Growing confidence in forestry's future Research Programme

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Technical Note

Use of productivity indices to spatially predict optimal final stand density, value and the economic feasibility of pruning

Summary

A simple model has been developed for determining the final crop stand density that maximises value in *Pinus radiata* structural and clearwood regimes, and for determining the relative profitability of growing for clearwood or structural grade. The model uses the productivity indices 300 Index and Site Index, and was developed using the 300 Index growth model implemented in Forecaster, a forest stand growth and yield simulation system.

The mean predicted optimal stand density (S_{opt}) was 603 stems ha^{-1} for the structural regime and 569 and 449 stems ha^{-1} for two clearwood regimes targeting production of either small or large diameter pruned logs. The highest values of S_{opt} (ca. 500-700 stems ha^{-1}) were found on sites with high 300 Index (high volume) and low to moderate Site Index (moderate height). The lowest values of S_{opt} (ca. 200-300 stems ha^{-1}) were found on sites with low to moderate 300 Index and moderate to high Site Index.

The profitability of pruning is largely determined by the pruned log premium. Log prices over the past 21 years show reductions in the pruned log premium. Using values from 2011-2015, pruning was less profitable than the structural regime within at least 95% of plantations. The most profitable areas for pruning were located in regions where 300 Index ranges from moderate to high and Site Index is relatively low.

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Introduction

Forest stand density management involves manipulating the level of growing stock through initial spacing and subsequent thinning to achieve specific management objectives[1]. Determination of appropriate levels of growing stock is a complex process incorporating biological, technological and economic factors specific to a particular management situation. Identifying the optimal stand occupancy often requires balancing numerous constraints that can include achieving a minimum tree size, while maximising stand volumes and stability thresholds[2].

Thinning objectives are predominantly driven by economic considerations within New Zealand. Production thinning is only undertaken in 15% of the estate[3] and one or two thinnings to waste are typically undertaken within most plantations[4].

Pruning is undertaken in a significant proportion of *Pinus radiata* plantations in New Zealand[3]. Trees are pruned to produce clearwood in the lower logs. Unpruned plantations are grown predominantly to maximise production of structural grade timber.

Final stand densities vary widely for *P. radiata* between countries and regimes. For pruned regimes, these range from 250 stems ha^{-1} in New Zealand to 446 stems ha^{-1} in Spain on sites with comparable Site Index (SI)[5]. Regimes grown for structural grade timber range from 250-350 stems ha^{-1} on sites where production thinning is undertaken to 500 stems ha^{-1} where stands are thinned to waste. Despite wide variation in advocated stand densities we are unaware of any research that has investigated the influence of site quality and management objectives on realised final crop stand density or value across a broad spatial extent.

A model that can spatially predict optimal stand density (S_{opt}) and value for different regimes would be of considerable value to forest managers. Although large corporates undertake considerable analyses around regime selection this information is unpublished and unavailable to growers of smaller plantations. Many managers apply similar regimes, with identical final crop stand densities, across broad areas as there is little information describing how site factors influence S_{opt}. Similarly, regime selection for a particular site is often undertaken in a relatively

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uninformed manner as little research has been undertaken comparing the relative value of pruned and structural grade regimes across sites. A model that is sensitive to site conditions and log value would provide broad guidance on whether the regimes and final stand densities that are currently being implemented are likely to yield optimal returns for a particular site.

This article describes a model of S_{opt} for *P. radiata* pruned and structural grade regimes. Inputs to the model include productivity indices (300 Index (I_{300}) and SI), pruning costs and log grade values. The model has been used to generate surfaces across the spatial extent of New Zealand describing S_{opt} and the relative profitability of pruning. Variation in the relative value of pruned regimes was examined through time using log prices over the last 21 years.

Method

Model Development

This study used Forecaster, a flexible forest stand growth and yield simulation system that can be used to predict growth and potential log-product yield for a forest stand[5]. Forecaster was used to predict log product volumes for a range of site types, and stand densities for *P. radiata* plantations. Component models used within Forecaster included the 300 index growth model and a branch diameter model.

Optimum stand density was defined for structural grade regimes as the stand density that maximised the volume of S30 logs (small end diameters (sed) 27 cm, length 5.5 m, largest branch diameter < 7 cm). For pruned regimes, a criterion of maximising the value of either a P30 (sed 30 cm, length 5.5m) or P40 (sed 40 cm, length 5.5m) pruned log, together with S30 logs, was used. Note that in this article we define S_{opt} in terms of stand density at the final thinning; stand density at harvest will typically be 10-15% lower due to mortality.

Forecaster runs were undertaken for 15 combinations of SI and I_{300} covering the range of sites typically used for growing *P. radiata* in New Zealand, with 5 levels of I_{300} and 3 levels of SI at each I_{300}, and with final stand density ranging from 200 to 700 stems ha^{-1} in steps of 100 stems ha^{-1}. For each combination, two regimes were tested, an unpruned structural regime, waste thinned to final stocking at 14 m height, and an appearance grade regime with trees pruned to 6 m and waste thinned following the final pruning lift. Both regimes used a rotation length of 28 years.

For the structural regime, a quadratic surface regression model predicting S30 volume as a function of stand density at final thinning, and I_{300} and SI as independent variables was obtained using the output from the Forecaster runs. The value per hectare was determined by multiplying volume by net value per cubic metre of S30 logs.

For pruned regimes, regression models were fitted for predicting pruned log volume (one using P30 and another P40) and S30 volume (for upper logs and butt logs too small to satisfy the pruned log grade), using stand density at final thinning, and I_{300} and SI as independent variables. Using these regressions, the net value of pruned regimes was determined from the premium of pruned logs over S30 logs and the cost of pruning.

For both regimes, S_{opt} was determined by differentiating the predicted value equation.

Data analysis

Two simulations were undertaken to examine how changes in log value influence S_{opt} and the relative value of pruning. Relative value was defined as the net value of a clearwood regime/net value of a structural grade regime. Under the first simulation mean values of pruned log premium and net structural log value from the 1995-2015 period were used. In the second simulation, S_{opt} and relative value were determined over four periods using values for pruned log premium and net structural log value averaged over 1995-2000; 2001-2005; 2006-2010 and 2011-2015.

Log value data, describing quarterly values for pruned log-products (P30, P40) and structural grades on the domestic market, from 1995-2015, were used to determine model inputs (MPI[6]). Pruned log premiums were determined, respectively, for P40 and P30 as the values of these grades less the mean value of domestic grades similar to our S30 grade with sed exceeding 30 cm and branch size ≤ 6 cm. Net structural grade value was determined as the value of structural grade less an assumed harvesting and transport cost of \$68.5 m^{-3}. All log values are expressed as real values and were adjusted to \$2015 using the consumer price index.

Figure 1 shows variation in real log values with time (Figure 1a), pruned log premium (Fig. 1b) and net structural grade value (Fig. 1c). Mean pruned log premiums were \$38.14 for P30 and \$77.37 for P40, while the net structural grade value was \$46.35. For the second simulation, values of the five year averages for pruned log premium and net structural grade are shown, respectively, as horizontal lines in Figures 1b and c.

Maps were developed under the first simulation showing the spatial distribution in S_{opt} across New Zealand in areas suitable for *P. radiata*. These were made using the I_{300} and SI surfaces described in Palmer et al.[7] with predictions constrained to the potential range of *P. radiata* through excluding areas with mean annual temperature < 7.9°C, water bodies, the Department of Conservation estate, urban areas and areas containing natural forests. Values of S_{opt} and relative value were extracted from these surfaces for the New Zealand plantation resource for the four time periods. Using these data we examined the profitability of pruning through time using historical log prices from the four simulation periods.

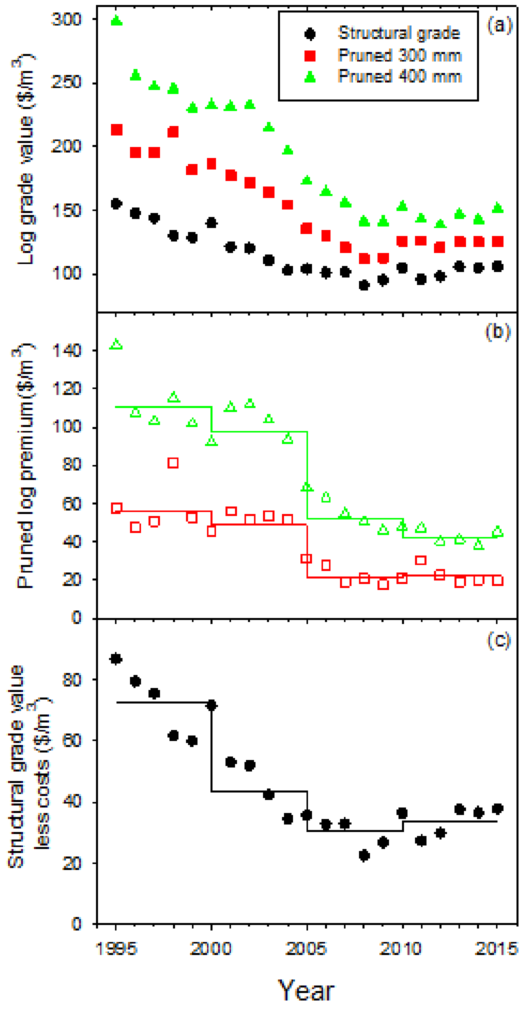

Figure 1. Variation in (a) real (inflation adjusted) log grade value, (b) real pruned log premium for P30 and P40 and (c) real net structural grade value from 1995 to 2015. Horizontal lines drawn through the data in figures (b) and (c) represent averages from 1995-2000; 2001-2005; 2006-2010 and 2011-2015.

Results

Optimal stand density

The mean S_{opt} for each regime and the percentage of sites where S_{opt} exceeded a given level of stems ha^{-1} are listed in Table 1. Figure 2 shows the spatial variation in optimal stand density for the S30, P30 and P40 regimes.

S30 Regime

Values of S_{opt} for the S30 regime exceeded 650 stems ha^{-1} in many parts of the North Island and were only markedly lower in northern and central regions, where S_{opt} mainly ranged from 450 – 650 stems ha^{-1}. Values of S_{opt} exceeded 650 stems ha^{-1} in the south of the South Island where I_{300} is relatively high compared to *SI* (Figure 2a). The lowest values of S_{opt} were found on the east coast of the South Island where S_{opt} ranged from 250 – 550 ha^{-1} in response to the extremely low I_{300} (Figure 2a) The distribution of S_{opt} throughout the New Zealand plantation estate reflected the national surfaces with S_{opt} averaging 603 stems ha^{-1}.

P30 regime

Spatial variation in S_{opt} for the P30 regime was very similar to that of S30 (Figure 2b). Values of S_{opt} were highest in eastern and western areas in the North Island and southern areas in the South Island where values commonly exceeded 650 stems ha^{-1} (Figure 2b). The lowest S_{opt} was found in the eastern South Island where values were as low as 250 stems ha^{-1} (Figure 2b). Within plantation forests an S_{opt} of 550 – 650 ha^{-1} was most common with a mean S_{opt} of 569 stems ha^{-1}.

P40 regime

Values of S_{opt} were markedly lower for P40 than P30 throughout New Zealand (Figure 2c). The highest values of S_{opt} ranged from 550 – 650 stems ha^{-1} and were found on sites with high I_{300} in western and eastern areas in the North Island and the southern South Island (Figure 2c). The lowest values of between 250 – 350 ha^{-1} were located in the eastern South Island and northern and central regions of the North Island where the I_{300} was relatively low compared to the SI (i.e. there was a high height/diameter ratio). Within the plantation estate the most common S_{opt} ranged from 350 – 550 ha^{-1} and mean S_{opt} was 449 stems ha^{-1}.

Table 1. Mean S_{opt} for each regime and the percentage of current plantation areas where S_{opt} exceeded various levels of stems ha^{-1}.

	S30	**P30**	**P40**
Mean S_{opt} (stems ha^{-1})	603	569	449
Percentage of plantations where S_{opt} exceeded			
550 stems ha^{-1}	73%	59%	13%
450 stems ha^{-1}	95%	89%	49%
350 stems ha^{-1}		99%	86%
250 stems ha^{-1}			99%

Profitability of pruning

Predictions of relative value (net value of a clearwood regime/net value of a structural grade regime) across plantation forests were largely positive using inputs from 1995-2000 and 2001-2005). Histograms show that relative value was positive at more than 99% of sites for the P30 regime (Figure 3a), and at more than 95% of sites for the P40 regime (Figure 3b).

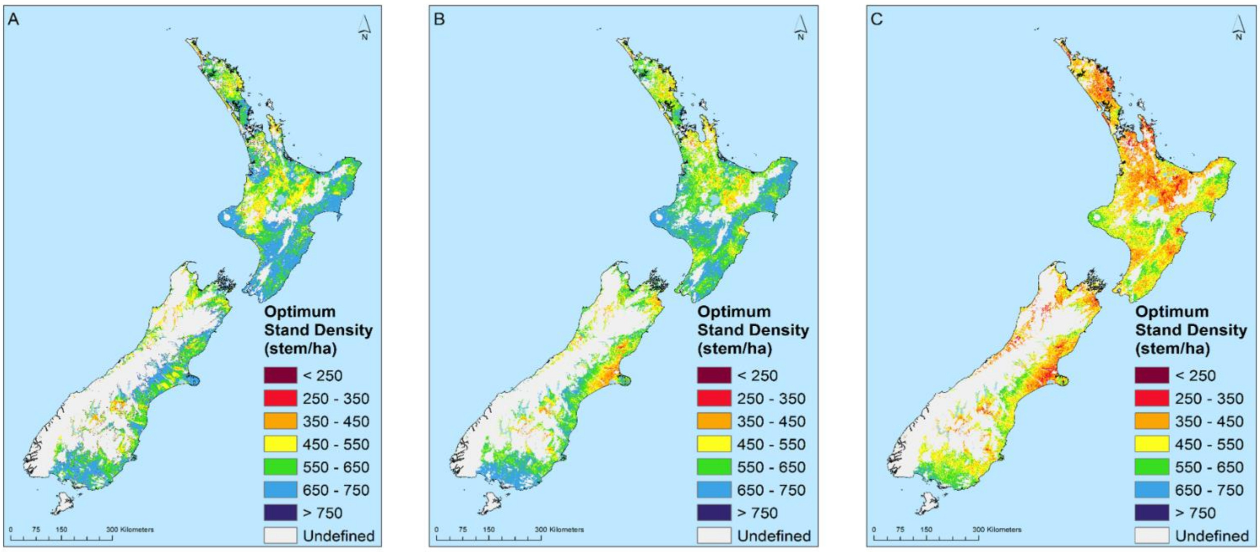

Figure 2. Spatial variation in optimal stand density for (a) S30, (b) P30 and (c) P40. Surfaces were generated using values of pruned log premium and net structural grade value that were averaged from 1995-2015.

In contrast, relative value was predominantly negative over the second two periods (2006-2010 and 2011-2015) for P30 (Figure 3a). The least negative relative values occuring in areas with high I_{300} and low *SI* while the most negative values occurred in areas with low I_{300} (data not shown). Pruning was predicted to be less profitable than the structural log regime within more than 98% of plantations (Figure 3a).

Discussion

The predicted optimal stand densities shown greatly exceed advocated final stand densities for structural log regimes for *P. radiata*. The mean value of S_{opt} predicted for plantations was 603 stems ha^{-1}. Within stands grown for structural grade final stand densities of 250 and 350 sltems ha^{-1} have been reported within Australia on sites with moderate SI (26 - 29 m) where production thinning is practiced. Within typical New Zealand sites (SI ranging from 25-27 m) final stand densities of 350 and 500 stems ha^{-1} were respectively reported, on sites where production thinning, and thinning to waste were practiced[5]. A survey of New Zealand forest owners found ca. 500 stems ha^{-1} to be a typical final stand density on sites without production thinning (Dash, J., unpub. data).

Values of S_{opt} predicted for pruned regimes also markedly exceeded final stand densities that are used operationally. Mean values of S_{opt} found here were 569 and 449 stems ha^{-1}, respectively, for P30 and P40 regimes. Within New Zealand, densities as low as ca. 200 stems ha^{-1} were advocated during the 1980's, particularly in situations where silvopastoral systems were being advocated[8]. However, low stand densities were found to be associated with poor wood properties and low volumes[9], and final stand densities have therefore been increasing since this time[4]. Typical final stand densities currently advocated on sites with average to good fertility range from 250-350 stems ha^{-1} within New Zealand. Higher final stand densities of 400 and 446 stems ha^{-1}, respectively, are advocated on sites in Chile (*SI* = 31) and Spain (*SI* = 26). Optimum stand density for P30 was higher than for P40 but it is worth noting that the market for P30 logs may be less relaible than for P40 logs.

The considerable spatial variation in S_{opt} found for all three regimes suggests managers should more closely match silviculture to site to optimise stand value. Variation in S_{opt} was largely attributable to a complex interplay between diameter and height growth which influences grade out-turn through impacts on log diameter and, for structural grades, branch diameter. Although optimum stockings were generally higher than those actually practiced it is worth noting that they were relatively low within the central North Island which is the largest plantation growing region within New Zealand.

Results clearly show the sensitivity of the relative value of pruning to input prices and values. Relative value declines as pruned log premium declines and net structural grade value increases. Thus the decline through time in relative value was attributable to the marked reductions in pruned log premium that more than offset the effect of declining net structural grade value. Despite the general downwards trend in the profitability of pruning, it is worth noting that there has been a dramatic increase in pruned prices during 2016. This increase is thought to be due to decreasing supply in the CNI, export demand, and increased profitability from appearance mills as their markets shift away from the US mouldings market (pers. comm. S Papps).

A number of simplifying assumptions have been made within this study. These include an asumption that optimum stand density can be approximated by maximising the value of a single desirable log grade in structural regimes, or single pruned and unpruned grades in pruned stands, and the use of a constant cost of harvesting. We have also assumed that log diameter is the key criterion that buyers target while in reality the proportion of clearwood may also be of importance.

Although our approach is somewhat simplistic, we believe that it provides **a useful guide to forest managers**, and hope it will contribute to the debate over the important issue of final stand density. Our intention **was** to gain a better understanding of the factors influencing optimum stand density, and to highlight areas where **stands could be potentially understocked.**

Before accepting our results for a particular forest, **we recommend that forest managers under**take more detailed analyses using less simplistic modelling asumptions, and taking account of local factors that could influence optimum stand density. For example, high stockings may encourage disease and exessive mortality on some sites.

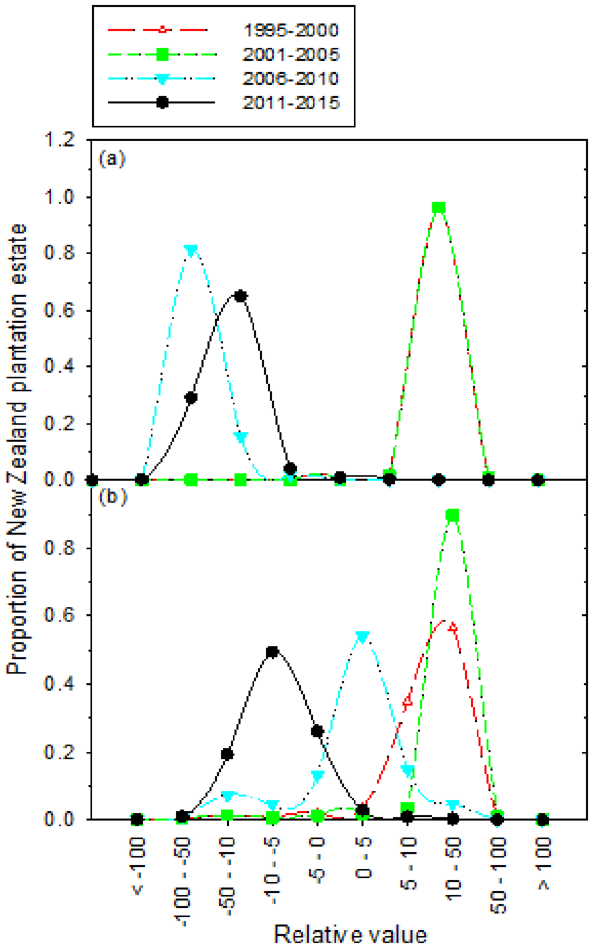

Figure 3. The distribution of relative value (net value of a clearwood regime/net value of a structural grade regime) for the New Zealand plantation estate from 1995-2000, 2001-2005, 2006-2010 and 2011-2015 for (a) P30 and (b) P40.

Conclusion

This research shows a wide spatial variation in S_{opt} for both clearwood and structural grade regimes that can be attributable to variation in SI, I_{300} and the interaction between these productivity indices.

Temporal analyses show pruning profitablity has declined markedly over the past two decades in New Zealand primarily in response to reductions in the pruned log premium. Analyses show pruning to be less profitable than the structural log regime within at least 95% of plantations using log values from 2011-2015.

The model allows managers to identify the optimal regime for a given site and to determine where final stand density can be increased to improve plantation value.

Acknowledgements

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