Species, Site and Silviculture:

A Critical Match for Successful Farm Forestry

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Abstract

Both public and private investment has contributed to a rapid expansion of plantation forestry onto more marginal farmland. Since 1990 considerable energy was expended in the field of ‘low rainfall farm forestry.’ In this context, the matching of species and silviculture to site characteristics is necessary to produce commercial tree crops successfully and to create associated environmental benefits.

Several mature and immature plantations of varied history and site characteristics were investigated to determine what could be achieved on sites of moderate to lower productivity. During 2007 - 2009 Private Forests Tasmania (PFT) trialled several levels of early thinning and fertilizer application to maximize diameter growth of pruned final crop trees on five *Eucalyptus nitens* and three *Pinus radiata* plantations across a mean annual rainfall range of 600 to 1,000mm in Northern Tasmania.

Early thinning had an impact on tree diameter growth across species and sites. Impacts of fertilizer application were less conclusive. Results suggest it is advisable to thin plantations early to either a final crop stocking, or to a stocking which allows production of intermediate plantation products, to achieve target final crop diameters. The study also indicates there is risk of plantation failure if species are planted on sites outside of their climatic limitations.

Introduction

In Tasmania, the plantation forest industry has revolved around *Pinus radiata* (Radiata pine) as the backbone of sawn timber production. *P. radiata* has been a proven performer across Tasmania from the rich basalt soils and high rainfall Northwest to the dry sand dunes of the Northeast, totalling some 75,000 ha softwood plantation area state-wide. Harvesting *P. radiata* from areas of lower productivity has tended to be for salvage or to meet spot markets, usually for low grade products.

In coastal and lower altitude areas *Eucalyptus globulus* (Tasmanian bluegum) was the preferred hardwood species for bulk fibre production. In more recent times *Eucalyptus nitens* (shining gum), has been the species of choice across the State to provide export woodchips for high quality paper production. Since the mid1990s there has been interest in funding programs to produce high value sawlogs and veneers from plantation grown eucalypts through pruning and early thinning silviculture, often in low rainfall zones.

Traditionally *E. nitens* plantations were limited to fertile sites with a mean annual rainfall (MAR) greater than 800mm. The rapid development of managed investment schemes (MIS) saw large scale *E. nitens* plantations established on less fertile sites, down to MAR of 550mm. Laffan's (1997) site productivity assessment model which acted as a guide to suitable site conditions and estimates of site productivity is based on limiting site factors, that is the factor in most limited supply is predicted to determine the expected productivity of a plantation.

With the benefit of hindsight, this approach raises a number of important questions which hitherto need to be answered.

- Are some plantation species being planted outside their climatic ranges, and are these plantations able to survive and produce to maturity?
- Is it possible to achieve target piece size by varying silvicultural regimes to manipulate moisture availability and access to nutrients of individual trees?
- Should we be revisiting research into alternative hardwood plantation species and appropriate seed provenances for less productive sites?

Some 35% of Tasmania's land area has MAR below 1,000mm. Much of this land has potential for farm forestry and timber production. Historically however, areas with MAR less than 800mm have not attracted investment, and therefore have lacked research interest from industrial forestry companies. A key criterion of economic suitability has been the potential to achieve a mean annual increment (MAI) greater than 15m^3/ha/yr by harvest. In 2013, in an absence of market for pine veneer logs, pruned sawlogs (at $70 - $80 per cubic metre return to the grower) were double the value of knotty sawlogs ($35 - $40 per cubic metre). This differential in sawlog prices provides an argument for pruning of plantation pine. However, as the target diameters for knotty sawlogs are around 45cm, as opposed to 60cm for clearwood logs, knotty sawlog diameters might be more achievable within acceptable rotation timeframes, even on sites of lower productivity. However, is it actually possible to achieve these piece sizes on sites of moderate to lower productivity?

Empirical data from mature aged *P. radiata* stands, suggests that it is possible to achieve a MAI of 15 -20 m^3 /ha/yr by age 30 year in areas with MAR of 600mm to 1,000mm. There are few data with respect to possible growth rates of *E. nitens* in the same areas.

For both *P. radiata* and *E. nitens* sawlog and veneer regimes, the standard final crop stocking on high productivity sites is 250-350 sph. On lower productivity sites, final crop stockings of 150-200 sph would appear more realistic. This is based on mainland experiences, professional experience and the outputs of the 2003 work conducted by PFT (Tas. Land and Forest, 2003).

Methods

Investigations were spread over 3 areas:

- Mature stands of *P. radiata* over 30 years of age.
- Mid rotation stands of *P. radiata* where landowners had applied some of their own 'silviculture' by way of early thinning.
- Trials established by PFT over immature stands (both *P.radiata* and *E.nitens*) in order to gage more immediate responses to silvicultural treatments.

Plantations Investigated (not part of silvicultural trials)

In order to establish some base line site productivity and piece size information, tree data were collected from six privately owned mature *P. radiata* plantations, each over 30 years of age, with varying management histories. A single plot, of area 0.06 ha, was established in each stand.

Data were also collected from three immature *P. radiata* stands (13 to 14 years of age) where landowners had 'tinkered' or 'experimented' with early non-commercial thinning in parts of their stands. Three such plantations were identified where portions had been thinned at an early age (around 5 years old), with a subsequent growth response period of some 8 to10 years. These were considered a valuable component in the study. Several plots, each 0.05 - 0.06 ha in size, were established in each of these stands.

Site locations are listed in Table 1 below. The spread of sites covers a MAR range of 600mm to 1100mm, and extends across a range of soil types.

Table 1: *P. radiata* sites contributing comparative data (non silvicultural trial)

Location	Mean Annual Rainfall (MAR in mm)	Age when trees measured (yrs)	Soils
Blessington	1 100	33	Shale and gravel
Rosevale- Four Springs	800	30	Both shallow duplex and sandy
Cressy - Formosa	600	39	Brickendon - texture contrast
Launceston- Travellers Rest	700	38	
Fingal- Tullochgoram	550	30	
Cressy-Saundridge Rd	700	13	Dolerite based – rocky
Longford	600	14	Brumby - shallow texture contrast
Cressy- Macquarie Rd	600	14	Brickendon - texture contrast

Silvicultural Trails

Private Forests Tasmania (PFT) staff established eight trial sites between 2006 and 2008, in stands 3 to 6 years old, at a time when pruning operations had commenced. Three were in small *P. radiata* stands and five were in young stands of *E. nitens*.

All of the eight silvicultural trials were superimposed within existing plantations in close cooperation with landowners (Tables 2 and 3). Many of these small farm forestry plantations were established under federal government assistance schemes such as Natural Heritage Trust (NHT) or the National Landcare Programme (NLP) which were administered through PFT during 1990- 2010.

Trial site locations are listed in Tables 2 and 3 below. The spread of sites covers a MAR range of 600 - 1100 mm, and extends across a range of soil types. Tree data were gathered from both *P. radiata* and *E. nitens* stands, (both in silvicultural trials and the three immature *P. radiata* stands of similar age) in relatively close proximity to each other as an 'approximate yardstick' for comparative performance of the two species.

Table 2: *P. radiata* silvicultural trial locations in northern Tasmania

Location	Mean Annual Rainfall (MAR, mm)	Age when trial established (yrs)	Soils
Rosevale	800	6	Dolerite based
Hagley	720	5	Brickendon- texture contrast
Carrick	720	5	Brickendon – texture contrast (ex-gravel quarry)

Table 3: *E. nitens* silvicultural trial locations in northern Tasmania

Location	Mean Annual Rainfall (MAR, mm)	Age when trial established (yrs)	Soils
Liffey	1100	3	Shale and mudstone based
Blackwood Creek	750	4	Shallow - texture contrast
Rosevale	800	3	Dolerite based
Cressy – Poatina Rd	700	6	Deep sandy
Cressy- Lake River Rd	600	4	Newham - texture contrast

All trial stands were managed for sawlog production with approximately 200 - 300 sph final crop trees pruned to a height of approximately 6.0 m, over three pruning lifts. Replicated treatments and treatment combinations were applied as thinning treatment x fertilizer applications in complete factorial designs (Randomized Complete Block Design) where possible. (See Table 4 below.) Where possible, three thinning treatments were applied, as follows:

1. No thinning – original stocking of around 850 to 1100 stems per ha;
2. Intermediate thinning to 600 to 650 stems per hectare; and
3. A high degree of thinning to around 300 to 400 stems per hectare.

In *P. radiata* stands, thinning was undertaken at approximate age 5 years with consideration of a second commercial thinning for intermediate products into established markets. Consideration was given to maintaining site occupancy by the plantation species, what level of early thinning is required to maintain productivity and site occupancy, that is to release the remaining trees until a commercial thinning is undertaken (at around age 15-18 years) without a significant check in diameter growth?

For *E. nitens*, the higher levels of thinning were at the high end of final crop stocking providing a little insurance against 'windthrow' or mortality. For *P. radiata* there was a compromise with the level of thinning. No plots were thinned to final crop stocking only.

The most intense levels of thinning were to around 400 sph, allowing for a further commercial thinning of small sawlogs.

A suite of trace elements was included in fertilizer application blends, (except urea application), including Boron and Copper, (not just those nutrients identified as marginal or deficient in pine foliar samples), and Phosphorous and Potassium were also included in all blends. Foliar samples from all *P. radiata* stands were obtained in advance of the trial and these showed adequate levels of Nitrogen, hence only low Nitrogen levels were included in blends applied to *P. radiata* stands. Fertilizer blends applied to *E. nitens* contained 13% Nitrogen and extra application of fertilizer to *E. nitens* consisted of urea, containing 49% Nitrogen.

It was assumed that all trial stands would have received fertilizer around the time of planting, typically 100 - 150g of DAP per seedling.

Fertilizer treatments in *P. radiata* trial sites consisted of:-

- No secondary fertilizer application (described as ' Treatment 0'),
- Secondary fertilizer application determined by the analysis of plant foliage (described as ' Treatment 1')
- Extra fertilizer application of macro nutrients Nitrogen, Phosphorus, in addition to the recommended treatment, (described a 'Treatment 2').

E. nitens trial sites only received 'Treatment 0' and ' Treatment 2' fertilizer treatments.

For pine trials, single fertilizer application consisted of 500 kg per ha of low Nitrogen NPK fertilizer blend with trace elements, applied in spring 2007. Extra fertilizer application consisted of an additional 400 kg of DAP applied in spring 2008. For eucalypt trial sites single fertilizer application consisted of 400 kg per ha high Nitrogen NPK fertilizer blend applied in spring 2007. Extra fertilizer application consisted of an additional 400kg per ha of urea in spring 2009. It was planned to apply urea in 2 x 200kg/ha doses over 2 years. However, 2008 was a drought year and considered 'too dry' to add urea to the *E. nitens* trial sites. Thus, 400 kg/ ha of urea was applied in one application in 2009.

Table 4. Treatments applied to silvicultural trial sites, by species

	Trial Species	
Thinning Treatment	***P. radiata***	***E. nitens***
Unthinned (original stocking)	850- 1200	1000 - 1100
Intermediate Thinning	600 - 650	600 - 650
High level of Thinning	400	300
Fertilizer Application		
Treatment 0	No Secondary fertilizer application	No Secondary fertilizer application
Treatment 1	500 kg/ha NPK (low N) + Trace elements Applied in Spring 2007	No treatment 1 Applied to *E. nitens* sites
Treatment 2	Treatment 1 + 400kg/ha DAP in the following year (Spring 2008)	400kg/ha NPK (high N) + Trace elements (Spring 2007) + 400kg/ha Urea (Spring 2009)

In silvicultural trials each plot was 7 rows, including buffers, by approximately 25m long, and approximately 0.04 - 0.06 ha in area.

On trial sites DBHOB, in cm, were measured for each plot tree at both 2 and 4 years after treatment. MDH for each plot was also assessed.

The regimes undertaken in trial stands involve thinning the plantations in order to produce a sawlog crop. Key questions regarding silvicultural management revolve around the rate of diameter growth of pruned or final crop trees. Statistical analysis of comparative diameter growth was restricted to the diameters of the pruned trees within each trial plot. Mean dominant height was also measured within each plot.

Data were analysed using the Statistical Package for Social Sciences (SPSS). Where design permitted, a multifactor analysis of variance (ANOVA) was the primary analysis method augmented where necessary by data suitability and post-hoc analysis techniques.

Many farm forestry plantations tended to be small in size, and landowners often had personal preferences and management objectives. There was also a need to maintain the potential economic viability of landowner plantations. These factors posed restrictions on trial layout in a number of instances. On the Carrick *P. radiata* site the compromise was that there were only two replications of each treatment, limiting the statistical power of the analysis. On the Liffey, Blackwood Creek and two Cressy *E. nitens* sites there was only two fertilizer treatments, no fertilizer (Treatment 0) and extra fertilizer (Treatment 2).

Attempts were made to interpret results in conjunction with data collected from other related projects, and in light of other factors which may have influenced the observed outcomes. Recent rainfall trends, soil profile work and plant nutrition information were also considered.

Results

Table 5: Summary of plot data from mature stands over 30 years of age.

Plot location	Annual rainfall (mm)	Age (years)	Current Stocking (sph)	Mean DBHOB (cm)	MDH (m)	BA (m^2/ha)	Wood Volume (m^3/ha)	MAI (m^3/ha/yr)
Blessington (unthinned)	1000	33	1550	25	28.0	77	750	22.7
Blessington (Partially thinned)	1000	33	650	31	28.0	52	480	14.7
Rosevale - Four Springs 1 (unthinned)	800	30	517	30	26.8	39	351	11.7
Rosevale - Four Springs 2 (thinned)	800	30	183	50	32.6	37	409	13.6
Rosevale - Four Springs 3 (thinned)	800	30	217	47	32.7	39	440	14.7
Launceston - Travellers Rest (Partially thinned)	700	38	667	35	29.0	69	670	17.7
Cressy- Formosa (unthinned)	600	39	583	36	31.0	63	644	16.5
Fingal - Tullochgorum (unthinned)	550	30	533	30	27.0	40	360	12.0

Table 6: Plot measurement summaries from 3 immature *P. radiata* stands in Northern Tasmania

- **Sections of the stands were thinned at an early age.**

Site and Plot	MAR (mm)	Age (yrs)	Current stocking (stems/ha)	DBHOB (cm)	DBH (cm) Pruned stems	MDH (m)	Stand vol (m^3/ha)	MAI (m^3/ha)	Mean DBHOB gain over unthinned (cm)	Silviculture
Longford 1	600	14	750	25.2	23.7	18.1	227.4	16.2	0	Unthinned
Longford 2		14	283	29.1	29.1	16.5	104.3	7.4	+5.4 cm	Thinned (age 5yrs*)
Longford 3		14	250	32.9	32.9	17.8	126.9	9.1	+9.2 cm	Thinned (age 5yrs*)
Cressy -Saundridge Rd 1	700	13	1000	22.7	23.3	17.8	246	19.0	0	Unthinned
Cressy -Saundridge Rd 2		13	838	22.9	23.8	18.1	209	16.1	0	Unthinned
Cressy -Saundridge Rd 3		13	530	27.3	27.3	17.5	186	14.3	+4.0 cm	Thinned (age 5yrs*)
Cressy -Saundridge Rd 4		13	433	29.2	29.2	17.5	172	13.3	+6.0 cm	Thinned (age 5yrs*)
Cressy- Macquarie Rd 1	600	14	1004	21.0	22.5	15.9	194.3	13.9	0	Unthinned
Cressy- Macquarie Rd 2		14	403	29.2	29.2	15.1	138.4	9.9	+6.7 cm	Thinned (age 5yrs*)
Cressy- Macquarie Rd 3		14	240	31.2	31.2	15.4	95.8	6.8	+8.7 cm	Thinned (age 5yrs*)

* Approximate age when thinned

Results from Plots in Immature *Pinus radiata* Stands in Cressy Longford Area

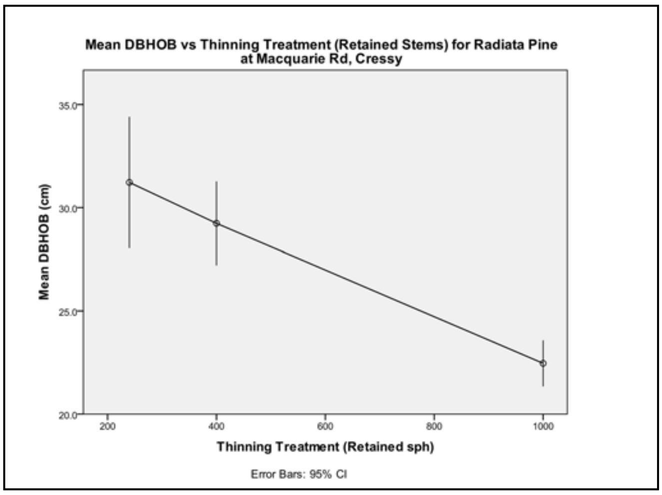

Figure 1: Graph of results from Cressy – Macquarie Rd plots

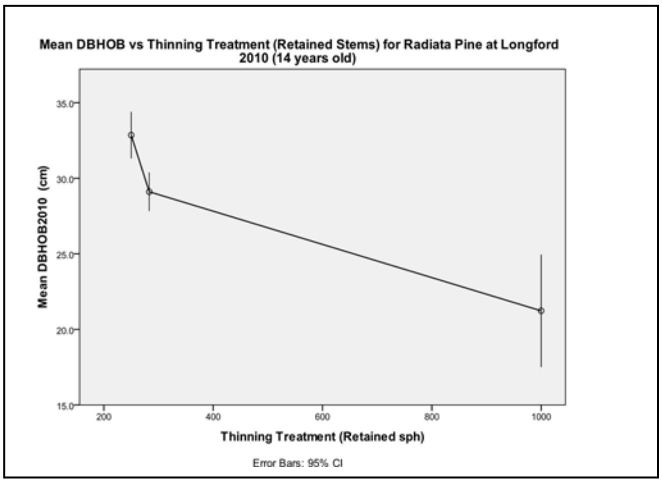

Figure 2: Graph of results from Longford plots

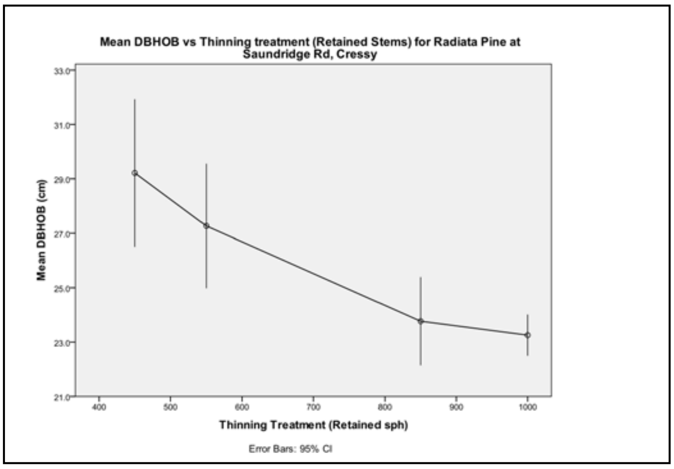

Figure 3: Graph of results from Cressy - Saundridge Rd plots

Results from the 3 *Pinus radiata* Trial Sites

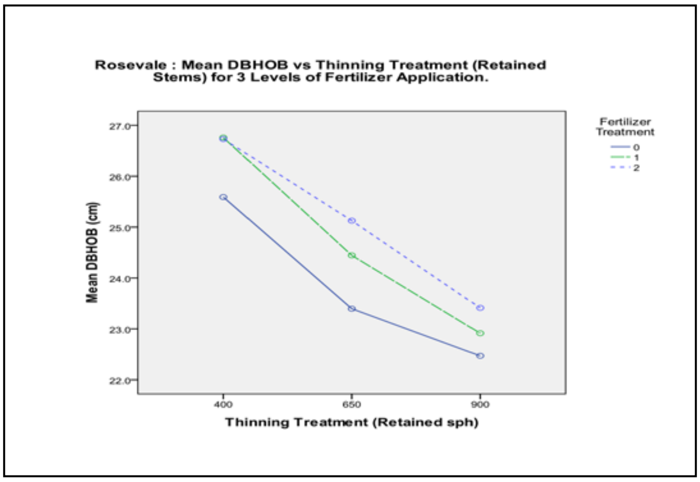

Figure 4: Mean DBHOB for silvicultural treatments at Rosevale

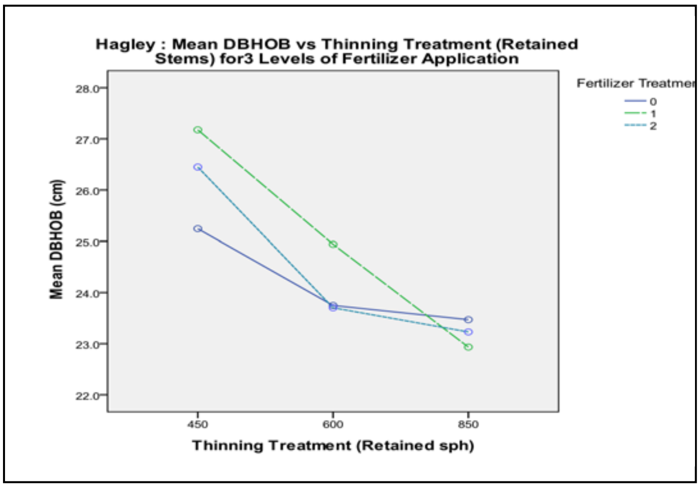

Figure 5: Mean DBHOB for silvicultural treatments at Hagley

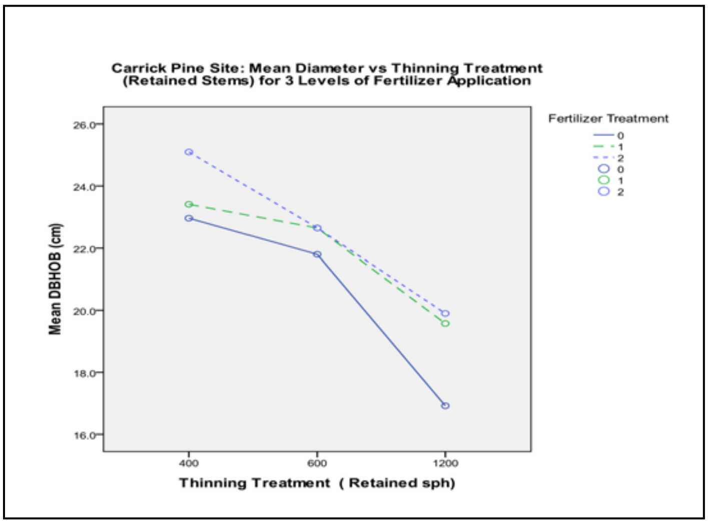

Figure 6: Mean DBHOB for silvicultural treatments at Carrick

Results from Eucalypt Trial Sites

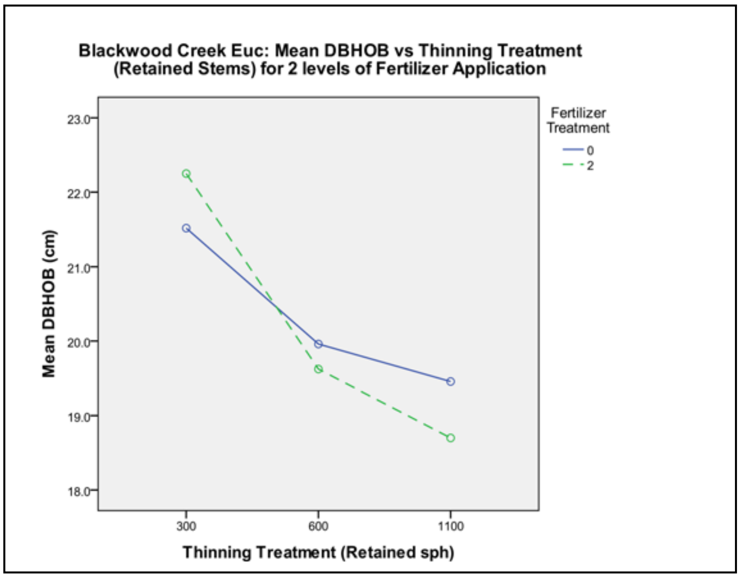

Figure 7: Mean DBHOB for silvicultural treatments at Blackwood Creek

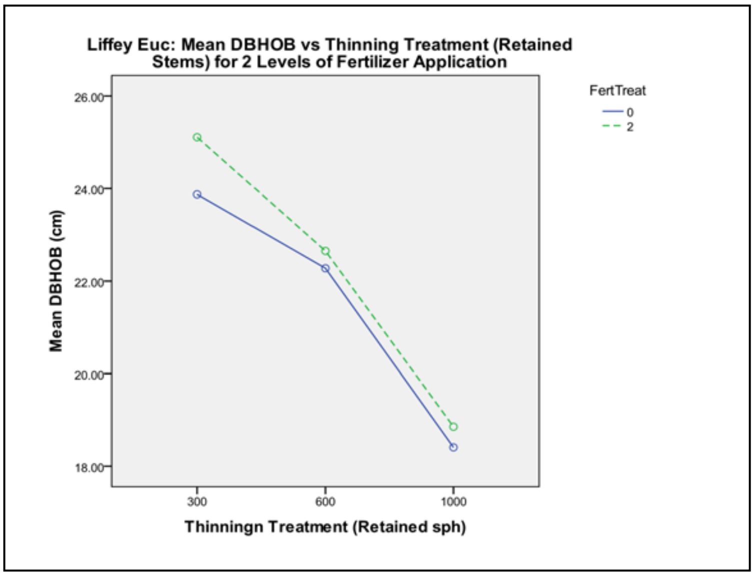

Figure 8: Mean DBHOB for silvicultural treatments at Liffey

Discussion

There are 3 basic questions posed in this discussion.

1. Is it possible to grow 45cm and 60cm diameter butt logs on sites of moderate to lower productivity?
2. On such sites, is it possible to modify existing plantation regimes (thinning and fertilizer application) to achieve target piece size?
3. Are *P.radiata* and/ or *E. nitens* suitable for respective sites, or is more work required to identify more appropriate species (or species provenance) to match different sites?

Pinus radiata

Data were gathered from 6 mature stands, each exceeding 30 years of age, across a range of sites, some limited by rainfall, some by soil fertility and some by both. Some were unmanaged and some had received silvicultural 'intervention' through 'thinning.' The history of these stands is not completely clear, introducing a number of uncontrolled variables into observed growth and productivity outputs.

Whilst there were many variables, several important observations were made. Firstly, on sites of moderate/medium productivity (by Laffan's 1997 classification), the results show it is possible to achieve mean butt log diameters greater than 45cm (Table 5). These data suggest that to achieve mean target log diameters, the site needs be able to grow a wood volume exceeding 400 m^3/ha by age 30 years, after being thinned to around 200 sph at some stage during the rotation. To do so, the stand MAI would need to be in the order of 13 - 15 m^3/ha/yr by age 30 years. Several trees, in plots within the thinned stands at Four Springs, exceeded 70cm DBHOB. Secondly, across all 6 mature stands, where final stocking levels were above 500 sph, mean DBHOB fell well below the target 45cm. Thirdly, there was little stand history available and a number of uncontrolled variables were therefore of unknown influence on the observed growth outcomes. There was limited silviculture applied in all cases. There needs to be greater attention to and understanding of the level and timing of thinning and fertilizer treatments required to provide final crop trees with sufficient resources to achieve target log diameters.

The three immature stands in the Cressy and Longford areas (Table 6) provided more information regarding the level and timing of thinning operations. All were approximately the same age of 13 - 14 years when tree DBHOBs were measured and all were thinned early, around age 5 - 6 years. It would be fair to assume that these stands received one fertilizer application, at planting. On these 3 sites all retained trees in thinned stands had been pruned.

At all 3 sites, Mean DBHOB of pruned trees in thinned plots was significantly greater ($p<0.01$) than those of pruned trees in unthinned plots stocked at 1000 sph (see Fig: 1, 2 and 3). At Macquarie Rd the mean DBHOB in plots thinned to 400 sph was not significantly different from those thinned to 240 sph. Whilst data are in short supply and designs are not statistically robust, there is a suggestion that stocking levels could be held at say 400 sph until age 13 or 14 years without significant suppression of mean DBHOB of pruned trees. This is a hypothesis worthy of testing.

Across all 3 sites, early thinning to stocking of 400 - 500 sph gave an increase in mean diameter of pruned trees of around 4 to 6.7 cm approximately 8 years after treatment. On the two sites with early thinning at age 5 years to a stocking of around 250 sph, the mean gain in DBHOB of pruned trees was 8.7 to 9.2 cm, an average of 1 cm gain in mean DBHOB of pruned trees per year over the 8 years since thinning (Table 6).

At age 14 years, mean diameters of trees in plots thinned to around 250 sph, were 31 to 33 cm, suggesting that mean target diameters of 45cm may be achievable around age 30 years. Target mean clearwood log diameters of 60cm will be more difficult to achieve, particularly on sites of lower productivity. Should the gains in diameter growth from early release thinning continue and should the trees keep growing at similar rates, mean diameters may approach 60cm if the rotation length extends beyond 30 years.

The Forestry Commission Tasmania Plantation Handbook (Neilson, 1990) outlines several pine sawlog regimes. The Clearwood regime proposes radical thinning when the stand achieves an MDH of 3 to 4 m. Modifications to this regime recommend that all thinning be completed by the time stands achieve an MDH of 16 m "to avoid excessive loss on pruned stems and reduce variability… through suppression of some pruned stems" (Neilson, p 214).

Knot control systems delay all thinning until stands reach an MDH of around 20m, ensuring "the suppression of branches over the lower 10 m of the stem, and hence the knots are small… it is then left to grow on until the MDH is about 35 m and final stem diameter is 45 cm" (Neilson, p221).

The ability to hold stocking levels of say 400 - 500 sph for a longer period would have several advantages:

- In Tasmania there are markets, both domestic and spot export, for small pine sawlogs, improving the economics of the overall enterprise, should a commercial thinning be an option.
- Slightly higher stocking assists in risk management with respect to hazards such as windthrow and minor pathogen attack.
- Early heavy thinning compromises branch control in logs above the pruned 6m butt log. Large branches introduce added defect to the second log and hence it is devalued. Holding stockings higher for longer assists in the reduction of branch size and increases timber recovery rates and the value of second and third logs.
- Excessive early thinning on lower productivity sites may result in the stand failing to achieve early 'site occupancy,' through canopy closure, and allow weed infestation.
- On moderate to low productivity sites, intermediate thinning may assist in the control of branch size, with minor or insignificant suppression of diameter growth on final crop trees.

Options for early thinning regimes were also investigated at the three pine trial sites. Radical thinning to final crop was not considered. As all sites were within 100km of a mill which is able to receive sawlogs down to small end diameter (SED) of 20cm, early thinning was capped at retaining 400 sph in order to allow a potential commercial thinning.

On two of the three sites (Rosevale and Carrick) there was no significant interaction between the effects of Fertilizer Level and Thinning Treatment ($F=0.46$, df 4, 420, $p=0.766$; and $F=1.56$, df 4, 228, $p=0.18$). At the Hagley site, acceptance or rejection of the null hypothesis (H_0) that there was no interaction between the effects of thinning treatment and level of fertilizer application was less clear at the 5% level of significance ($F=2.44$, df 2,398, $p=0.047$). On the basis of $p<0.05$, it was accepted (H_1) that there was an interaction between thinning treatment and level of fertilizer application. At Hagley, the effects of fertilizer application are also unclear at the 5% level of significance ($F=2.77$, df 2, 398, $p=0.064$).

At Rosevale (MAR 800mm), thinning from 900 sph to 400 sph resulted in an increase in mean DBHOB of around 3.4 cm over 4 years (Fig. 4). The addition of fertilizer had a significant impact on mean DBHOB. The addition of extra levels of macro-nutrients did not significantly increase mean diameter growth over the effect of the prescribed level. At stocking of 400 sph, there appears to be a significant increase in mean DBHOB where fertilizer is applied. At stocking levels of 900 sph and 650 sph, the addition of fertilizer did not significantly affect mean DBHOB of pruned trees.

At Carrick (MAR700mm), the least robust trial design, thinning from 1200 sph to 400 sph resulted in a significant increase in mean DBHOB of pruned trees, in the order of 5cm over 4 years (Fig. 6). Thinning to 600 sph resulted in an increase of some 1.5 cm in diameter over 4 years. In a similar manner to Rosevale site, the addition of extra levels of macro-nutrients did not significantly increase mean diameter growth over the effect of prescribed fertilizer levels.

At Hagley, (with higher stocking levels of 600 sph and 850 sph respectively) there was no significant difference in mean DBHOB across all thinning and fertilizer combinations (Fig. 5). At 600 and 850 sph, this may suggest that nutrient and moisture availability are not the most limiting factors in plantation productivity. Alternatively, it may also suggest that reduction in stocking from 850 to 600 sph did not provide sufficient improvement in tree water relations to significantly increase productivity and hence mean DBHOB in pruned trees.

At a retained stocking of 450 sph mean DBHOB of pruned trees was significantly greater than those of other thinning and fertilizer combinations (Fig. 6). At 450 sph retained stocking level, the application of fertilizer, both prescribed and extra macro-nutrient, produced significant gains in mean DBHOB over those in unfertilized plots. It would appear that, at Hagley, fertilizer application had a significant impact on Mean DBHOB of pruned trees only at a lower stocking rate of 450sph. Thus, by thinning the stand from 850 sph to 450 sph and adding prescribed fertilizer treatment, an increase of 3 to 4 cm in the mean DBHOB of pruned trees was achieved over 4 years.

Little account was taken of existing needle nutrient status prior to fertilizer application. Prior needle analysis indicated that Copper (Cu) levels were marginal across all sites. The Carrick site also had marginal levels of Phosphorus (P), Potassium (K) and Boron (B). Rosevale also had marginal levels of P and B. All sites had experienced pruning operations during the period of the trial. Hence, the release of nutrients from the decomposition of needles and twigs may have masked, to some degree, the impacts of fertilizer addition or omission.

Eucalyptus nitens

At Rosevale the site was abandoned at age 7 years due to tree mortality across a number of plots. Plot mortality at the Rosevale site was typically 20 - 25%. Mortalities were 45% and 55% in the worst affected plots. Several plots thinned to 300 sph also had substantial mortalities. The worst mortalities in 600 sph plots were 45%, 37% and 32%. High mortalities by year 4 after treatment confounded attempts to analyse data. Tests of Equality of Variances indicated that the null hypothesis (H_0 should be rejected ($p< 0.01$), that is that plots did not originate from populations with the same variance, supporting the decision not to proceed with data analysis. It would appear that there were point sources of either *Phytophthora cinnamomi* or *Armillaria* spp root rot which appeared spread year after year, to the point where the above mortalities occurred over four years.

At the time of trial establishment, all of the sites at Cressy, Poatina Rd and Lake River Rd were in good health and fully stocked after treatments. Within two years of observations, both sites experienced significant levels of mortality. One untreated plot at Poatina Rd experienced 95% mortality four years after the trial commenced. The average mortality for unthinned plots was 68%, for stocking of 600 sph it was 39%, and for 300 sph plot stockings mortality was 30%. At Poatina Rd the average MAI for unthinned plots was 2.4 m^3/ha/yr at age 11. Lake River faired a little better with unthinned plots averaging 30% mortality and plots thinned to 600 sph averaging 17% mortality. At Lake River Rd thinning plots to 300 sph assisted with survival with average mortality of only 3%. However, MAI in unthinned plots averaged only 4.4 m^3/ha/yr at age 9 years. By comparison, the 3 stands of *P. radiata* in the Cressy –Longford area were averaging an MAI of 16.1 m^3/ha/yr at age 13 to 14 years, with only Longford stand beginning to exhibit 'self-thinning.'

Historically, in Tasmania *E. nitens* was considered suitable for planting on fertile sites with MAR above 800 mm. One plantation forest company, in Victoria, stated that it was their policy to establish *E. nitens* only on sites with MAR above 1000mm (personal communication (Carter, Holt, Harvey, 2005). At Rosevale (MAR 800 mm) the MAI of healthy unthinned *E .nitens* plots averaged approximately15 m^3/ha/yr at age 8 years. Similar *P. radiata* plots at Rosevale averaged an MAI of 16.6 m^3/ha/yr at age 10 years, quite comparable.

Jovanovic and Booth (2002) report a MAR of 700 - 2300 mm as a climatic requirement for *E. nitens*. Given such criteria, Cressy sites, with MAR 600 - 700mm, could be described as having marginal suitability, at best, for growing *E. nitens* plantations. Documented climatic requirements (Javanovic and Booth, 2002) combined with observed extremely low MAI and high mortality in *E nitens* plantations, in the Cressy area, bring into question its suitability as a plantation species for sites in this marginal region.

Annual rainfall dropped to 300 to 400 mm per annum during extended drought in the 2006 - 2008 period (Fig. 12) and reasonably this could have contributed to high mortality and plantation failure, particularly on the sandy soil at Poatina Rd.

Given the very high mortality in several plots at Poatina Rd, other factors may also be at play. There are known saline drainage lines in reasonable proximity to this site. With sandy soils overlaying clay, the tree roots in certain areas of the stand may have accessed saline ground water. Such an hypothesis has not been explored here.

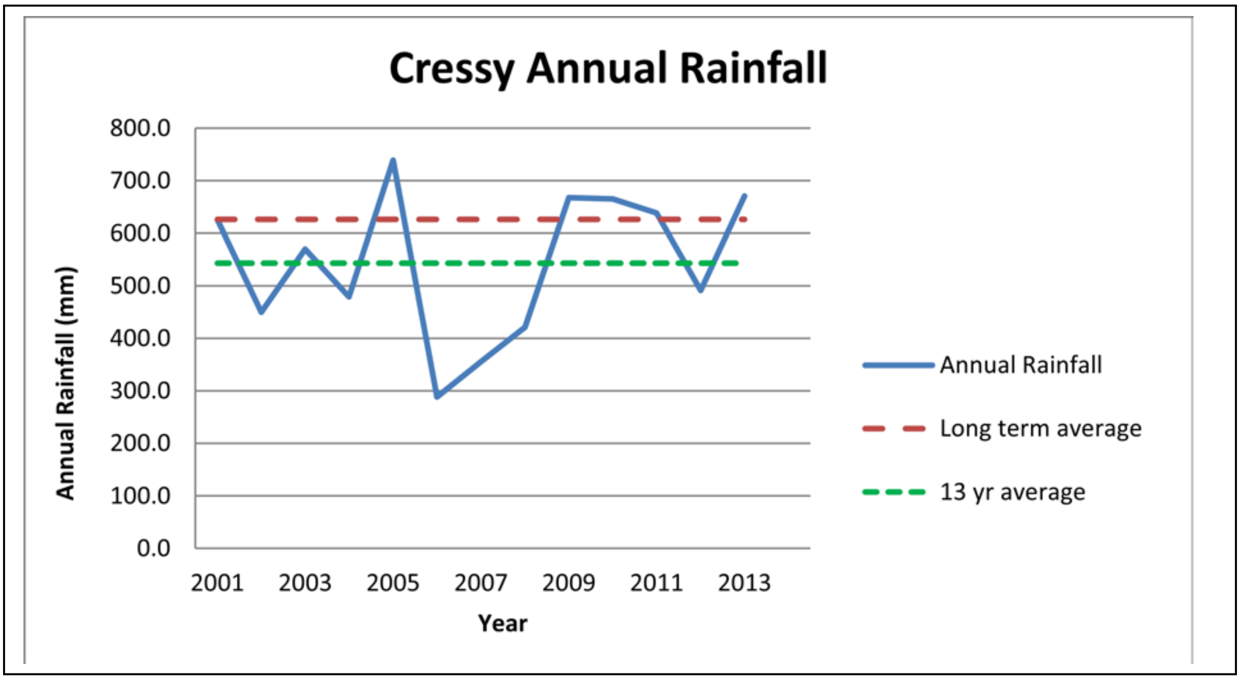

Fig. 12. Annual rainfall at Macquarie Rd Cressy over 2001 to 2013. (Source: Landowner Record, 2013)

At Blackwood Creek (MAR 750 mm) there was no interaction between the effects of Fertilizer Level and Thinning Treatment (F= 0.461, df 2, 444, p= 0.631). The null hypothesis (H_0) that the level of fertilizer applied had no effect on the Mean DBHOB of pruned trees, could not be rejected (F=3.185, df, 1, 444, p=0.075). Thinning Level did have a significant effect on the Mean DBHOB of pruned trees (F= 16.91, df, 2, 250, p< 0.01). Thinning to a retained stocking of 300 sph gave on average a 2 - 3cm gain over trees in unthinned plots at four years after thinning treatment. Thinning the stand from 1100 sph to 600 sph yielded no significant impact on Mean DBHOB of pruned trees.

At Liffey (MAR 1000 mm) there was no interaction between the effects of Fertilizer Level and Thinning Treatment (F= 0.461, df 2, 250, p= 0.665). The null hypothesis that the level of fertilizer applied had no effect on the Mean DBHOB of pruned trees, was not rejected (F= 0.418, df 1, 250, p=0.52). Thinning Level did have a significant effect on the Mean DBHOB of pruned trees (F= 81.546, df 2, 444, p< 0.01). Thinning to 600 sph resulted in an average increase of 3.8 cm in mean DBHOB of pruned trees over those in unthinned plots. Thinning to 300 sph resulted in an average gain of 5.8 cm in mean DBHOB of pruned trees over those in unthinned plots.

Conclusions

Results of this study suggest that it is possible to grow *P. radiata* butt logs of 45 cm DBHOB in areas of moderate to lower productivity (MAR 600 -800 mm) if stands are thinned to final crop stocking of around 200 sph. Achieving butt logs of 60cm mean DBHOB will be more difficult requiring gains from more radical silviculture to be carried on throughout the rotation and a probable extension of the rotation length beyond 30 years.

The *P. radiata* trials on moderate productivity sites demonstrate the benefits of release thinning that can be realized at an early age. When thinned to around 400 sph, at ages 5 to 6 years, significant increases in the diameters of pruned trees, above those in unthinned stands, were achieved during the 4 years following thinning.

It would have been useful to have thinning treatment levels down to 250 sph in the three *P.radiata* trial sites to gauge the diameter gains from more radical thinning regimes. However, in this instance, this could not be negotiated with landowners.

There is no evidence to suggest that fertilizer regimes, above, Treatment 1, those prescribed by the analysis of foliar samples, will significantly impact on mean DBHOB of pruned trees on the sites studied. However, assessment of nutrient status via needle analysis in order to evaluate the need for, and level of, secondary fertilizer application may be worthwhile.

In terms of Laffan's (1997) model, responses in tree diameter growth, to fertilizer application, are generally greater when nutrient supply is the most limiting factor, that is, when stands are thinned to at least 400 sph.

On the Cressy sites with MAR 600 - 700mm and lower productivity, gains of 8 - 9 cm in pruned tree diameter were achieved 8 - 10 years after radical thinning at approximately age 5. More work also needs to be done on the use of less radical thinning regimes (i.e. with two thinning operations in the rotation) to provide intermediate plantation products.

There is support for growing *P.radiata* to achieve an MAI of over $15m^3$/ha/yr and target log diameters (of 45 cm and possibly 60 cm) on low productivity sites similar to Cressy and Longford. Modified regimes which include early release thinning appear to be keys to success.

Of the five *E. nitens* trial sites, three were abandoned due to high mortality rates which compromised the data analysis. The site at Rosevale sustained a substantial fungal attack. Given the low long term average rainfall (MAR 600 - 700) being equal to or less than the reported climatic requirement for *E. nitens*, and the concurrence of two years of extended drought during this study, it appears that the two Cressy sites suffered from severe moisture stress and subsequent attack by wood boring insects. Accordingly, there is a high risk of plantation failure if *E. nitens* is established on sites outside the documented climatic requirements for the species. The greatest gains in diameter growth of pruned eucalypts, from the effect of thinning, were at Liffey, a site of high productivity (MAR 1100 mm). In thinned and fertilized plots, Mean DBHOB of pruned trees was 25.1 cm at age 9 years.

High mortalities in *E.nitens* stands on sites of lower productivity (MAR 600 - 700 mm) would suggest that there is scope to investigate more suitable species for these areas.

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References

Adams P.R., Warren G.D and Robertson D., (2005), Nutrition and Growth Issues in Low-Rainfall *P.radiata* Plantations in Northern Tasmania, Confidential Report for PFT.

Nielson, W. A. (editor), (1990), Plantation Handbook, Forestry Commission, Tasmania.

Gerrand, A. M., Neilson, W.A., and Medhurst, J.L. Research Results for Thinning and Pruning of Eucalypt Plantations for Sawlog production in Tasmania. Forestry Tasmania, 1997: 210 pp.

Gerrand, A. M., Neilson, W.A., and Medhurst, J.L.(1997) Thinning and Pruning of Eucalypt Plantations for Sawlog production in Tasmania. Tasforests9:15-34.

Holden.D.G. and Menzies M.I. Field Use of Radiata Pine Cuttings, NZ Forest Research Institute Ltd.

Hopmans, P., Kitching, M., and Croatto, G., Stem Deformity in *Pinus radiata* Plantations in South-Eastern Australia, Plant and Soil 175: 31- 44.

Jovanovic, T. and Booth , T. H., Improved Species Climatic Profiles. RIRDC Publication No. 02/095, July 2002

Laffan, M. D. (1997), Site selection for hardwood and softwood plantations in Tasmania. A methodology for assessing site productivity and suitability for plantations using land resource information, Soils Technical report No. 3, second edition, Forestry Tasmania and Forest Practices Board.

Laffan, M. D. (1999) Field procedures for recording land attributes and assessing plantation potential in Tasmania, Draft No. 9, (unpublished report), Forestry Tasmania.

Turner, L. and Lambert, M. J., Nutrition and Nutritional Relationships of *Pinus radiata*, Ann. Rev. Ecol. Syst.1986. 17: 325-50.

Moore, R. and Buckton, M., The new Sawlog Industry Project in the 450 to 600mm Rainfall Zone in Western Australia, National Low Rainfall Farm Forestry Conference, Horsham, October 2002.

More ,R., Buckton,M. et al , Producing High Quality Timber from Fast Grown Blue Gum – Silvicultural Options and Profitability for Small Growers in Medium Rainfall Areas, AFG Conference Ballarat, April 2004.

Tas Land & Forest (2003), Management Regimes for Low Rainfall Radiata Pine Plantations. Report Prepared For Private Forests Tasmania.

Turvey, N. D., Carlyle, C. and Downes, G. D., (1992), Effects of Micronutrients on the Growth Form of Two Families of *Pinus radiata* (D.don) Seedlings. Plant and Soil 139 59-65.

Volker, P., et al, Silvicultural Management of Eucalypt Plantations for Solid Wood and Engineered Wood Products – Experience from Tasmania, Australia. International Conference on Plantation Eucalyptus, Guangdong, China, Nov 28-Dec1, 2005.

Will, G. M., (1985) Nutrient Deficiencies and Fertilizer Use in NZ Exotic Forests, FRI Bulletin No. 97.

Will, G. M., (1985) Field Guide to Nutrient Deficiencies in Radiata Pine, FRI Bulletin No. 97 Supplement.

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