PART 5

THE ECONOMICS OF THINNING PLANTATIONS

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ABSTRACT

The economic evaluation of thinning is complex and should include the interaction of tree-stand, utilisation, linked economic, and local management factors. Tree-stand data needed include the malformation percentage; mortality rates; stand volume and piece-size projections; changes in timber quality; hydrological and ground-cover effects. Utilisation data include the differential costs and returns of each piece-size class. Linked economic data include differential haul rates; returns to scale of utilisation plants; and economic multiplier effects through time. Local influences, which may become dominant, include biological, climatic and topographical considerations. The opportunity costs of thinning can include reduction in final crop increment rate; postponement of cash flows from greater volumes of clearfellings, and postponement of linked utilisation benefits.

As thinning is a more complex operation than clearfelling the postponement of the greater yields foregone should be justified when production thinning is prescribed.

INTRODUCTION

Thinning in this paper refers to intentional removal of part of a tree crop. Some silvicultural systems, e.g., Selection Forest — never incur clearfelling, but are excluded from consideration here. Discussion is primarily concerned with forests where the eventual aim is log production, although as other yields such as water, animals and sport can be produced and may become dominant, they are also included in the paper.

Thinning formed an integral part of early European organised forestry and still retains an important role in forestry training and management in their fullest sense. In common with the general trend, plantation concepts in Australasia have generally involved regimes which include thinning. The primary aim in this paper is to specify the economic factors involved in evaluating thinning. Where possible these factors are either quantified from the data available, or relevant literature is cited.

The areas of plantations thinned and clearfelled in State plantations in Australasia over the last five to seven years is shown in Table 1. The contrast between the concentration on clearfelling in New Zealand as against that on thinning in Australia is largely due to the relatively more abundant older age-classes present in New Zealand.

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TABLE 1—Areas Thinned and Clearfelled (ha) in Australasia

Year	W. Aust. Thin	W. Aust. c/f	S. Aust. Thin	S. Aust. c/f	NSW Thin	NSW c/f	Q'land Thin	Q'land c/f	Tasmania Thin	Tasmania c/f	NZ Thin	NZ c/f
67/68	520	42	3225	107	Not avail.		2955	—	348	2.6	7046	2598
68/69	804	96	3159	119	Not avail.		3232	—	411	2.0	6518	3254
69/70	684	57	3687	171	3000	—	3952	—	414	5.4	7015	3997
70/71	1845	77	3987	235	3200	—	3777	—	353	0.9	8590	4405
71/72	1908	—	3917	216	3000	—	3616	—	302	5.4	10880	4548
72/73	1746	—	4610	194	3300	—	3854	—	272	0.4	16696	4663
73/74	2017	—	Not avail.		4000	—	Not avail.		Not avail.		12490	5300

ECONOMIC EVALUATION

Overall Economic Factors Involved in Thinning

Fundamentally it is, or should be, necessary to justify a more complex operation—such as thinning—when a simpler operation—clearfelling—would apparently achieve a similar result. This applies as much to thinning-to-waste as to log production. After all, the overwhelming proportion of the yield from New Zealand plantations (about 64 million m^3 from 1951 to 1970) has come from forests almost completely unthinned and unpruned, apart from the erratic benefits associated with *Sirex noctilio*. The forests established since ca. 1950 have, however, been subject to the attention of foresters and both thinning and foresters have since increased locally (probably a strong correlation could be shown between the two).

To quantify thinning economics it is necessary to know:

(a) *Stand data*

(i) The malformation percentage, and the stages of growth at which it occurs.
(ii) The mortality rate.
(iii) The stand volume and tree size projections for the widest range of stocking density (viz. Assman/Moller problems: inter-stand competition and growth transfer).
(iv) The piece-size distribution at each year.
(v) The change in timber quality induced by thinning.
(vi) Hydrological effects.

(b) *Utilisation data*

(i) The differential utilisation costs for different piece-sizes.
(ii) The value of outturn from each piece-size class.

(c) *Linked economic data*

(i) Differential log-haul rates.
(ii) Real returns to scale for utilisation plants.

(iii) Economic multiplier effects of utilisation.
(iv) Risk of failing to thin.

(d) *Secondary data*
(i) Loss of volume through loss of stand area; roading intensity.
(ii) Importance of stand damage.
(iii) Accident rates.

(e) *Local influences*
(i) Other biological/wind/fire risk/conservation/topographical considerations that can be locally dominant.

This classification is not exhaustive, nor in a particular ranked order. Each of these headings is expanded below, but the subjects all interact.

Malformation Effects

When thoroughly domesticated, that is highly-bred plants are used, as in some poplar (*Populus* spp.) management, one basic reason for thinning — that of stem selection — is diminished; but most Australasian softwood plantation forestry has not reached this stage. So increased chances of selecting better stems remains a major reason for thinning, with the implicit assumption of lower values from malformed stems.

The interaction of genetics and environment on tree form is fundamentally important,, and has been of major concern in New Zealand forestry. As a generalisation, gross malformation and poor form are more widespread than in Australian radiata pine (*Pinus radiata* D. Don).

Stem shape — that is divergence of the major axis from a straight line — has been quantified for Scandinavian sawmilling, and deviation from straightness is of major importance in sawmill recovery. It also adversely affects grade results (Fenton, 1960). It is reasonable to infer it also affects utilisation costs, though this is tedious to record and quantify. A large-scale study on logs of 15 to 30 cm small-end diameter inside-bark when frame-sawn showed average conversion factors increased by 13% to 16%, sawing time decreased by up to 40%, and desirable timber sizes as well as grade out-turn all improved when sawing "normal" as against malformed logs.

But the stem straightness effects decrease in importance as log diameter increases (MacDonald and Sutton, 1970) though the malformed logs would still be less valuable than straight ones.

In trees intended for sawlogs the formidable concentration of net stem value in the lowest log-height classes (Fenton and Sutton, 1968) should facilitate stem choice if thinning is undertaken and perfect form, though desirable, is not an absolute criterion.

It has been reported (J. Beekhuis, pers. comm.) that double or multiple leadered trees in the New Zealand Permanent Sample Plots have a very high chance of losing one or more leaders, and hence these trees are at considerable risk in any production regime. If thinnings are proposed, their removal can be considered as avoiding mortality. The risk of multiple leader loss will increase with longer rotations.

The simplest forest regime evaluated in New Zealand has been the production of crops to satisfy export-log specifications. The combination of stem malformation on the sites concerned and, to anticipate, transfer of potential increment and stem mortality, led to formulation of a regime reducing initial stocking of 1530 to 370 stems/ha by one thinning at 10.7 m top height (Fenton and Tustin, 1972; Fenton and Dick, 1972). The profitability of this regime has been evaluated for 1967 and 1973 costs and prices; and on a range of site qualities and afforestation rates. It should be stressed these were evaluations of technical rotations. With shorter rotations and limited value/size differentials, as in some pulpwood crops, acceptance of stem malformation could lessen this motive for thinning.

Mortality Rate

The difficulties of forecasting mortality in New Zealand were stressed, although qualified trends, based on permanent sample plot data, were produced for radiata pine (Beekhuis, 1966). The utilisation of material that would otherwise die is a long-established reason for extraction-thinning.

If stand mortality is caused by inter-stand competition, it is unlikely that full potential increment is being attained on all stems. Inter-stand competition is clearly inferred. The extraction of trees "about to die", apart from its practical difficulties of identification, is intimately connected with the next topic — stand competition and growth. Mortality alone could be a facile justification for thinning.

Volume Projections

Two aspects are involved here — the competition between stems, and the redistribution of volume within a stem. These topics, particularly the former, probably form the central theme in thinning literature. A resolution of both problems is, of course, necessary before conclusive economic analyses can be made and it is highly convenient to have appropriate yield data for such less rigorous economic assessments as deciding between silvicultural regimes. These data are necessary prerequisites for any national planning; and this need is particularly urgent when exotic species are grown. Therefore, this work should have high priority in management research.

The full piece-size distribution is needed for any financial analysis involving products (even pulpwood). These have been made in New Zealand for Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) sawlog regimes (Fenton, 1967a; 1975); radiata pine export-log type regimes (Fenton and Tustin, 1972); and radiata pine sawlog regimes (Fenton, 1972) but they were again largely evaluations of technical rotations.

Preliminary studies on 200 final crop trees in thinned stands of radiata pine showed considerable changes (over 9% greater volume) in butt log form (Fenton, 1972) compared with the taper table figures for unthinned stands (Duff, 1954). These differences have a marked financial effect — in this study every extra 1 cu. ft (0.028 m^3) on a butt log was financially equivalent to doubling the pulpwood stumpage on the 15.3 cu. ft (0.433 m^3) of the toplogs (logs above 19 m on 34.5 m high trees).

Thinning Effects on Timber Quality

(a) *Branch condition*

One of the traditional justifications for dense stocking and frequent thinning operations in continental European forestry has been the self-pruning induced by dense stands, whether of hardwoods or softwoods. Results vary according to species, being best for hardwoods, but rotations are long; one result, for example, being ". . . currently unfavourable financial returns from forestry in the Federal Republic (of Germany)" (Assman, 1970). The contrast between this management and the rapid self-pruning obtained in tropical hardwood plantations at wide spacing is extreme.

This concept, however, had been implicit in some of the early hypothetical regimes proposed for New Zealand exotic softwoods. The net result has been dead branches, and hence encased knots but not clearwood if rotations are prolonged (Fenton and Familton, 1961). The retention of deep green crowns to improve timber grade returns of Corsican pine (*Pinus nigra)* was initially thought to be possible (Fenton, 1960), but this now appears to be of limited utility. So knotty-board timber-grades are affected by thinning — more open stands tending to have higher proportions of better quality face boards, but the difficulties of retaining deep green crowns and the increasing interaction of stem cone holes and the variation in branch size whereby small (ca. 1 cm) branches die, reduce the potential recovery of these grades in radiata pine (Fenton, 1967b).

(b) *Timber density*

Thinning effects on timber density are well recorded in New Zealand radiata pine (Sutton and Harris, 1973; Cown, 1974) and ". . . rapid radial growth rate has a very small depressing effect on wood density within normal limits of growth. Spacing at time of planting and thinning therefore have relatively little direct effect on wood density over a rotation" (Harris, James and Collins, 1975). The question of rotation appears to be more directly important for wood density than that of thinning intensity for radiata pine in New Zealand; high density wood only being produced after 25 years.

(c) *Timber stability*

The tendency of plantation pine timber, particularly *Pinus patula* to be unstable has been considered to be increased by Craibian-type silviculture in South Africa and there is now a reverse emphasis on evenness of growth. There has been considerable success by the South Australians in commercial practice in seasoning radiata pine, even including pith stock, without distortion; the timber originating (at least in the initial stages) from generally more densely stocked stands than in South Africa.

(d) *Branch size and timber strength*

The increase in branch size at different stocking regimes and on different sites has been quantified to some extent for different initial spacings (Sutton, 1969; 1971) and after thinning (James and Tustin, 1970) of New Zealand radiata pine. The economic answer requires, among other things, knowledge of the relative annual production of the different strength-timber-grades, and thinning intensity has a complex effect. The production of larger logs, albeit with larger branches, increases the chances of avoiding defects; some results are available for visually graded timber from Ashley Forest (Tustin, 1970) and showed about the same proportionate yield of framing grades from three different initial spacings. Greater use of stress grading machines and more grade studies can help resolve this point, and initial studies have been made in New Zealand (Knowles and James, 1973).

The weighting that should be given to the importance of branch size and condition and timber density can be resolved to some extent by the gross (roundwood) and net (volume after utilisation) volumes in the different log-height-classes. The financial studies to date reinforce the obvious — concentrate on the lowest two log-height-classes

(12-14 m) of the trees; the remainder are probably too expensive and/or difficult and/or of intrinsic low value to ameliorate. The interaction of pruning and thinning must then inevitably be considered.

Hydrological Effects

Consideration of water yields have not often been paramount in New Zealand plantation forestry. A study of a plantation established specifically for water yield showed formidably decreased yields from young dense stands of radiata pine in the district studied (Fahey, 1964). There is still lack of quantification of effects of different species and stocking regimes in forests, established as much for erosion control as for production, in the East Cape region of New Zealand, though preliminary data are published (Olsen, 1970). Generally speaking, however, water is much more abundant in New Zealand than in the other Southern Hemisphere softwood plantation countries (Australia; South Africa; East Central Africa; Chile) and the problems of increasing water yields (or reducing them as little as possible) are understandably of more importance in the drier countries. The influence of production forests on the water regime is, of course, considerable, and criteria prepared for protection forest as such (Morris, 1970) apply equally to production forests.

Price-size Gradients

If all wood units were rated as equal it would follow (a) either that all utilisation costs (logging and subsequent processing) are the same, with equal value yields, or (b) higher value yields would be needed to offset increases in utilisation costs with greater piece-size. A feasible instance could be of young wood for a refiner groundwood plant. With appropriate machinery it may cost the same to log stands of the same total volume per unit area, whether the mean tree is 30 or 45 cm d.b.h. If value gradients to be considered is volume, and volume increment. The rotation should be determined by the interaction of the interest rate on the total net production. Thinning economics, under these conditions, would be relatively easy to calculate as the future value potential would depend only on net volume; as soon as the trees are big enough to sell, and thinnings can "break-even" on direct costs; the remaining stand has to achieve a greater net value increment than that foregone by not clearfelling. The calculations should be made for the total costs and returns over the rotation; the rotation will tend to be dominated by the interest rate used.

The lack of comprehensive price size data, both for costs and returns, continues to restrict analysis in New Zealand to evaluating technical rotations. The combination of two pulp log prices, and differential felling costs, with growth projections available from correlation curve trend (CCT) plots, enabled more positive analysis of pulpwood regimes to be made in South Africa (Cawse, du Toit and Willcock, 1972). Reduction in cost per unit volume in that study was deduced to be a $7\frac{1}{2}\%$ decrease for each inch increase in mean tree diameter between 5 and 14 inches (12 to 35 cm). Even here, however, ". . . in the absence of satisfactory data the cost of thinning operations was, somewhat arbitrarily, assumed to be 25% higher than . . . (equivalent) . . . clearfelling". Over 4000 regimes were tested in the study, and the recommended schedules for the three southern pines, established at four different spacings on three site qualities (36 regimes in all), can be approximately summarised for 25 year rotations, and under the financial assumptions of the study as: 16 regimes with one extraction thinning; 7 with two extraction thinnings and 13 with none (all 2.1 m × 2.1 m and 2.4 m × 2.4 m spacings were to be thinned).

A flat value for pulpwood, but differential logging costs were used in simulation models of radiata pine afforestation in Australia (Hall, 1973); these models apparently excluded a no-thinning regime. Rotations were 20 years.

The calculations become more complex when price-size differentials exist for products, as well as costs. Differentials are used for Australian examples (Forrest, 1975), and have been reviewed (Sutton, 1973). Values for log s.e.d. classes, by 1-cm steps, are published annually for Sweden; the data for 1971 showing a general increase in price of about 25 to 35% as log s.e.d. rises from 15 to 32 cm (National Board Forestry, 1973), with a marked flattening for the top of the diameter range. The latter is explicable by the old age, and associated chances of decay in logs of this size in Sweden. Later figures from Great Britain (Anon, 1974) show much steeper gradients than in Sweden when mean log volume increases from 0.124 m^3 to over 0.425 m^3. Most Australian States have positive prize-size gradients for sawlogs.

Such a positive gradient, especially if it increases sharply with diameter, would generally help to justify thinning up to the point where between-tree competition occurs. In the case of relatively slight increases in unit value, as with the pulpwood examples cited, financial rotations inevitably become short as the thinned stand has to produce a value increment which outweighs the opportunity foregone by not clear-felling. It seems worthwhile to suggest that such a rotation should always be calculated on a "control" to find the opportunity cost foregone in profitability calculations. As soon as a stand can be clearfelled to break-even on its total costs, its retention has to achieve a greater value increment than that foregone by not clearfelling, if profitability is not to suffer. The second component of opportunity cost represented by thinning is the competitive effect of denser stocking reducing diameter growth in crop stems. The steeper the price size gradient, the greater this cost becomes.

Differential Log-haul Rates

This is another apparently straight-forward variable that is more complex on examination. In an established forest, with an existing series of major roads, the possibly greater M.A.I. obtainable by thinning can be extracted without additional roading capital cost (on appropriate topography). Thinning can benefit by being marginally costed. The opposite effect applies if utilisation begins from thinnings in a newly established forest. The lower yield per unit area results in lower loads per length of road, and a substantially greater roading requirement. In theory, an upper limit on substituting clearfelling yields for thinning (plus eventual clearfelling) yields is set when the marginal cost of producing extra wood from an additional area—which is the most remote from the utilisation point—exceeds the extra cost of producing the wood from thinnings (assuming the thinned regime produces greater M.A.I.). Such a theory presupposes a knowledge of the true optimum volume for a given utilisation plant complex, and the returns to scale for utilisation plants. The innocent looking problem of calculating log haul differentials leads directly into larger scale economic problems.

Economic Multiplier Effects of Utilisation

A parallel result comes from considering the benefits (and associated costs) of utilising wood. An established forest and industry may wish to increase its wood supply and thinning may be one apparent way of doing this. Pulp companies — being primarily concerned with volume — could consider obvious alternatives such as closer spacing and clearfelling or obtaining other wood. The extra cost, if any, of thinning can be offset by the multiplier effects of processing more wood, where these are positive in the full economic sense. The reverse applies in new afforestation — and most of the world's plantations are new afforestation. Prolonging rotations by thinning decreases the opportunity to utilise the standing volume, and the multiplier effects, etc., become a third component of opportunity cost foregone. The higher the interest rate, the greater these effects will be.

Risk of Not Thinning

A variety of forest technical troubles may follow failure to achieve thinning targets. Direct data are not available on the gap between prescription and performance in Australasian plantations, though the arrears are given in South Africa. In the South African State softwood plantations arrears generally exceeded the area actually thinned up to 1963 (The areas annually thinned, and in arrears, in South African State plantations have considerably exceeded corresponding Australasian totals in the last 15 years). Clearly the effects of this management risk must be included in economic calculations; the New Zealand State "arrears" figure would be closer to 80%, in the writer's judgment, for production thinnings. It is suggested that these results are published in future in all Australasian annual reports, as in South Africa.

Loss of Stand Area; Roading Intensity

Allowance may be necessary for loss of productive area due to roads and extraction operations, these tend to be higher as topography becomes more difficult. The effect is estimated at 3% of area for Kaingaroa Forest, the volume loss depending on whether road lines are planted or not; the reduction of final crop stems numbers being the more important financial component.

A denser network of roads would usually have some secondary advantages, and allowance for these could be made.

Stand Damage

Softwood plantation rotations are relatively short and this combined with the rapid resin flow over logging wounds appears to prevent much rot, except in susceptible species such as larch (*Larix decidua* L.). There is, however, little quantified data on either rot or other loss of value due to extraction damage. Root damage may interact with stand increment and stability, but there are apparently no data available on this aspect in Australasian conifer plantations.

Accident Rates

It has not been possible to obtain relative figures on the accident rate in thinning and clearfelling. Logging in general is three to five times more dangerous than the next most risky industry in New Zealand and it is feasible that there are differential accident rates. Thinning is, after all, a more complicated operation than clearfelling and there is often a greater chance of working under danger. The injury severity and financial loss should be calculated per unit volume and value of production.

Local Influences

Though termed "local" these influences may be dominant in any management regime. Wind is obviously an inter-related influence—too dense a stand initially may introduce marked limitations on future stocking regimes. It seems likely that the earlier that stands are opened up, the greater the chance of developing extensive root systems. The chances of stem-break, as against windfall, presumably depend on the interaction of wood density, branch size and stem diameter.

Accumulation of fuel from thinning debris can give rise to an increased fire risk until the slash rots. Similar qualifications can be added for most local influences.

The need to suppress competing vegetation may require denser tree stocking in some areas. By contrast, stimulus of other vegetation may be needed for regimes encouraging animals (wild or domestic). Where amenity is a dominant aim of management only open canopies may be tolerated. Topography, of course, presents no theoretical barrier even to production thinning; clearfelling systems are illegal in Swiss State and local body forests, for example—all timber is extracted by thinning. Understandably, many of these forests are on steep sites. The problem then becomes one of determining the economic cost of extracting material from progressively more difficult sites.

DISCUSSION

The points listed above would all need consideration before a full economic basis existed to justify thinning. While it is not surprising that this basis hardly exists, owing to the comprehensive data needed, it does raise the opposite question as to how good are the arguments for thinning? Both Australia and New Zealand are planning for export surpluses of softwood, and, in New Zealand's case at least, the supply side of this programme will certainly be affected by the management regimes adopted. The most important question for any established stand will be when to clearfell, and the rotations can be greatly influenced by the thinning regime. The writer suspects many thinning operations are prescribed from habit, or early training. It is noticeable that the proportion of roundwood obtained from clearfelling in Sweden, for example, has increased from 42 to 69% in the period 1960/61 to 1970/71 (National Board of Forestry, 1973). It is reiterated that the more complex operation needs justification and this should cover the points mentioned earlier.

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