ECONOMICS OF FINAL CROP STOCKING AT THE TIKITERE AGROFORESTRY TRIAL. PART 1: VOLUME AND QUALITY COMPARISONS

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ABSTRACT

Data produced by the "Method for Assessment of Recoverable Volume by Log Type" (MARVL) from the Tikitere Agroforestry Trial were used to compare volumes of *Pinus radiata* D. Don by log type for a range of final-crop stockings on a fertile farm site. The 93-ha 21-year-old trial included stockings at 400, 200, 100, and 50 stems/ha; intermediate stockings were simulated using the stand growth program STANDPAK as calibrated by the MARVL data.

Higher stockings tended to have a greater total and recoverable volume, unpruned volume, volume of large-diameter unpruned logs, and volume of small-branched logs (nearly 200 m^3/ha). At age 21, all stockings over 250 stems/ha generated approximately the same pruned volume, but higher stockings are expected to have greater pruned volumes at older ages. The greatest pulpwood volume occurred at 100 stems/ha, comprising 30% of the total recoverable volume.

The volume at Tikitere for the 400 stems/ha stocking was about one-third higher than expected for an equivalent non-farm site, but this difference may decrease with age.

Keywords: stocking; final-crop stocking; MARVL; rotation age; farm sites.

INTRODUCTION

The Tikitere Agroforestry Trial, near Rotorua, was established in 1973 to examine the combination of *P. radiata* forestry and understorey grazing with sheep. The 93-ha trial incorporated tree stockings of 400, 200, 100, and 50 stems/ha, as well as open pasture and 100 stems/ha in twin rows. Each treatment had four replicates, and each replicate had four permanent sample plots, usually comprising 10 trees each. The trees were seed orchard stock (GF13) planted at five times the intended final stocking.

Many researchers (e.g., Knowles 1991; Hawke & Percival 1992; Hawke & O'Connor 1993) have used the trial to examine a range of issues, including:

- Tree growth and quality at various stockings on fertile sites;
- Understorey pasture and livestock production;
- Soil and meteorological changes with increasing tree cover.

In the first part of this report, we examine the effect of final-crop stocking on wood volume and log grade in the Tikitere trial. Indications are that much afforestation in recent years has been on fertile farm sites such as Tikitere, and the small-scale growers responsible for much of this planting require guidance in their choice of final-crop stocking and therefore in their initial stocking (Maclaren 1994). The issue of final-crop stocking has generated intense debate, often heated, with some factions pointing to the desirability of low stockings in order to maintain high levels of understorey grazing and to generate large-diameter butt logs at an early age, and others arguing that high stockings are necessary to ensure high recoverable volume per hectare and acceptable wood quality.

Indeed, "agroforestry trees" are perceived as being of inferior quality by some commentators (e.g., D.McConchie unpubl. data). Often the reasons are not clearly stated, and it is uncertain whether the poor quality is being attributed to:

- Low stockings;
- Ex-farm sites;
- The combination of low stockings and ex-farm sites;
- Felling of immature stands, because acceptable size is reached at an early age;
- Poor management by small-scale growers;
- Inferior wood density from an early phase of the breeding programme using '850' genetic stock.

If there is a genuine problem, and if it is caused by site or tree-breed factors, then in view of the widespread afforestation that is taking place on these sites with improved breeds, there may be cause for alarm. If the problem arises from poor management, there is a need to correct this immediately. If there is no problem, time and energy would be better directed addressing more important issues.

Now that the Tikitere trees are of harvestable size, what can we say about the quantity and quality of wood in the various stockings?

METHODS

Estimation of Existing Recoverable Volume by Log Grade

Every tree in every plot was assessed using the Method for the Assessment of Recoverable Volume by Log Types (MARVL) (Deadman & Goulding 1978; Manley *et al.* 1987). This method involves describing the external quality of each tree from ground to tip, and taking measurements of diameter at breast height, total height, and boundary heights of quality characteristics. As the trees were not climbed in order to take measurements, subjectivity of the assessment of external quality (stem straightness and branch size) was minimised by the use of more than one assessor on each tree, and by using broad categories of quality. Error was likely to occur only at the margins between categories, and this happened only rarely.

The data were transferred to a computer file where the trees were "cut into logs" using an algorithm which maximises value recovery. This can be done in a number of ways (or *cutting* *strategies*), depending on the exact specifications (branch size, small-end diameter, length, etc.) provided for the log types, and their corresponding stumpage values. The cutting strategy used in this analysis is described in Appendix 1.

MARVL is in widespread use throughout the New Zealand forestry sector, and in parts of Australia. Its application in this situation was a little different from normal practice, because trees were subjected to more-than-usual scrutiny. For example, the height of each tree was measured instead of being estimated by the relationship of a sample of diameters and heights. Most of the defects and major changes of quality at points up the stem were measured rather than estimated. Branch size estimates were checked against known figures (all branches on the second logs of 48 trees in each of the three higher stockings had been previously measured for other purposes).

MARVL reports only on characteristics that are externally visible. In this trial, however, the diameter over stubs (DOS) and the DOS height had been recorded for each tree at each pruning lift, and had been added to the Permanent Sample Plot database. There is concern that other internal wood quality characteristics at Tikitere (e.g., wood density, spiral grain, resin pockets, corewood ratio, drying degrade, dimensional stability) may be inferior (McConchie unpubl. data), but because the market does not yet provide clear price signals based on such features, they cannot be quantified in dollar terms and were not included in the analysis.

Grading of Pruned Butt Logs

During data collection for MARVL, pruned logs were assumed to be homogeneous in quality (as regards both sweep and DOS), because the objective of this study was to contrast stocking. It was determined in previous studies (I.McInnes & R.Beamish-White unpubl. data; Maclaren unpubl. data) that differences in sweep and DOS between stockings at Tikitere were indistinguishable statistically, and that therefore there was no compelling reason to include these factors. Moreover, neither moderate sweep nor DOS are reflected in most current specifications for pruned logs.

Many of the pruned logs from Tikitere were swept for at least part of their length. A major reason was the occurrence of Cyclone Alison in March 1975, which had toppled many trees. While wind-induced sweep is a common occurrence, events of the magnitude of Cyclone Alison are fairly rare and so sweep, if included in this analysis, would have given atypical values to the final crop.

Choice of Quality Dictionary and Cutting Strategy

The quality dictionary used is described in Appendix 2. The codes in a MARVL assessment are not important, so long as they contain sufficient detail to be useful under all likely cutting strategies. Codes can later be merged, but they cannot be subdivided. In this instance, data were collected at a level of detail that was not subsequently required. In the final analysis, the straight and moderately swept log categories were combined, as were the 7–10 and 11–14 cm branch sizes. This reflects the common failure of the domestic market to discriminate between these features for pruned, S, or L logs. Only export grades, such as Japanese A and Korean K logs, would require this level of detail.

A pilot MARVL run using export grades of unpruned logs indicated that export grades could not be obtained at Tikitere, even with the highest stockings at advanced ages. While the *minimum* criteria (small-end diameter (s.e.d.) and log length) could be met for a sizable volume of logs, there are also criteria for *average* log length and s.e.d. in any one consignment. These could not be met. At least 70% of A grade logs must be 12.1 m long, and at least 60% of K grade must be 11.1 m long. Although the minimum s.e.d. for A grade is 22 cm, the average should be 34 cm. Undoubtedly, by tightening the specifications in the MARVL cutting strategy, low-volume consignments of export logs could have been generated which would have met average specifications, particularly for higher stockings at higher rotation ages.

The log grades selected for analysis were Pruned, S1, S2, L1, L2, and pulp. (There was also a "Waste" grade with a nominal stumpage of $\$1/m^3$, because some wood is often too deformed to meet even pulpwood specifications, and it may be useful to record this separately from the "cutting waste" that is routinely predicted by MARVL). Details of these grades are given in Appendix 1.

The volume/taper functions used were 182 ("*Pinus radiata*, all NZ, direct sawlog"), and the breakage function 1 ("*Pinus radiata* Kaingaroa 1976"), but the volume/taper function is not critical as there appears to be very little difference in volume out-turn with an incorrect choice (N.Eggleston unpubl. data).

Log Prices Assumed

When MARVL is used to determine recoverable volumes by log grade, it is not necessary for log prices to be realistic. The MARVL algorithm will preferentially cut those log types which provide the highest return. So long as the log prices are ranked correctly, and the differential between grades exceeds the cost of a sawcut (here assumed to be $0.50), the program will generate the same volumes regardless of assumed prices. Stumpage prices used in this analysis are given in Table 1.

Table 1–Stumpage prices assumed for the MARVL analysis

Log grade	Stumpage price
Pruned	172
S1 sawlogs	55
S2 sawlogs	43
L1 sawlogs	50
L2 sawlogs	30
Pulp	11
Waste (e.g., firewood)	1

Interpolation of Values for Intermediate Stockings

By necessity, the Tikitere trial had a limited range of treatments. Because forest growers are likely to be interested in stockings other than the 50, 100, 200, and 400 stems/ha that were assessed with MARVL, the stand growth program STANDPAK (West 1993) was calibrated by MARVL data from the stockings actually present in order to determine the effects of intermediate stockings.

While such *interpolation* may not result in significant errors, it is probably unwise to *extrapolate* results for stockings higher than the maximum stocking at Tikitere (400 stems/ha). Unforeseen mortality, or changes in Weibull distribution of diameters, could well occur.

Assumptions used in the STAND GROWTH module of STANDPAK are given in Table 2.

In order to calibrate STANDPAK, the predicted basal area at age 20 for each of the existing stockings (100, 200, and 400 stems/ha) was compared to that obtained from the MARVL assessment which proved to be 3–5% greater (Table 3). This gave some guidance as to appropriate percentage adjustments for intermediate stockings.

TABLE 2–Assumptions used in the STAND GROWTH module of STANDPAK.

GF rating	13
Height models	34 and 26
Growth models	23 (EARLY) and 9 (NAPIRAD)
Stand volume table	29
Monthly growth table	3
BA increment level	High (nil adjustment)
Crown height function	Beekhuis
DOS function	Standard
DOS adjustment	Nil

TABLE 3–Basal areas of interpolated stockings (250, 300, 350 stems/ha) using STANDPAK calibrated by MARVL data from actual stockings (100, 200, 400 stems/ha)

Stems/ha	STANDPAK prediction (m^2/ha)	MARVL assessment (m^2/ha)	% BA adjustment to calibrate STANDPAK	% BA adjustment made to interpolated stockings	Adjusted BA for interpolated stockings
100	30.97	32.52	+5.0		
200	45.15	46.50	+3.0		
250	51.63			+3.5	53.44
300	56.14			+4.0	58.39
350	59.29			+4.5	61.96
400	61.32	64.20	+5.0		

Simulation of Growth to Ages 25, 28, and 31

Volume

The program GROMARVL (v. 3.30) was used to simulate the volume by log grade for the treatments at ages 25, 28, and 31 years. The chosen growth model was NAPIRAD, as this was considered the most suitable model for fertile farm sites (G.West unpubl. data). Nevertheless, the accuracy of the NAPIRAD predictions for advanced ages is not known, because there has been an absence of data pertaining to old stands on fertile farm sites, managed on a direct regime, and using genetically improved stock.

A model run using the Pumice Plateau Model PPM88 and the medium fertility level in EARLY but calibrated with Tikitere data of early stocking, diameter, height, and site index, gave substantially lower volumes (Table 4). Height predictions were similar, but NAPIRAD most closely anticipated the increased individual-tree basal area that results both from the farm site and from lower stockings. This "farm site bonus" is expected to decrease with rotation age, in both absolute and relative terms (as illustrated in Table 4 using the 400 stems/ha data).

TABLE 4–Volume gains (m^3/ha) from a farm site relative to a forest site

Age	Predicted for a forest site, using STANDPAK & PPM88	Predicted for a farm site, using GROMARVL & NAPIRAD	Difference	Percentage gain
21	584	774	190	33
25	755	935	180	24
28	877	1038	161	18
31	992	1125	133	13

Wood quality

It is important to note that GROMARVL neither makes changes to quality codes as trees grow older, nor alters the diameter and height relativity of individual trees. Considerable work has been done to rectify these deficiencies, but the research has not yet been incorporated into GROMARVL. The net result is that GROMARVL predictions can be expected to be accurate for at most 5 years. When interpreting this paper, therefore, extreme caution should be exercised in accepting wood quality extrapolations made here to ages 28 and 31 years.

In the higher stockings (e.g., 400 stems/ha), the branches in the second and third logs are dead, and therefore the branch size for these logs will be much the same at age 31 as at 21. The bulk of the volume and value of the tree is accounted for by the lowest three logs. In contrast, the lowest branches in the 100 stems/ha treatment were actively growing and could be expected to be even larger by age 31, although their categorisation as pulp would not change. The biggest errors due to increased branch size would be associated with those logs that are likely to change categories within 10 years, with significant economic effect. For example, the branches on third logs in the 200 stems/ha treatment are currently small but may eventually exceed sawlog specifications.

Probably the most serious error in using GROMARVL for a 10-year extrapolation lies in the continuing stem breakage due to wind. This cannot be modelled, and may bias the results because damage is expected to occur preferentially in lower stockings.

RESULTS and DISCUSSION

Volumes (by log grade) and values for each stocking treatment at years 21, 25, 28, and 31 are given in Table 5. The following trends are apparent.

- Total volume, recoverable volume, unpruned volume, volume of large-diameter unpruned logs, and volume of small-branched logs all increased with stocking.

TABLE 5–Volumes (m^3/ha) of treatments at four ages

Age	Stems /ha*	Pruned	S1	S2	L1	L2	Pulp	Total rec. vol.†	Total vol.
21	400	210.7	22.4	164.2	111.2	112.9	46.5	668	774
	350	212.9	11.6	97.5	50.1	147.7	64.9	585	686
	300	212.2	8.9	45.5	65.2	146.7	58.5	537	634
	250	200.7	5.2	26.0	62.2	134.6	50.8	480	570
	200	182.6	3.7	17.8	88.6	47.1	67.2	407	501
	100	128.5	0.3	1.4	44.6	13.2	81.3	269	320
	50	69.6	0.8	0.5	11.8	3.3	42.1	128	150
25	400	256.4	43.7	158.4	180.1	115.2	59.3	813	935
	350	251.8	30.5	97.6	115.6	159.7	65.8	721	854
	300	247.4	21.9	45.9	140.7	154.8	60.4	671	798
	250	233.2	14.8	21.2	152.6	130.9	56.5	609	728
	200	211.4	9.6	17.4	145.1	46.0	93.4	523	637
	100	149.1	0.9	1.8	68.9	11.1	114.5	346	410
	50	84.2	1.0	1.0	20.8	2.1	62.9	172	200
28	400	280.4	61.7	155.5	229.3	109.7	67.9	905	1038
	350	271.4	42.5	84.6	177.7	159.8	75.6	812	963
	300	265.3	32.1	46.1	195.5	151.8	68.3	759	905
	250	250.2	20.9	19.0	212.9	121.6	68.4	693	832
	200	228.4	12.7	18.0	183.2	40.7	114.2	597	725
	100	161.1	1.6	1.8	84.1	10.4	138.0	397	469
	50	94.1	1.1	0.8	26.5	2.2	78.4	203	236
31	400	300.9	75.9	151.3	276.4	101.0	78.1	984	1125
	350	285.3	46.4	75.7	228.0	165.2	92.0	893	1058
	300	278.2	34.1	41.9	253.2	145.7	87.3	840	998
	250	262.8	21.0	10.1	250.6	125.5	92.0	771	924
	200	241.5	15.6	18.0	219.1	38.0	133.1	665	803
	100	170.9	2.0	2.1	98.5	10.5	158.8	443	522
	50	101.6	1.1	1.0	31.7	2.1	92.8	230	268

* The figures for 400, 200, 100, and 50 stems/ha were derived from MARVL and GROMARVL outputs, whereas those for 350, 300, and 250 stems/ha were from STANDPAK runs calibrated by MARVL assessments at age 21.

† "Total recoverable volume" does not include stumps, wood lost through breakage or sawcuts, or wood categorised as "waste". These are, however, included in "Total volume".

- Pruned log volume was very similar for stockings over 250 stems/ha at age 21, but relativities increased with time so that higher stockings had significantly more recoverable pruned volume at older ages.
- Pulpwood volume generally increased with decreasing stockings, reaching a peak at 100 stems/ha. Indeed, at 100 stems/ha pruned logs and pulpwood together accounted for 78% of the production at age 21.
- There was considerable volume of small-branched logs at the highest stockings (over 200 m^3/ha at age 25 for the 400 stems/ha), thus refuting the argument that "top-logs on farm sites are inferior because of branch size". Even on a fertile ex-pasture site, the presence of small-branched logs was greatly dependent on the stocking.

Volume growth at the higher stockings was impressive. At 400 stems/ha, the mean annual increment (volume) at age 21 was 36.9 m^3/ha, and is likely to increase substantially with age, given that the current annual increment (volume) averaged 53.6 m^3/ha between age 11 and age 21 (Knowles unpubl. data). The reason for this high level of production is not yet known, but it is hypothesised that the fertility (especially the nitrogen level) of the ex-farm site is the major factor. There may be synergistic contribution from the improved growth rate of the '850' genetic stock, the absence of competing vegetation, the early grazing regime (recycling nutrients), and the silvicultural practices (thinning and pruning to reduce disease and to balance between-tree competition).

This study detailed some of the physical characteristics of a range of final-crop stockings grown on a farm site capable of producing very high volumes of log grades that, under current grading rules, are of high value. Nevertheless, there is a distinct possibility that grade specifications may eventually be tightened and may incorporate internal wood qualities that cannot be assessed by external examination. If changing specifications result in a downgrading of the value of ex-pasture stands, particularly because of low stockings or short rotation ages, then this analysis may have to be revised.

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REFERENCES

COX, O.; McGREGOR, M.; MACLAREN, P. 1988: Agroforestry components of the radiata pine stand model. Pp. 175–182 *in* Maclaren, P. (Ed.) "Proceedings of the Agroforestry Symposium Rotorua 24–27 November 1986". *New Zealand Ministry of Forestry, FRI Bulletin No.139.*

DEADMAN, M.W.; GOULDING, C.J. 1978: Method for the assessment of recoverable volume by log types. *New Zealand Journal of Forestry Science 9*: 225–239.

HAWKE, M.F.; PERCIVAL, N.S. 1992: Sheep growth rates under *Pinus radiata*. Proceedings of New Zealand Society of Animal Production 52: 229–231.

HAWKE, M.F.; O'CONNOR, M.B. 1993: Soil pH and nutrient levels at Tikitere Agroforestry Research Area. *New Zealand Journal of Forestry Science 23(1)*: 40–48.

KNOWLES, R.L. 1991: New Zealand experience with silvopastoral systems: a review. *Forest Ecology and Management 45*: 252–267.

MACLAREN, J.P. 1994: The radiata pine growers' manual. *New Zealand Forest Research Institute, FRI Bulletin No.184.* 140 p.

MANLEY, B.R.; GOULDING, C.J.; LAWRENCE, M.E. 1987: Stand assessment by log grades using MARVL. *New Zealand Ministry of Forestry, FRI Bulletin No.132.*

WEST, G.G. 1993: A review of the development and use of the New Zealand modelling system: STANDPAK. International Symposium on "System Analysis and Management Decisions in Forestry", Valdivia, Chile.

APPENDIX 1

CUTTING STRATEGY USED

Stump height: 0.3 m
Round-off length: 0.1 m
Cost of saw cut: $0.50

Log grade	Price ($/m^3)	Min. s.e.d. (cm)	Max. s.e.d. (cm)	Max. l.e.d. (cm)	Min. length (m)	Max. length (m)	Qualities*
Pruned	172	35.0	150.0	150.0	3.70	6.10	A
S1 Sawlogs	55	35.0	150.0	150.0	3.70	6.10	ANEG
S2 Sawlogs	43	20.0	35.0	150.0	3.70	6.10	ANEG
L1 Sawlogs	50	35.0	150.0	150.0	3.70	6.10	ANEGFHLK
L2 Sawlogs	30	20.0	35.0	150.0	3.70	6.10	ANEGFHLK
Pulp	11	10.0	150.0	150.0	2.40	6.10	ANEGFHLKP
Waste	1	0.0	150.0	150.0	0.10	20.0	ANEGFHLKPW

* *See* Appendix 2 for definitions

APPENDIX 2

QUALITY CODE DICTIONARY USED

A	Pruned
E	Unpruned, branches < 7 cm, straight, not peeler quality
G	Unpruned, branches < 7 cm, moderate sweep
F	Unpruned, branches 7–10 cm, straight
H	Unpruned, branches 7–10 cm, moderate sweep
K	Unpruned, branches 11–14 cm, moderate sweep
L	Unpruned, branches 11–14 cm, straight
N	Unpruned, branches < 7 cm, straight, peeler quality
P	Pulp. Branches > 14 cm or severe sweep
W	Waste. Inferior to pulp. (Firewood?)

Where: Peeler quality was determined by out-of-roundness (less than 10%), stemcone holes (none), and evenness (e.g., minimum nodal swelling, wobble).

Sweep was determined by the following table:

Classification	For 5.5-m log	For < 3.7-m log
Straight	< s.e.d./8	< s.e.d./16
Moderate sweep	s.e.d./8 to s.e.d./4	s.e.d./16 to s.e.d./8
Severe sweep	s.e.d./4 to s.e.d./2	s.e.d./8 to s.e.d./4
Waste	> s.e.d./2	>s.e.d./4