last measurement	24-Aug-09	25-Aug-09	25-Aug-09	24-Aug-09	25-Aug-09	26-Aug-09
Number of measurements	7	7	7	7	7	7
Stems/ha planted	1333	1333	1333	1333	1333	1333
Stems/ha at 1st measurement	750	750	750	750	750	775
Stems/ha at last measurement	750	750	725	750	750	750
Number of recorded thinnings	.	.	1	.	.	1
Total stems/ha thinned	.	.	25	.	.	25
Stems/ha windthrown	0	0	0	0	0	0
Stems/ha dead	0	0	0	0	0	0
Number of prunings	1	1	1	1	1	1
Maximum prune height (m)	4.4	4.2	4.3	5.2	5	4.5

Experiment	475	475	475	475	475	475
Sub-experiment	65	65	65	65	65	65
Plot	0	0	9	9	55	55
Sub-plot	16	19	15	18	4	5
Region	Hawkes Bay					
Forest	Tutira					
Latitude	-39.2379	-39.2383	-39.2382	-39.2382	-39.2384	-39.2382
Longitude	176.8885	176.8876	176.8887	176.8879	176.8894	176.8892
Plant date	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98	1-Jun-98
Age 1st measurement	5.75	5.75	5.75	5.75	5.75	5.75
Age last measurement	11.15	11.15	11.15	11.15	11.15	11.15
Date last measurement	25-Aug-09	26-Aug-09	25-Aug-09	25-Aug-09	22-Aug-09	24-Aug-09
Number of measurements	7	7	7	7	7	7
Stems/ha planted	1333	1333	1333	1333	1333	1333
Stems/ha at 1st measurement	975	975	975	1000	1000	1000
Stems/ha at last measurement	975	950	950	975	925	950
Number of recorded thinnings	.	.	1	2	1	.
Total stems/ha thinned	.	.	25	25	50	.
Stems/ha windthrown	0	0	0	0	0	50
Stems/ha dead	0	25	0	0	25	0
Number of prunings	.	.	1	1	1	1
Maximum prune height (m)	.	.	4.8	2.9	5	5.6

Experiment	230
Sub-experiment	0
Plot	1
Sub-plot	0
Region	CNI
Forest	Whakarewarewa
Latitude	-38.16
Longitude	176.2687
Plant date	1-Jun-1901
Age 1st measurement	47.05
Age last measurement	107.25
Date last measurement	25-Sep-08
Number of measurements	16
Stems/ha planted	7000
Stems/ha at 1st measurement	203
Stems/ha at last measurement	203
Number of recorded thinnings	.
Total stems/ha thinned	.
Stems/ha windthrown	0
Stems/ha dead	0
Number of prunings	3
Maximum prune height (m)	12.3

Experiment	2021	2021	2021
Sub-experiment	6	6	6
Plot	8	9	10
Sub-plot	1	1	1
Region	CNI		
Forest	G. Brann, Paengaroa		
Latitude	-37.9133	-37.910813	-37.9077
Longitude	176.4112	176.41052	176.4117
Plant date	1-Jul-69	1-Jun-00	1-Jun-97
Age 1st measurement	29.95	3.05	6.05
Age last measurement	40.95	9	13
Date last measurement	30-Jun-10	11-May-09	30-Jun-10
Number of measurements	9	7	7
Stems/ha planted	2500	833	714
Stems/ha at 1st measurement	363	883	583
Stems/ha at last measurement	363	883	333
Number of recorded thinnings	.	.	1
Total stems/ha thinned	.	.	233
Stems/ha windthrown	0	0	0
Stems/ha dead	0	0	17
Number of prunings	.	2	4
Maximum prune height (m)	.	4.2	6.6

These are three separate PSPs. Plot 9 pruned in 2009 and Plot 10 in 2010. May need to be monitored more frequently to capture response to pruning.