An evaluation of the production and profitability of *Pinus radiata* on a fertile site

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Abstract

The *Pinus radiata* D. Don stand modelling system 'Standpak' was calibrated for a fertile site using data (including diameter at breast height, mean crop height, and stocking) collected from a 12.5 ha stand established in 1973 on a former farm site. These were used to configure the 'Early' and 'Napirad' growth models within the 'Stand Growth' module of 'Standpak'. During configuration, basal area increment potential was adjusted to provide the best agreement with the field estimate of stand basal area. After configuration, 'Standpak' was able to predict basal area to within 6% of the field estimate by combining the 'Early' (high + 20% basal area increment) and 'Napirad' growth models (switched at mean top height 18 m). This configuration was subsequently used to simulate and evaluate the growth of new stands under both clearwood and framing regimes. 'Standpak' calculated site index at 23 m. The combined influence of this low site index and high basal area increment created problems associated with maintaining a target diameter over stubs while utilizing an acceptable number of pruning lifts in the clearwood regimes. The most profitable regime utilized a three lift pruning schedule and was achieved by reducing crown length remaining for early puning lifts, delayed thinning, and maintaining a high ratio of unpruned to pruned trees. Clearwood regimes were generally more profitable than framing regimes because of a higher average log value, despite increased silvicultural costs and reduced log volume. The most profitable clearwood regime produced 698 m^3/ha of logs, of which 37% graded P1 and P2, resulting in a net present value (NPV) of $2,681/ha (8% discount rate). In contrast, the best framing regime produced a log volume of 787 m^3/ha, resulting in a NPV of $1,100/ha.

Additional key words: *standpak, silviculture, basal area potential, net present value.*

Introduction

The New Zealand forest industry earned $2.7 billion in export earnings during 1996 making it the third largest land based sector after dairy and meat. Plantation forests occupy approximately 5% (1.5 million ha) of total land area and are expanding at a rate of approximately 60,000 ha/annum, mostly as a result of conversion of farmland to forestry, particularly in the North Island hill country (Anon. 1995). *Pinus radiata* D. Don accounts for 91% of the total plantation area (Anon. 1996). The potential forest productivity of former farm sites is high, mainly because of their high fertility status (West *et al.*, 1982). However high fertility can often result in poor tree quality caused by excessive branching, large branches and stem defects (Maclaren, 1993). Appropriate silvicultural practices for fertile sites are necessary if this yield potential is to be effectively utilized. The New Zealand Forest Research Institutes' stand modelling system, 'Standpak', allows managers to predict the yield and growth of stands in response to alternative silvicultural treatments and site characteristics. It is made up of a number of modules able to predict tree growth, log yield and log quality, and to undertake financial analyses of different stand management options.

Existing growth models in 'Standpak' have primarily been derived from a broad database consisting of mainly traditional forest site data. These models can be utilized for simulating growth on a wide range of sites including former farm sites, but will generally provide more accurate predictions of growth and yield if local growth data can be input (Maclaren, 1996). Accurate predictions are important for planning and selecting alternative silvicultural options.

This paper reports the use of field data to configure 'Standpak', which was then be used to simulate the growth of new stands based on clearwood and framing regimes. Alternative silviculture regimes within each of these broad regimes was assessed using net harvest revenues, net present value (NPV), and ease of management as criteria.

Methods and Materials

Background

Massey University is converting 68 ha of less productive hill country on the 'Tuapaka' sheep and beef unit to *P. radiata*. Information from a 12.5 ha stand nearing maturity was collected for inputting into 'Standpak'. The stand was planted in 1973 at approximately 1500 stems/ha using GF7 seedlings. Apart from releasing, the only silvicultural treatment applied was thinning to 300 stems/ha at age 17.

Tuapaka is located 15 km north of Palmerston North on the flanks of the Tararua range. The soil type is predominantly Halcombe hill and Halcombe steepland (Land Use Class 6 and 7). The site lies between 100-140 m altitude and receives 1200 mm of rainfall per annum.

Stand Inventory and Configuration

A stand inventory was undertaken to collect stand growth parameters including mean crop height (MCH), diameter at breast height (DBH at 1.4 m), and stocking (stems/ha) using the methods outlined in Ellis and Dunlop (1991). These parameters were required for calculating site index and basal area potential, which indicated potential site productivity. Sample numbers were determined using a pilot inventory which allowed calculation of the required number of samples to achieve probable limits of error of 5% and 2.5% for MCH and DBH respectively (Goulding and Lawrence, 1992). Height was measured using a Suunto clinometer (60 trees) and DBH was measured with a diameter tape (180 trees) using a structured walk sampling technique (Maclaren, 1996).

The stand growth module of 'Standpak' contained a number of growth models, including the 'Early' growth model, which was used to quantify the effects of silvicultural management (pruning and thinning). 'Early' predicted stand growth up until a mean top height (MTH) of 18 m after which a regional growth model was selected (West *et al.*, 1982). Several of these regional growth models were potentially suitable for the Manawatu region including the 'Napirad' growth model which was derived from Hawke's Bay growth data but has been recommended for predicting growth on a range of farm sites (West and Dean, 1988). In this study the 'Early' and 'Napirad' growth models were selected for the early and later set of growth models respectively.

Data from the measured Tuapaka stand were used to configure 'Standpak' by altering the basal area level in 'Early' within the SET MODELS menu and varying stand age at the switch from 'Early' to 'Napirad' in the TREATMENTS menu. Site index was calculated from stand age and MCH in the INITIAL STAND menu. The objective was to obtain the best match between the predicted ('Standpak') and measured basal area (m^2/ha) derived from DBH and stems/ha, and MCH at a stand age of 23.2 years. Default settings for height, growth, stand volume, diameter over stubs (DOS), and crown functions were accepted in all configurations.

For this study, medium default values were used for monthly growth ('Diameter Distributions' module), the site dependent (sweep, internode index and wood density) and regime dependent parameters (branch index, maximum branch and defect core) within the 'Log Making' module. Logs were graded in the 'Log Grading' module using the New Zealand domestic cutting pattern.

Clearwood and Framing Regime Simulation

'Standpak' was used to simulate the growth of a stand under clearwood (pruned), and framing (unpruned) regimes (Table 1). The objective for the clearwood regimes (regimes 1-4) was to produce a 6.0 m pruned log while maintaining a uniform crop DOS (19 cm). A target DOS of 19 cm was near the upper end of the acceptable range but was appropriate for fertile, low site index areas (Maclaren and Knowles, 1995). These regimes were developed by altering pruning and thinning to change the required number of pruning lifts. The framing regimes (regimes 5 and 6) involved a late thinning to final stocking, the objective being to restrict branch size while attaining acceptable log diameters at harvest. These regimes were developed by varying age at thinning. The profitability of alternative regimes was compared using harvest revenue and NPV as criteria (van Rossen, 1995). NPV was calculated by forecasting the costs and benefits over the time associated with each regime at the stand level (1 ha) using the 'Economic Analysis' module in 'Standpak' (Anon., 1994). NPV provided the most useful indicator of regime profitability at the stand level because it reflected both harvest revenue and associated silvicultural costs. A discount rate of 8% was used to calculate NPV.

The simulations began with a typical regime for a high fertility site (regime 1, Table 1) (Maclaren, 1993) and was subsequently modified to improve profitability and to simplify stand management. All results are for a rotation length of 28 years.

Results

Configuration

Site index at Tuapaka was estimated to be 23 m. Initial runs utilized a medium basal area adjustment in

Table 1. Silvicultural detail of clearwood and framing regimes compared at Tuapaka. Planting density was 1000 stems/ha.

		Regime No.					
		1	2	3	4	5	6
Final stocking (stems/ha)		350	350	350	300	400	400
Crown lengths (m)	after one pruning	3.0	2.0	2.0	2.0	-	-
	after two prunings	3.0	2.5	2.5	2.2	-	-
	after three prunings	3.0	3.0	3.0	3.2	-	-
	after four or more prunings	3.0	3.0	3.0	-	-	-
Age at final thinning (yrs)		6.0	6.4	8.4	9.2	12.6	10.0

'Early', with a switch to the later growth model at MTH of 18 m, but resulted in a large under prediction of stand basal area. Subsequent adjustment of basal area increment to high +20% (maximum adjustment) improved accuracy, predicting basal area to within 6% that of the field estimate (39.7 m^2/ha predicted vs. 42.2 m^2/ha measured).

Clearwood and Framing Simulations

The initial simulation (regime 1) required 10 pruning lifts to attain a 6.0 m pruned height while achieving target DOS and maintaining a crown length remaining (CLR) of 3 m (Table 2). Subsequent simulations sought to reduce the number of pruning lifts required by reducing the CLR (regime 2); delaying thinning (regime 3); and increasing the unpruned to pruned ratio prior to final thinning by reducing the final crop element (regime 4). These changes helped suppress early stem and branch diameter growth allowing a reduction in the number of pruning operations because of the greater pruned height achievable at each lift. For example, regime 1 produced a DBH and branch size at the final prune of 26.1 cm and 6.0 cm respectively while regime 4 resulted in a DBH and branch size of 20.5 cm and 5.3 cm respectively (Table 2).

As expected the clearwood regimes produced lower wood volumes than the framing regimes (Table 2) with harvest volumes progressively declining in response to the modifications to the pruning and thinning program to achieve a 3 lift pruning schedule. Log volumes declined from 772 m^3/ha (regime 1) to 698 m^3/ha (regime 4).

Pre tax, net harvest revenue ranged from $42,600 (regime 1) to $39,500/ha (regime 4) for the clearwood regimes while harvest revenues for the framing regimes were less than 50% of these values. There were large differences in NPV among the clearwood regimes but ranking was reversed to that of harvest revenue. The number of pruning lifts had a strong influence on NPV in these simulations (Table 2). Regime 4 produced the highest NPV ($2,681/ha) with small declines for regimes 2 and 3 ($2,475/ha and $2,226/ha respectively) and a large decrease to regime 1 ($840/ha). This was the result

Table 2. The physical and financial results from alternative silvicultural regimes.

	Regime No.					
	1	2	3	4*	5*	6
No. of prunes	10	5	4	3	-	-
DBH at last prune (cm)	26.1	25.2	23.5	20.5	-	-
Branch size at last prune (cm)	6.0	5.9	5.5	5.3	-	-
MCH at last prune (m)	9.9	9.8	10.2	9.2	-	-
DBH at harvest (cm)	54.1	53.9	53.4	55.5	51.5	53.2
Harvest revenue* ($/ha)	42,600	42,300	41,400	39,500	18,797	18,846
NPV ($/ha @8%DR)	840	2,226	2,475	2,681	1,100	1,082

*[after extraction and cartage]

of higher pruning costs incurred earlier in the rotation offsetting higher harvest revenues. In contrast, NPV for the framing regimes were similar but, with the exception of regime 1, were less than 50% of those of the clearwood regimes.

Approximately 36% of total harvest log volume in the clearwood regimes fell into the high value P1/P2 grades (pruned butt logs) and, with the exception of regime 1, was the major reason for the high revenue and NPVs of the clearwood regimes (Table 3). However, in the framing regimes many unpruned butt logs fell into the lower value L1/L2 grades which comprised over 50% of total log volumes, highlighting the disadvantages of not pruning. The L1/L2 grades were also significant in the clearwood regimes reflecting the difficulty of controlling branch size on fertile sites. Conversely few S1 and S2 logs were produced, particularly in the clearwood regimes.

Discussion

The 'Early' and 'Napirad' growth models are recommended for simulating growth on farm sites. The combination of these models has been found to be the most accurate for predicting basal areas and testing a range of stockings on these sites (West and Dean, 1988). 'Standpak' was able to predict stand basal area to within 6% of the measured basal area, well within the 10% limits established by these authors. These authors also suggested that from 12 years of age (or possibly canopy closure) growth development for *P. radiata* was similar for both farm and forest sites, inferring that a separate growth model for farm sites may not be necessary. The very high basal area potential of this site was consistent with the regular use of phosphate fertiliser on Tuapaka which had stimulated the pasture legume growth and increased soil nitrogen status. This resulted in increased diameter growth in *P. radiata* (Ballard, 1978; Mead and Cadgill, 1978)

The estimated site index at Tuapaka (23 m) was lower than expected. Estimates for similar sites in the Manawatu were around 25-28 m (Eyles, 1986). Low site index at Tuapaka was probably a result of site exposure to wind which is known to reduce height growth in *P. radiata* (Maclaren and Knowles, 1995). The Manawatu region is characterised by high wind runs, particularly on the exposed hill country near the Manawatu Gorge where Tuapaka is located (Burgess, 1986).

The combined influence of low site index and high basal area potential on this site resulted in problems maintaining target DOS while utilizing an acceptable number of pruning lifts. These sites have tended to produce short fat trees, restricting the amount of green crown that can be removed in any one pruning lift if target DOS was to be achieved and a minimum length of green crown was to be retained. In this study the required number of pruning lifts to achieve a 6.0 m pruned height was able to be manipulated by reducing the CLR at the first and second lifts (CLR of 2.0 m and 2.2 m), delaying thinning, and maintaining a high ratio of unpruned to pruned trees through to thinning.

When pruning resulted in the removal of "active" crown, stand basal area increment was reduced in proportion to the reduction in green crown length (West *et al.*, 1982). This suggests that the removal of more green crown (i.e., reducing the CLR) during pruning will reduce diameter growth allowing increased height growth prior to trees reaching target DOS. The consequences of

Table 3. Volume (m^3/ha) out turn for each regime using New Zealand domestic log grade specifications.

		Regime No.					
		1	2	3	4*	5*	6
Log grade	P1	213.1	210.0	202.4	206.1	-	-
	P2	65.4	66.6	69.5	46.9	-	-
	S1	1.4	1.5	1.5	2.0	65.6	44.0
	S2	4.2	4.4	4.9	4.3	75.5	41.1
	S3/L3	113.2	114	115.9	95	135.6	126.9
	L1/L2	236.0	234.2	229.9	226.9	421.9	517.3
	Pulp	138.9	136.5	130.7	117.3	88.6	108.8
Total		772.2	767.1	754.9	698.4	787.2	837.3

*[Selected for further analysis]

retaining less green crown, i.e., 2.0-2.5 m CLR for the first and second prunes, was a reduction in the number of required prunings to 5. The potential for further cost reductions and simplification of management was investigated by seeking additional reductions in the required number of pruning lifts.

The timing of thinning has a significant influence on tree growth. If thinning occurs well before pruning there will be less control over branch size, and if significantly delayed, the pruned crop trees will be suppressed by the more competitive unpruned or partially pruned element (Maclaren and Knowles, 1995). Delaying thinning until the third pruning lift reduced the required number of lifts to 4, a result of decreased diameter growth, a delay in achieving target DOS (Tombleson *et al.*, 1990) and temporarily increased height growth associated with higher stockings (West *et al.*, 1982; Maclaren *et al.*, 1995).

In selective clearwood regimes the basal area of the pruned crop element was reduced in proportion to the basal area increment of the following element (West *et al.*, 1982). This effect was investigated in regime 4 by reducing the final stocking of the pruned element from 350 to 300 stems/ha. When combined with reduced CLR (2.2 m) at the second lift, increasing the proportion of the unpruned following element in the stand resulted in a suppressed basal area increment and a small increase in height growth of the pruned crop element. The resulting control over DOS allowed pruning to be delayed which in turn allowed the pruned height to be increased because the tree was taller at each lift.

Pruning to CLR levels utilised in regime 4 produced a warning message in the 'Stand Growth' module of 'Standpak' to indicate that the large amount of 'active' crown removed in this regime significantly reduced the basal area potential of the stand (West *et al.*, 1982). However, crown length did not take into account needle density, needle retention, or width of crown. These were all factors affecting the amount of foliage present and the photosynthetic capacity of the tree. In general, trees with larger stem diameters tend to have greater amounts of foliage for a given crown length (McInnes, 1997). Also, West *et al.*, (1982) observed that trees demonstrating a large DBH to height ratio generally have an improved basal area increment to crown height ratio. This suggests that trees grown on high basal area sites may be pruned to a lower CLR, without the same loss of growth experienced by trees on less fertile sites, because of the greater foliage mass per unit of crown length. The first prune (regime 2, 3 &4) was effectively a half height prune which has been prescribed for the first pruning lift (Maclaren, 1993).

After configuration, 'Standpak' is expected to predict tree heights, basal area and stand volumes with greater accuracy, but log quality predictions are less certain. The configuration may not adequately account for the inherent variability that often occurs within a stand (Maclaren, 1996), particularly for farm sites which tend to express malformations more regularly (Maclaren, 1993). The most accurate predictions of log quality parameters can be obtained from either a pre-harvest inventory assessment, e.g., MARVL or from existing harvest data. The 12.5 ha stand under consideration had not been subjected to a pre-harvest assessment. The medium input values utilized in the 'Log Making' module may not be appropriate because of the high fertility and high wind runs at this site, particularly the regime dependent parameters associated with branching and the site dependent parameters, e.g., sweep.

The configured 'Standpak' predictions of log grade out turns may be conservative. For example clearwood regime 4 predicted a 37% log grade out turn by volume for P1/P2 class logs. However stands on farm sites in the Manawatu have produced 40-50% P1/P2 log classes (Hocking, 1997). This highlights the need for log grading information from high basal area sites (ex. farm sites).

The 'Standpak' version used in this study only allowed a genetic improvement of GF7. Future plantings will use genetic stock of higher GF rating, improving both site productivity and tree form, and the use of physiologically aged cuttings may further improve tree growth and form on this fertile site (Tombleson, 1991; Maclaren, 1993). This will effectively increase site index allowing moderation of silvicultural regimes, improving early tree growth and final harvest revenues but without increasing silvicultural costs.

Discounted cashflow analysis (DCF) is a standard method of appraising long-term projects including forestry. In particular, NPV is able to reflect the combined effect of final harvest revenues and silvicultural costs. For example, regimes that produce the highest net harvest revenues do not necessarily produce the best NPVs. A problem associated with using DCF is that there is no simple or non-controversial way of determining an appropriate discount rate. The choice largely depends on investors' attitude towards risk. Most forestry investment analysis focuses on the internal rate of return (IRR) required or being achieved by the project largely because of the difficulty of selecting acceptable discount rates (Fischer, 1996). However, IRR gives no indication of the dollar return on investment (Table 4). The use of NPV with an appropriate discount rate generally gives a better

Table 4. Comparison of the physical and financial outputs (pre-tax) for the selected clearwood and framing regimes.

	Framing	Clearwood
Merchantable volume (m^3/ha)	787	698
Net harvest value ($/ha)	18,797	39,461
Establishment costs ($/ha)	650	650
Pruning/thinning ($/ha)	350	1,408
Total funds required* ($/ha)	1,000	2,058
NPV (@ 8% DR) ($/ha)	1,100	2,681
IRR (%)	11.2	12.1

*[Excludes administration, insurance and harvest costs]

indication of potential profit from a given area of land (Maclaren, 1993). The use of an 8% discount rate in this analysis reflected the current rates of return on forest investments and was therefore appropriate for making comparative analyses (Fischer, 1996).

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