PROFITABILITY OF THINNING IN RADIATA PINE PLANTATIONS

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ABSTRACT

The effects of non-commercial and production thinning during the rotation of a commercial forest plantation are discussed. Such factors as log size, tree size and stand volume are considered briefly to emphasise the relative profitability of a management regime is a function of all costs and all benefits. The enhanced future value of the residual stand is a major benefit from all thinning.

Economic analysis, using simulation to compare alternative management regimes, confirms non-commercial thinning to be profitable relative to delayed thinning. Production thinning might be even more profitable if done before intense stand competition develops.

If, late in the rotation, there is no thinning then dense stands result, with intense competition on the dominant trees. Production thinning then could be beneficial, sustaining crop tree growth and resulting in both profitable and silviculturally desirable management.

INTRODUCTION

Managers of exotic pine plantations in Australia generally have accepted periodic production thinning to be a normal and desirable part of plantation management practice. Some plantations, particularly of slash pine (*P. elliottii Engelm.*), are thinned non-commercially; this is usually a release thinning to waste before intense competition develops, removing about one-half the original 1,500-2,000 trees per hectare. Later in the rotation, these plantations again are thinned for merchantable production. However, non-commercial thinning has been relatively unusual, although the New Zealand example (Fenton, 1972a) shows the great financial advantage gained in some circumstances through early release of the crop trees.

Most Australian plantations, particularly of radiata pine (*P. radiata* D. Don), receive several production thinnings; that is, intermediate harvesting and sale of the smallest, most poorly formed and competing trees, progressively to upgrade the average tree quality and to ensure adequate residual tree and stand growth. Production thinning has been considered acceptable because of the silvicultural benefits associated with stand vigour and health, the desire to supply markets from young stands and the possibilities for using early financial returns to offset in part the heavy costs of establishment.

In the absence of thinning, competition between trees intensifies till eventually many trees die; merchantable volume increments and individual tree growth are less, the eventual harvest is either delayed or smaller and the end-product may be less valuable because of the smaller average piece size. Thus the full value of the final crop is not obtained and an opportunity cost is incurred.

The profitability of production thinning has been queried quite strongly in recent years, culminating in a series of excellent papers by Fenton and co-workers (*see* particularly Fenton, 1972b). Production thinning usually is possible only after a period of intense competition; practicable limits for both individual tree size and stand merchantable volume first must be attained. Thus, commonly, there is an opportunity cost incurred also by production thinning, depending on the duration and impact of intense competition before thinning; a cost which engenders doubt about the profitability of production thinning generally. The discussion has been such that opinions tend to polarise for or against production thinning in isolation of other factors (*see,* for example, comments of Spiers and Tustin in Tustin and Bunn, 1970, page 98 Vol. 1).

Some aspects of thinning in radiata pine plantations are discussed in this paper in relation to both tree growth and product market conditions.

STAND COMPETITION AND OPPORTUNITY COSTS

It is relevant to examine stand and tree growth particularly during the ages of 6 to 15 years, when radiata pine stands might be thinned, and to identify those factors likely to influence the relative profitability of thinning.

Production thinning is constrained by the need for acceptable tree and log size and an adequate total stand volume such that an economically practicable merchantable volume can be removed while still retaining an acceptable residual stand. The interrelationships between stocking and tree size and stand volume are illustrated (Fig. 1)

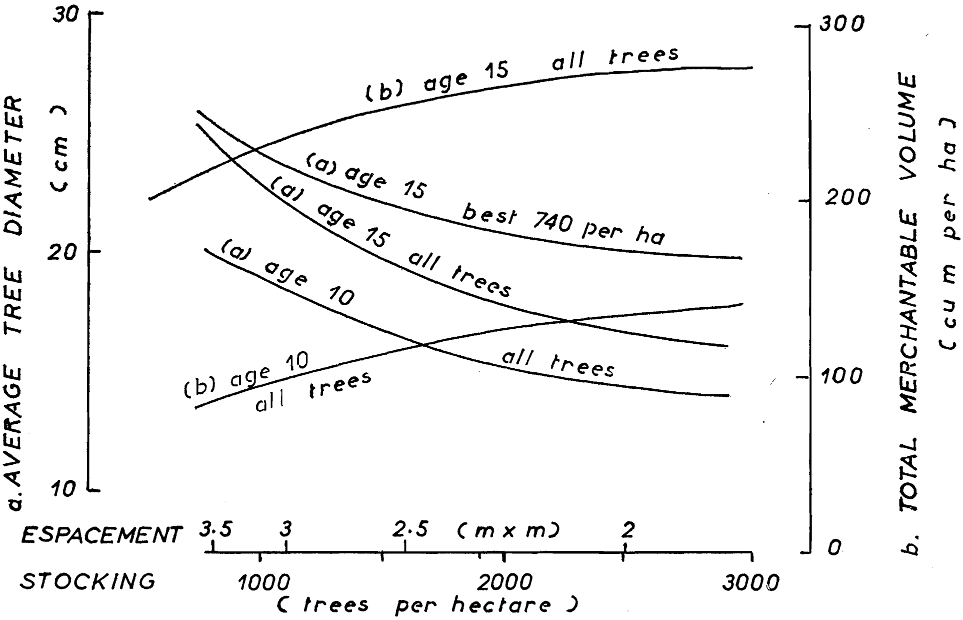

FIG. 1—Relationships between stocking and (a) average tree diameter (d.b.h.o.b.) and (b) merchantable volume production to 11 cm u.b.)

using data from South Australian plantations (Cromer and Pawsey, 1957). These data are supported closely by results from more recent unpublished New South Wales (NSW) studies (Table 1). No single establishment espacement is optimal for early attainment both of adequate stand volume and of minimum tree size limits. Stands planted closely, at, say, 3,000 trees per hectare, have appreciable merchantable volume two-three years sooner than more widely spaced stands; however, in denser stands the small tree size might inhibit early production thinning.

TABLE 1—Generalised summary of competition development in NSW radiata pine plantations

Competition level	1500 trees per ha 2.6 m × 2.6 m	3000 trees per ha 1.8 m × 1.8 m
Smallest tree dominated	age 6-7 years	age 4-5 years
Codominants crowns compete	8-9 years	6-7 years
Measurable decrease in diameter of crop trees	11 years	9 years
Thinning for pulp or chips practicable	13-14 years	15-16 years
Thinning for sawlogs practicable	17-20 years	20-25 years

Establishment of 2,500-3,000 trees per hectare may be most desirable in some situations, e.g., for early control of branch size or adequate tree selection. At this stocking, in typical NSW plantations, the crop trees would be subject to intense competition for about 13 years before production thinning for sawlogs on silvicultural lines was possible. By age 25 years the crop trees in an unthinned stand might have average diameter of 33 cm, up to 12 cm less than the diameter possible for an equivalent number of crop trees in a thinned stand (Shepherd and Forrest, 1973). Thus, in closely spaced stands, the opportunity cost of holding full stocking until production thinning becomes possible is very great.

Initial stocking in most NSW plantations has been commonly about 1,300-1,500 trees per hectare. If markets are accessible, early production thinning for pulp, chip, post or case log is possible at age 13-14 years, only two or three years after intense competition develops. Then the potential value of the residual stand is only marginally less than the maximum possible, i.e., the opportunity cost incurred by the time of first production thinning is very small.

Conditions of great stand density and intense tree competition also occur in older stands. Then the alternatives are to thin some years prior to clear felling or to retain the full stand to rotation age. The former choice is costly and the thinning produce is of less than optimal value; the latter choice involves the opportunity costs always associated with a period of intense competition. Again, the solution revolves around comparison of costs and benefits for each circumstance.

COMPARISON OF THINNING REGIMES

Methods

The effects of thinning policies on tree and stand growth can be assessed using the prediction simulation programme developed for NSW radiata pine plantations. The programme consists of a series of regression equations calculated from very complete growth data derived from 340 field experiment and continuous inventory growth-plots. Basal area increment and diameter distributions are recalculated annually with reference to stand age, density, site index and the intensity of and time since previous thinning. Stand height growth is simulated in relation to a series of height-age curves.

Small trees in dense stands, which in practice die, are held static in stand simulation. Their volumes contribute to the total volume at thinning or final harvest, thus harvest volumes are gross, including mortality. This results in a small overestimate of merchantable volume in regimes with light thinning and greatest stand density.

Tree volumes are calculated for each period, harvest or residual stand using a series of functions describing stem profile. Underbark volumes are calculated for each 2.5 cm tree diameter (d.b.h.o.b.) class and by 2.5 cm underbark log diameter classes. Thus the volumes estimated are totals by underbark log diameter class; total merchantable volumes include volumes in all log diameter classes to the 12.5 cm class (i.e., to 11.2 cm log diameter). Thus estimated merchantable volumes probably are greater than achieved in practice; again any overestimate will be greatest for regimes with light thinning and dense stands.

The base for simulation in this study was derived from a replicated field study of non-commercial and commercial thinning. A uniform stand had been selected in a Tumut (NSW) plantation at age 6 years and four non-commercial thinning treatments (including an unthinned control) each were replicated five times. Two of the four treatments were thinned commercially at age 13 years. Plots thinned at age 6 years to 450 and 740 trees per hectare, at age 13 years to 510 trees per hectare and the unthinned control plots with 1480 trees per hectare form the basis for further stand projection (Forrest, 1971). Many hypothetical management regimes have been compared; the six regimes described in Table 2 have been selected to illustrate the several points discussed. For each regime simulation begins after thinning at age 13 years, using as a base the average stand parameters existing in the experimental plots with the nominated thinning history.

The value returns have been calculated for each harvest of all six management regimes, using each of three contrasting but conceivable log size price structures (Fig. 2). The products of volume and values per size class have been summed to determine each harvest value. Harvest values have been discounted to age 0 as an annuity, at several rates of interest, to estimate net returns for each regime. The size-price structures used indicate residual stumpage, i.e., net return per unit volume after all direct harvesting costs as felling, snigging, haulage and conversion, but not forest supervision or administration, have been deducted. Structure A gives equal value per unit volume for produce of all log sizes; structure B has rapidly increasing value for size, with smaller logs of 20 cm diameter having 50% of largest log value; structure C corresponds more closely to common size-price structures, with small logs having relatively small value and 50% of largest log value being obtained for relatively large 40-cm-diameter logs.

Results

The effects of heavy thinning on volume production, tree size and product size class distribution are generally well known. Heavy thinning to less than full stocking density (as in regimes 1 and 2, Table 2) results in appreciably reduced merchantable volume

TABLE 2—Details of harvests and of residual stands for six hypothetical management regimes

REGIME No.	1	2	3	4	5	6
DETAILS OF HARVESTS (a)						
i. Age of thinning and clearcut (years)						
Harvest 1	6(a)	6	6	13	15	20
2	18	20	30	19	20	25
3	26	30		26	26	35
4	35			33	33	40
5					40	
ii. Number of trees removed (stems/hectare)						
Harvest 1	746	1037	1037	974	864	996
2	467	262	445	272	178	166
3	124	183		96	134	141
4	146			141	74	180
5					232	
iii. Merchantable volume removed (m^3/ha, to 11 cm diam. s.e.u.b.)						
Harvest 1	NIL	NIL	NIL	108	119	254
2	167	177	659	136	75	93
3	142	392		115	106	183
4	388			343	96	360
5					502	
Total	697	569	659	702	898	890
MAI	19.9	19.0	22.0	21.3	22.5	22.3
DETAILS OF RESIDUAL STANDS (b)						
i. Numbers of trees (stems/ha)						
Harvest 1	736	445	445	509	618	487
2	269	183	0	237	440	321
3	146	0		141	306	180
4	0			0	232	0
5					0	
ii. Basal area (m^2/ha)						
Harvest 1	4.2	3.2	3.2	16.1	21.1	23.0
2	16.2	16.0	57.3	16.1	25.3	23.2
3	18.3	33.1		18.2	27.3	22.9
4	29.9(b)			27.4	29.8	26.7
5					37.1	
iii. Average diameter (d.b.h.o.b.) = cm)						
Harvest 1	8.4	8.6	8.6	19.8	20.6	24.4
2	27.4	33.3	40.1	29.2	26.9	30.0
3	39.9	48.0		40.4	33.5	39.6
4	50.8(b)			49.5	40.1	42.9
5					44.7	
iv. Stand dominant height (m)						
Harvest 1	6.1	6.1	6.1	18.0	20.4	25.9
2	23.8	25.9	34.1	25.0	25.9	30.5
3	31.4	34.1		31.4	31.4	36.9
4	36.9(b)			35.7	35.7	38.4
5					38.4	

N.B. (a) All thinnings, including non-commercial thinnings, are referred to as harvests.
(b) The final values of basal area, diameter and height describe the stand at final harvest.

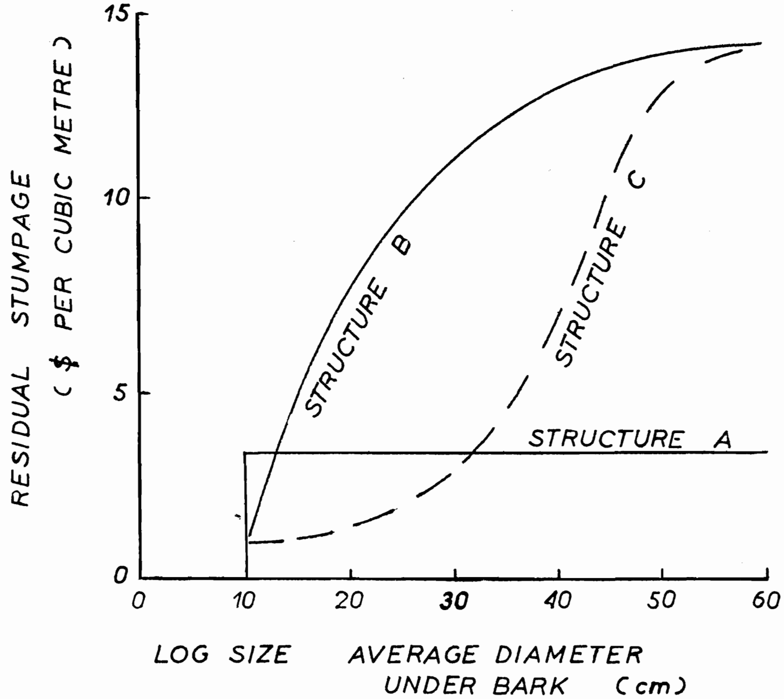

FIG. 2—Selling price-log size relationships used for calculating stumpage return

production, by up to 35% for the regimes compared. However, individual tree diameter growth is greater following heavy thinning and a butt log of 50 cm diameter can be obtained at least 10 years sooner than is possible with lighter thinning for maximum volume production (e.g., regime 5).

The distribution of the total volume within various product size classes, in response to various thinning policies, can be assessed (Table 3). As a result of early, heavy

TABLE 3—Merchantable volumes produced within product size classes for six plantation thinning regimes (m^3 per ha per annum)

Log Size Class — Average diameter under bark (cm)	Regime Number and Crop Rotation					
	1	2	3	4	5	6
	35 yrs	30 yrs	30 yrs	33 yrs	40 yrs	40 yrs
11.2-21.6	4.48	2.98	3.18	6.50	6.43	7.90
21.6-31.8	5.79	6.56	9.02	6.00	7.23	7.80
31.8-41.9	5.67	6.24	8.54	5.56	6.25	5.12
41.9-52.0	3.51	3.06	1.22	2.98	2.39	1.38
52.0+	0.45	0.12		0.26	0.16	0.06
TOTAL	19.90	18.96	21.96	21.30	22.46	22.26
31.8+	9.63	9.42	9.76	8.80	8.80	6.56

thinning the volume produced per annum in larger size classes may be greater by 30%, when compared with produce from light thinning regimes, though the total merchantable volume production per annum might be less and the rotation 10 years shorter.

The more useful comparison is of harvest value return (Table 4). Naturally there are large differences in the levels of returns for the three size-price structures because the average returns per unit volume differ markedly. Also naturally, the interest rate charged has overriding effect on the actual value return. However, within any price structure, the choice of interest rate has surprisingly small effect on relative profitability between the management regimes compared. Long rotations including several thinnings are relatively profitable only at unrealistically low interest rates or when no greater value is obtained for large logs. In general, non-commercial thinning regimes (Nos. 1-3) are more profitable than regimes where the first production harvest is delayed (Nos. 5 and 6), particularly where such delay is to obtain sawlogs at the first production harvest (No. 6). However, regimes with very early production thinning are at least as profitable as those with non-commercial thinning (cf. regimes 2 and 4) because there is little difference in future residual stand values but appreciable loss of early revenue return after non-commercial thinning.

TABLE 4—Total value for all harvests (thinnings plus clear felling) of each regime and value when discounted to age 0 as an annuity, calculated for each of three price-size structures and for several discounting rates

Regime Number	1	2	3	4	5	6
Rotation (years)	35	30	30	33	40	40
PRICE-SIZE STRUCTURE A.						
Total, 1st Rotation	945	772	895	954	1220	1208
Discounted at 4%	423	396	399	496	463	468
7%	165	152	136	212	181	181
10%	79	70	54	111	89	85
15%	27	23	14	46	34	29
PRICE-SIZE STRUCTURE B.						
Total, 1st Rotation	2912	2462	2798	2731	3503	3237
Discounted at 4%	1217	1230	1249	1289	1194	1146
7%	451	462	424	507	426	416
10%	203	209	170	245	190	184
15%	67	66	43	90	64	58
PRICE-SIZE STRUCTURE C.						
Total, 1st Rotation	1298	1026	948	1130	1330	1062
Discounted at 4%	493	486	423	487	412	344
7%	168	175	144	177	135	115
10%	69	75	57	78	55	48
15%	19	21	14	25	16	13

N.B. Underlined values indicate the regime of greatest value and other regimes with indicated value within 10% of the greatest, for each price structure and interest rate.

When average stumpage prices are reflected by size-price structure B, then management regime 4 is consistently most economic because the early revenue returns are greater without incurring excessive opportunity costs associated with high stand densities. Early returns are less important but opportunity costs are more important when the stumpage is similar to size-price structure C. But again, regimes with non-commercial thinning are not more profitable than those with heavy and early production thinning (regime 4).

The depressing effect on net returns associated with high stand density is seen in regime 6. It can also be seen in comparison between regimes 2 and 3. Stands thinned to 445 trees per ha at age 7 years have 37 m^2 per ha basal area at age 20 years. Corresponding simulation indicates the basal area would increase, in the absence of thinning, to 48 m^2 at age 25 years and to 57 m^2 at age 30 years when the average tree diameter (d.b.h.) is approximately 40 cm. Stands managed in New Zealand according to recommended sawlog production regimes also have in excess of 57 m^2 per ha basal area at time of clearfelling (Fenton, 1972a). Yet experimental data (Shepherd and Forrest, 1973) show the volume growth of radiata pine stands does not increase with increase in stand density beyond about 27 m^2 per ha basal area. The diameter growth of dominant trees is suppressed by 10% of that for corresponding trees in open stands, when the stand basal area is greater than about 18 m^2 per ha, in the age range 15-25 years. Consequently, stands at the end of a rotation and approaching a basal area of 57 m^2 per ha have suffered increasing competition and consequent economic opportunity cost for at least 5 and probably up to 10 years. The net royalty return from an intermediate production harvest need be only small, or even negative, for improvement in overall economics.

The value of production thinning can be judged through closer comparison (Table 5) of regimes 2 and 3, both of which include heavy non-commercial thinning at age 7 to 445 trees per hectare. Regime 2 includes a heavy production thinning at age 20 to 16 m^2 per ha basal area and hence the total volume production for the rotation is less than for regime 3. The total revenue return per rotation is greater for regime 3, even when a moderate size-price gradient applies. However, production thinning provides both an intermediate return and ensures full final crop development. Consequently, regime 2 is more economic at all discount interest rates and particularly so when a strong size-price gradient (as for structure C) applies, for precisely the same reasons as argued for non-commercial thinning.

DISCUSSION

It is not intended here to prove or disprove the overall economics of pine plantation forestry, so all costs of production and some other important considerations, e.g., pruning, have been omitted. Other important cost considerations appear to have been omitted though these can be accounted for within the three price structures examined; for example, the greater value of clear logs of the final crop is reflected in the greater value for large logs of price structure C.

Fenton (1972a) complains "the maximisation of volume production through production thinning continues to dominate management concepts in New Zealand". This has been equally true in other places. Fenton then argues the case for non-commercial thinning ". . . the cost of delaying final crop increment by waiting for a production thinning reduced the internal rate of return from 10% to 6½%. . . ."

TABLE 5—Details of financial return from each harvest within management regimes 2 and 3, for each size-price structure and selected interest rates

Size-price structure		A		B		C	
Regime Number		2	3	2	3	2	3
Harvest values, total 1 rotation							
Harvest	1	0	0	0	0	0	0
	2	241	895	613	2798	136	948
	3	531		1849		890	
TOTAL		772	895	2462	2798	1026	948
Harvest values, discounted at 7%							
Harvest	1	0	0	0	0	0	0
	2	71	136	182	424	40	144
	3	81		280		135	
TOTAL		152	136	462	424	175	144
Harvest values, discounted at 10%							
Harvest	1	0	0	0	0	0	0
	2	38	54	97	170	21	57
	3	32		112		54	
TOTAL		70	54	209	170	75	57

N.B.—Harvest numbers correspond with Table 2. In each case the first harvest is a non-commercial thinning.

The biological and economic analysis of other data in this paper supports his conclusions. It is silviculturally undesirable and economically unsound to retain stands at high density and suffer loss in increment on the final crop. However, early non-commercial thinning is not the only conceivable solution and does not necessarily adequately solve the problem. Two additional aspects are relevant.

Where initial stocking is less than in many New Zealand stands (e.g., about 1,500 trees per hectare) and a market can be guaranteed for small size logs, then production thinning is possible within only a few years of stand competition becoming significant. In such a case, which applies commonly in NSW plantations and elsewhere, an early production thinning can yield positive net value return without significant opportunity cost being incurred. Even with negligible financial gain from thinning the material productivity of the plantation is increased.

Secondly, whether by non-commercial or production thinning, it is rarely possible (or desirable) to reduce the stand at the first thinning to a stocking where the remaining trees can be then grown to maturity without appreciable competition and hence loss of increment. A second thinning usually will be necessary to gain maximum value from the final crop of dominant trees. Also, for those trees in excess of full stocking at rotation age, the discounted value is greater when removed in an intermediate harvest than if retained till rotation age, even though the cost of harvest is greater and the value per unit volume is less.

Other factors, such as risk of physical or biological damage or market uncertainty, are favoured by shorter rotations, early value returns and minimal standing capitalisation. These conditions are achieved by heavy early thinning, preferably for production where circumstances permit, and an intermediate harvest.

Clearly the optimal management regime applicable will vary between, and even within, plantations depending on stand structure, growth rates, harvesting conditions and present and future market outlets. In NSW plantations management policy is changing to ensure a balance between material productivity and overall financial benefits. Non-commercial thinning has increased in areas distant from small-piece markets or where topography hinders the harvesting of small material. The first production thinning tends to be earlier, to minimise competition on final crop trees and all thinnings tend to be heavier and less frequent.

SUMMARY

The relative profitability of non-commercial thinning and of production thinning in radiata pine plantations has been argued extensively in both New Zealand and Australia.

There is general agreement that intense competition, common after stand canopy closure, results in undesirable supression of the dominant, final crop trees. Total merchantable volume production might also be reduced eventually in unthinned stands. Serious economic opportunity cost is experienced in stands where intense competition develops, because of the smaller future value of the residual stand.

The case for non-commercial thinning has been argued strongly on economic grounds, to ensure full development of the final crop. Examination of extensive growth data, using growth simulation models, confirms the value of early thinning. However, in many circumstances it is possible to thin for sale only a short time after a non-commercial thinning might be applied. Production thinning might recoup all or most of the thinning costs and would then be more economic than non-commercial thinning. Frequently stands have been held unthinned till the first production thinning is feasible, beyond the time when competition becomes intense, and this should be avoided aggressively.

Management regimes which do not provide for release thinning in the second half of the rotation necessarily result in extremely dense stands. The growth of dominant trees is suppressed and an opportunity cost is incurred in the same manner as is evident in younger stands. Production thinning can result in positive net revenue return and considerably enhance the future value of the dominant trees, resulting in an improvement overall in relative profitability.

The primary need is for flexible management, choosing frequency and timing of thinning to optimise the returns against costs for each plantation growth-market situation.

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