PRODUCTIVITY OF COMMERCIAL THINNING OPERATIONS IN QUEENSLAND PLANTATIONS: INFLUENCE OF ALTERNATIVE SILVICULTURAL OPTIONS

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ABSTRACT

Changes in silvicultural practices (for instance, initial spacing, pre-commercial thinning, and row thinning) alter a number of stand characteristics, including average stem size, branching habit, and yield. These in turn exert a direct influence on harvesting productivity and consequently on costs.

INTRODUCTION

Plantation management objectives determine the "brand" of silviculture practised. Once production goals are formalised, including decisions on plantation siting, budgeting, and end-product usage, silvicultural options available in the crop-growing phase can be examined taking due cognisance of residual effects applying in the crop-harvesting phase.

Management of State-owned plantations in Queensland aims in part at:

(a) Ensuring the State gains self-sufficiency in wood commodities (other than pulp and paper);
(b) Decentralisation of population and industry;
(c) Production of high-quality veneer and sawlog material;
(d) Establishment of a pulp industry resource in the south-east coastal region;
(e) Operational efficiency through mechanisation of establishment, maintenance, and thinning operations.

These objectives have led to the establishment of both native (primarily hoop pine (*Araucaria cunninghamii* Ait. ex D. Don)) and introduced (mainly slash pine (*Pinus elliottii* Engelm.) and Caribbean pine (*Pinus caribaea* Morelet)) conifer estates along the coastal fringe with a more recent concentration on exotics in the south-east (Fig. 1). The resource as at March 1981 comprised 41 710 ha of native pines and 89 337 ha of exotic pines. Silvicultural options adopted locally, especially with regard to intensive site preparation, wide initial spacing, selective use of pre-commercial thinning, a commitment to green-crown pruning, and production thinning on an optimum basal area

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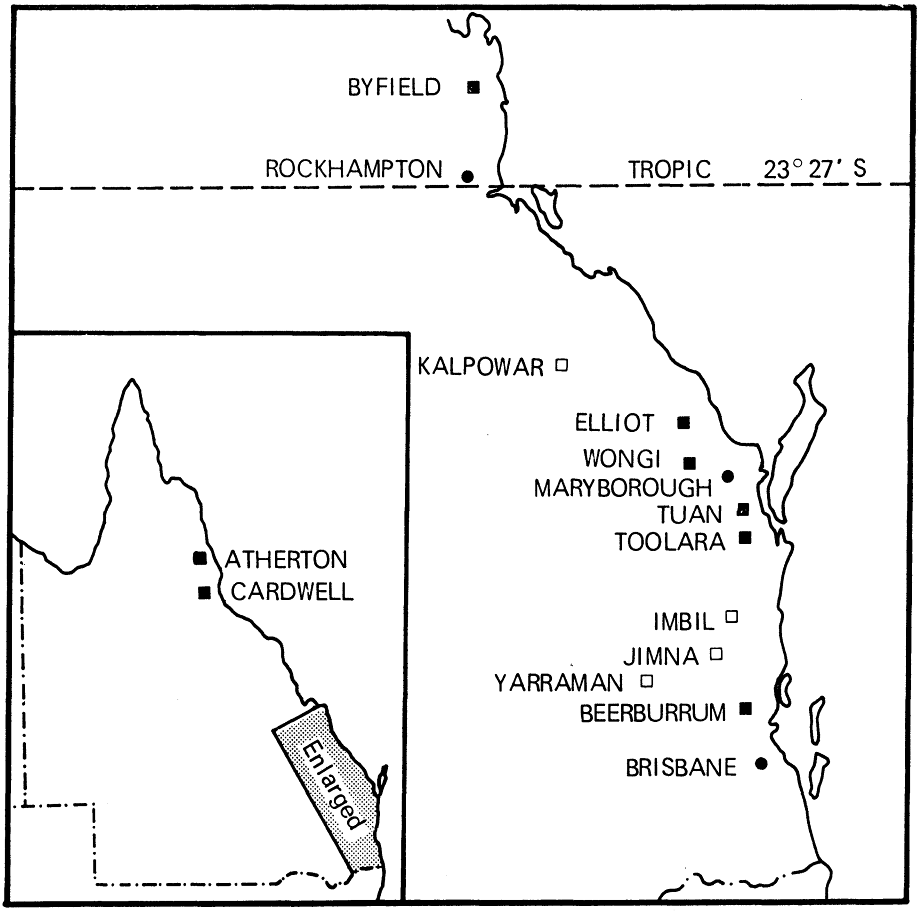

FIG. 1—Location of the major **Araucaria** (□) and **Pinus** (■) plantations in Queensland.

basis, have all recognised these particular goals (Hawkins & Muir 1968; Robinson 1968; Hawkins *et al.* 1978; Shea *et al.* 1979; Reilly 1980).

Silvicultural choices and techniques used in meeting over-all management goals and constraints must also promote efficiency in harvesting operations. The study reported here attempted to identify the relationship between silvicultural options available and harvesting (thinning) productivity.

SILVICULTURAL OPTIONS

The influence of silvicultural practices on logging productivity in plantations is often a mediated one. Certain stand characteristics (for instance, degree of ground debris, row width, average stem volume, green crown level, branch size, and available yield) directly affect the efficiency of harvesting operations and these effects will be examined later. It is through induced changes in these stand characteristics that selected silvicultural options exert their ultimate influence on harvesting productivity and costs.

Species Selection

The species in demand is generally that which maximises merchantable volume productivity and wood quality on a given site. The plantation establishment programme commenced in Queensland in the early 1920s using hoop pine on fertile, mountain-rainforest soils. The programme was extended in the early 1930s to the infertile, coastal, lowland soils using slash pine (Robinson 1968). Caribbean pine was introduced in the late 1940s. Slash pine cannot be successfully grown north of 25° 30′ S, largely because of summer-induced dormancy, and even in the south-east Caribbean pine is a more productive species on well-drained sites. In quantifying this growth superiority Smith (1973) recorded an average 35% merchantable-volume and 22% dry-weight yield advantage for Caribbean pine at age 19 years. Nevertheless, Caribbean pine was not completely accepted until stem straightness and wind firmness were markedly improved by genetic selection. This gradual change to Caribbean pine as the premier planting species on the coastal lowlands has resulted in improved thinning yields, larger sized thinnings, and a reduction in branch size (Caribbean pine is a more finely limbed species than slash pine).

Site Preparation

All exotic pine planting areas are intensively prepared by tractor clearing, windrowing of debris, burning of debris, and complete ploughing (Bacon 1975). A combination of macro-site drainage through the establishment of defined water courses and micro-site drainage by mound-ploughing techniques has significantly raised slash pine volume productivity on local swamp sites which comprise about 40% of the plantable area (Pegg 1967). Increasing the size of the mound profile (i.e., high mounding) now permits the successful establishment of Caribbean pine on wet sites (Table 1). Intensive site preparation as described reduces ground debris to a minimum. Routine fertiliser application at planting also promotes individual tree and stand volume productivity (Bevege 1975).

TABLE 1—Development of 8-year-old Caribbean pine on a Byfield ground water podzol (swamp site)

Site preparation	Stems /ha	Pred. Ht. (m)	Basal area (m^2/ha)	Total vol. (m^3/ha)
Major drainage + high mounding	1048	12.3	18.17	56.9
Major drainage only	976	8.4	9.90	22.8

Initial Spacing

Stem size

No consistent relationship between stand height and stocking has been recorded in Queensland trials (Table 2) or elsewhere (Smith & Anderson 1977), but it is usually safe to assume a constant or slightly improved height development with wider spacings. There is, however, no doubt about the significant positive response of diameter growth with wider spacings,

$$Y = 63.035 - 13.852\ x \text{ (hoop pine, age 22)}$$
$$Y = 64.202 - 14.321\ x \text{ (Caribbean pine, age 9)}$$
$$Y = 57.305 - 12.282\ x \text{ (slash pine, age 11)}$$

where Y = diameter at breast height (d.b.h.) (cm)
x = $\log_{10}$ stocking (stems/ha).

The combined height and diameter response is manifest in a marked increase in average stem volume (Table 2).

Wider spacings not only lead to larger stems, but it can also be demonstrated, with separate criteria, that uniformity in crop size is improved (Table 3).

Branching habit

Branch size and longevity (in the absence of green crown pruning) are increased as stocking is reduced (Table 4).

Stand productivity

There is a loss in merchantable volume productivity at time of first thinning, associated with wide initial spacings (Table 5). The extent of this loss is dependent on species and stand location, being higher for Pinus in the tropical north. It should be noted that this volume reduction occurs primarily in the poorer, smaller sized fraction of the stand; where a size price gradient exists, as in Queensland (Anderson *et al.* 1981), gains made in average stem size ensure dollar returns are maximised at wider spacings (>3.0 m^2) under a sawlog regime.

TABLE 2—Effects of initial spacing on tree size

	Spacing (m^2)					
	1.8	2.1	2.4	2.7	3.0	3.7
Hoop pine, Yarraman, age 21						
Pred. Ht. (m)	—	19.7	—	19.9	19.7	19.6
d.b.h. (cm)	—	17.9	—	19.6	21.4	24.1
A.S.V.* (m^3)	—	0.142	—	0.176	0.219	0.288
Caribbean pine, Byfield, age 9						
Pred. Ht. (m)	—	16.5	17.7	18.0	17.6	18.0
d.b.h. (cm)	—	17.0	18.9	20.0	21.5	23.3
A.S.V.† (m^3)	—	0.128	0.164	0.176	0.186	0.215
Slash pine, Beerburrum, age 10						
Pred.Ht.(m)	14.7	15.2	15.2	15.8	15.9	—
d.b.h. (cm)	15.0	16.4	17.9	19.0	20.3	—
A.S.V.† (m^3)	0.094	0.121	0.148	0.168	0.194	—

* Average stem volume of all stems

† Average stem volume of pruned stems

TABLE 3—Variability in stem size of 9-year-old Caribbean pine as influenced by initial spacing

Variability criteria	Spacing (m^2) 2.1	 3.7
Coefficient of variation (%)*:		
d.b.h. distribution	19.9	11.0
Total height distribution	14.3	9.5
Selection ratio†	1.45	1.11

* Calculated as standard deviation/mean

† Calculated as mean BA pruned stems/mean BA whole stand.

TABLE 4—Branch and crown characteristics as influenced by initial spacing*

Species	Age (years)	Spacing (m^2)	Green crown length (m)	Green crown (%)	Branch diam. (cm)
Caribbean pine	10	2.1	6.0	38.6	2.2
		2.4	7.1	42.0	2.3
		2.7	7.8	44.4	2.6
		3.0	8.0	45.3	2.6
		3.7	9.1	49.5	2.8
Slash pine	9	1.8	5.2	47.2	2.0
		2.1	5.8	51.3	2.3
		2.4	6.2	53.5	2.4
		2.7	6.6	55.7	2.6
		3.0	6.9	57.8	2.8
Hoop pine	17/28†	2.6	7.3		3.4
		3.3	8.7		3.6
		3.8	11.6		3.6
		4.7	11.1		4.1

* Data from Fisher (1978), Powell (1979), and Gordon (1980)

† Green crown length at age 28, branch diameter at age 17 years.

TABLE 5—Volume losses (m^3/ha) at first thinning, associated with wide initial spacings

	Spacing (m^2) 2.1	 2.4	 2.7	 3.0	 3.7
Caribbean pine (Cardwell)	0	3	11	21	38
Caribbean pine (Byfield)	3	0	2	8	23
Slash pine (Beerburrum)	15	4	0	2	10
Hoop pine (Yarraman)	0	2	6	15	31

Weed Control

Limiting lantana (*Lantana camara* L.) development in hoop pine plantations is the most important weed control measure adopted locally for access. Regeneration and colonisation peak after ground disturbance and entry of light associated with establishment and thinning. Extension of thinning intervals, retention of higher residual basal areas, and provision of tractor-pushed access tracks prior to thinning are means of reducing dependence on frequent herbicide application.

Pre-commercial Thinning

Provided pre-commercial thinning is completed prior to the onset of stand competition, responses are identical to those recorded at initial spacings of comparable stocking. Hence as the intensity of thinning increases, the greater is the improvement effected in stem size and stumpage value (Table 6). A volume productivity reduction, primarily in the pulp fraction, accompanies an increase in pre-commercial thinning intensity.

TABLE 6—Caribbean pine stand development after early pre-commercial thinning

Stand location	Age (yrs)	Residual stocking (stems/ha)	d.b.h. (cm)	Av. stem volume (m^3)	Sawlog volume* (m^3/ha)	Pulp volume† (m^3/ha)	Total value‡ (A$/ha)
Byfield	21	1400	28.3	0.528	409.5	34.1	3423
		1000	28.7	0.601	381.7	26.6	3326
		740	31.8	0.722	377.4	5.6	3687
Beerburrum	27	1500	34.0	0.661	373.6	75.0	4257
		1100	35.8	0.773	394.6	33.9	4627
		860	39.5	0.955	389.8	26.6	5197

* Sawlog = >22 cm d.b.h.o.b. to 10 cm top diam. under bark.
† Pulp = 12–22 cm d.b.h.o.b. to 7 cm top diam. under bark.
‡ 1978 values.

Green Crown Pruning

Selection rates (250 to 400 stems/ha) and final pruned height (4.8 to 6.4 m) have varied over the years but there has always been a firm commitment to the maintenance of a substantial pruning programme in both native and exotic plantations in Queensland (Robinson 1968). This has had a direct effect on thinning practice. Selection thinning has been directed at the maximum release of select stems by the removal of the worst other-than-select stem competitors during the early thinnings. The aim in exotic pine areas, for instance, is to remove all non-select stems during the three thinning stages that precede the clearfelling of the final crop. Row thinning of previously pruned stands can result in unacceptable losses of these "select" stems unless flexible outrows are permitted (Table 7). Rows that will be later used for outrow thinning are now excluded from pruning.

TABLE 7—High-pruned (select) stems lost in various thinning operations

Thinning treatment	Selects lost (%)		
	Trial 1	Trial 2	Trial 3
Straight 1 in 3	34.8	—	38.9
Straight 1 in 4	—	—	24.2
Straight 1 in 5 + selection	17.3	21.0	18.2
Flexible 1 in 5 + selection	3.7	—	—
Straight 1 in 10	—	6.3	—
Selection	0	—	0

Thinning

Thinning alternatives available include direct or commercial thinning regimes, and selection or row thinning.

Direct thinning regimes involving heavy, early, pre-commercial thinning (residual stockings 200–400 stems/ha) and a clearfelling (McKinnell 1981) are currently under test with Caribbean pine in north Queensland where no smallwood market currently exists. Local commercial thinning regimes are aimed at maintaining stand basal area within limits that maximise basal area and volume increment. For example, slash pine limits are OBA ± 30%,

where OBA (optimum basal area) = 0.89 Site Index + 8.1

An added aim is for the thinning yield to reach a minimum 50 m^3/ha. Mortality, accentuated by drought conditions, has been recorded in slash pine stands where basal area exceeded 40 m^2/ha at Beerburrum and 35 m^2/ha at Tuan. In contrast, Caribbean pine at Byfield has shown no ill effects growing at 70 m^2/ha. At this centre there is evidence that commercial thinning about a putative OBA has offered no consistent volume or value productivity advantage over regimes that permitted unrestricted basal area build-up after early pre-commercial thinning to 720 stems/ha (Anderson *et al.* 1981),

$$MV = -593.00 + 2.88\ BA + 30.68\ SI$$

$$DV = -7134.82 + 2.13\ BA + 335.25\ SI$$

where MV = merchantable volume (m^3/ha)
DV = discounted value ($/ha)
BA = basal area
SI = site index

Again, average stem size is negatively correlated with stand stocking.

In a row-thinning operation average stem size of removals is usually bigger than in a comparable (same residual basal area) selection thinning (Table 8) since the latter largely concentrates on removing the poorest fraction of the stand (Table 9). Retention of more small-sized stems in a row-thinned stand can lead to a reduction in post-thinning stand productivity, though the volume reduction in local trials has not exceeeded

7% to date (Table 10). Trees growing adjacent to outrows are advantaged to a small extent (0.1 cm d.b.h./year) compared with bays trees. Selection thinning within the bays reduces this advantage.

TABLE 8—Average stem volumes of slash pine removals under different thinning regimes (stand age 12 years)

Thinning regime	ASV (m^3)
Straight 1 in 3	0.151
Straight 1 in 5 + selection	0.147
Flexible 1 in 5 + selection	0.140
Selection	0.139

ASV = average stem volume

TABLE 9—Removal of small-sized Caribbean pine stems under different thinning regimes (stand age 11 years)

Thinning regime	Percentage trees in original stand <20 cm d.b.h.	Percentage trees <20 cm d.b.h. removed in thinning
Straight 1 in 3	23.3	26.7
Selection	22.6	85.2
Straight 1 in 4	21.9	25.5
Selection	19.1	63.3

TABLE 10—Loss in stand productivity after a first (row) thinning, expressed as a percentage of increment occurring in selection-only thinned stands

Trial	Loss in merch. vol. (%)			Loss in basal area (%)		
	1 in 3	1 in 4	1 in 5 + sel	1 in 3	1 in 4	1 in 5 + sel
A	0	21.0	+2.6	4.8	12.4	7.4
B	2.3	—	+2.5	4.9	—	+8.7
C	+1.7	1.2	+2.6	+8.2	+3.2	+3.4

A = Caribbean pine, 3.0 × 2.7 m, Byfield, loss 3 years after thinning
B = Slash pine, 2.4 × 2.4 m, Beerburrum, loss 4 years after thinning
C = Slash pine, 3.0 × 2.7 m, Toolara, loss 2 years after thinning

INPUTS INTO HARVESTING (THINNING) PRODUCTIVITY

Site Preparation

Ground debris

The amount of hardwood debris on the forest floor is dependent on the type of original vegetation, and the clearing and site-preparation techniques used.

The presence of ground debris will increase the cost of any skidding operation but becomes particularly important in the more mechanised harvesting systems. A Windsor Harvester, for example, operating in first thinnings in slash pine required hardwood logs to be crosscut and stumps to be cut off at 25 cm above ground level. This operation accounted for 0.14 man-hours/m^3 of thinnings produced (Hawkins & Rees 1976).

High mounds

At the time of construction, high mounds are up to 70 cm in height; however, after settling they decrease to 50 cm prior to first thinning. This has several implications for mechanical harvesting. For selection thinning the machine will have to cross mounds frequently and will therefore require a carefully engineered suspension system to prevent undue stress on both the machine and the operator. For row thinning the machine will have to straddle the mound. Table 11 shows the width and clearance of machines of current and potential use in mounded areas in Queensland.

The effect of high mounds on harvesting operations has not been fully researched, but trials are planned for the near future.

TABLE 11—Machine clearance and width specifications

Machine	Clearance (cm)	Width (m)
Mercedes MB Trac 800 wheeled tractor	51	2.2
Massey Ferguson 575 wheeled tractor	47	2.3
Bell Infield Logger	45	2.6
John Deere 550 Crawler	36	2.4
John Deere 745 Tree Harvester	59	3.2
National Hydro-ax	43	2.4

Weed Control

The major effect of weed (in particular lantana) infestation on harvesting is reduced access mainly at the felling stage where it increases:

(a) The time taken to clear around the tree;

(b) The difficulty in seeing the desired direction of fall as well as the next tree to be cut;

(c) The safety risk to the feller.

One alternative to lantana control is to allow the weed to develop, and then construct access tracks immediately prior to harvesting. Recent trials have shown that in a hoop pine stand being reduced from 284 trees/ha small crawler tracks are required only every two or three rows through 4-m tall lantana. The tracks cost A$20/ha, a small fraction of the cost of maintaining the area clear of lantana by chemical tending.

Row Widths

Wide initial spacings are of advantage in harvesting operations, particularly in selection-only thinning, because of the easier access they afford. Comparison of machine widths from Table 11 with the spacings in Table 5 shows that, without a fifth or third outrow for access, spacings of 2.1 m^2 and 2.4 m^2 present definite problems for both wheeled and tracked skidding machines, and 2.7 m^2 may not be wide enough for some machines which show potential, e.g., Bell Infield Logger and Hydro-ax Feller-Buncher.

Pruning

A commitment to pruning necessitates selection thinning, i.e., the removal of competing non-select stems. This complicates the introduction of the more efficient row-thinning methods. Flexible outrows were initially used to minimise premature select stem removal. Currently, trees in rows that will later be used in row thinning are not pruned.

Average Stem Volume

Average stem volume has direct influence on harvesting productivity and costs because most logging systems are oriented toward handling set numbers of trees per hour regardless (within design limits) of volume. The various phases of harvesting may be considered separately.

Chainsaw felling, delimbing, and bucking

The relationships between productivity and tree volume for first thinning of both slash pine and radiata pine (*Pinus radiata* D. Don) are very similar (Fig. 2). The vertical displacement is probably caused by the more persistent limbs on radiata pine and different conditions of slope. The reason for the steep rise in time per cubic metre below a certain average stem volume is the increased portion of time spent on delimbing small trees. The point where productivity starts to decrease steeply lies somewhere between 0.10 m^3 and 0.15 m^3 in slash pine, depending on the "limbiness" of the trees and the amount of bucking required.

Feller-buncher and delimber

Table 12 illustrates the positive relationship between productivity and stem size for a Boschen Feller-Buncher and "Clever-Hole" delimber operating in an outrow-only situation in 15-year-old slash pine.

Whole-tree processor

There are no processors working in Queensland at present. Data from Victoria (Table 13) show a similar pattern to that given by the feller-buncher/delimber system. As average stem volume rises, the number of stems processed per hour decreases, while the volume per hour increases.

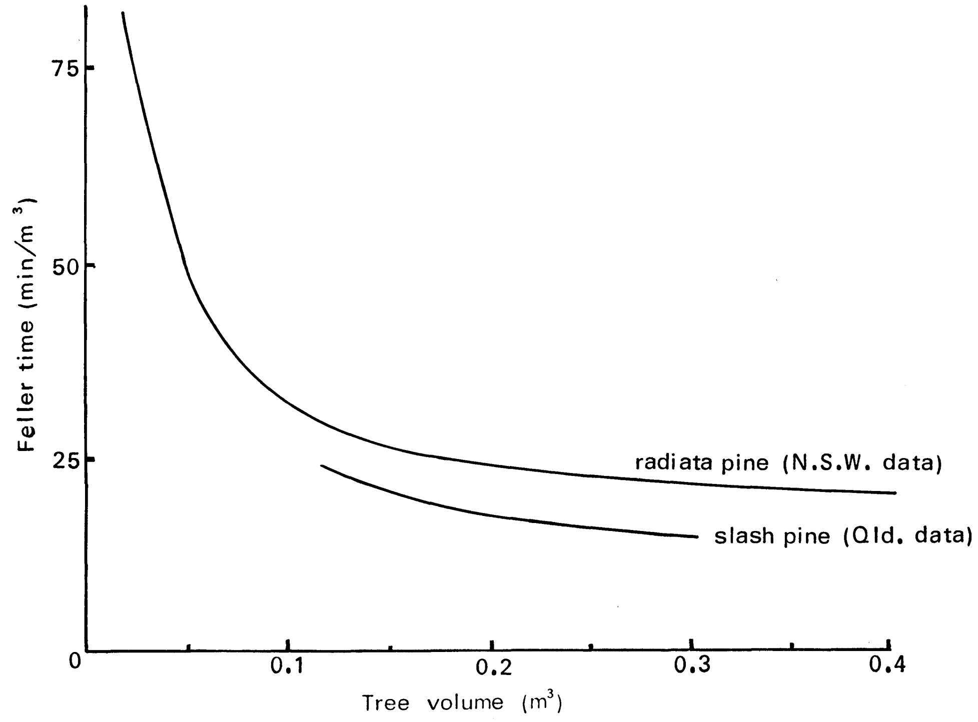

FIG. 2—Feller production time as influenced by tree size.

Haulage within stand

There are no Queensland data available showing the effect of average stem volume on haulage; however, overseas experience (Mackintosh & Bunn 1976) shows that productivity will increase with average stem volume (Fig. 3).

TABLE 12—Productivities for Boschen Feller-Buncher and "Clever-Hole" delimber

Average stem volume (m^3)	Trees per productive machine hour	Vol. (m^3) per productive machine hour
0.128	132.7	16.98
0.129	133.4	17.22
0.142	130.7	18.56

Stage of Thinning

Given the effect of average stem volume on the individual phases of harvesting, the gains in productivity and economy that later thinnings and clearfelled material offer become evident. Roughana (1981) has attempted to quantify these gains for radiata pine (Table 14). These figures would not be dependent solely on average stem volume because the extra working space available in later thinnings and clearfelling would also assist productivity levels.

TABLE 13—Estimated long-term productivity of a T310 processor on general terrain*

Average stem volume (m^3)	Trees per productive machine hour	Vol. (m^3) per productive machine hour
0.16	71.06	11.37
0.26	60.63	15.77
0.36	52.88	19.04
0.46	46.88	21.56
0.56	42.11	23.58
0.66	38.22	25.22

* Raymond (1979)

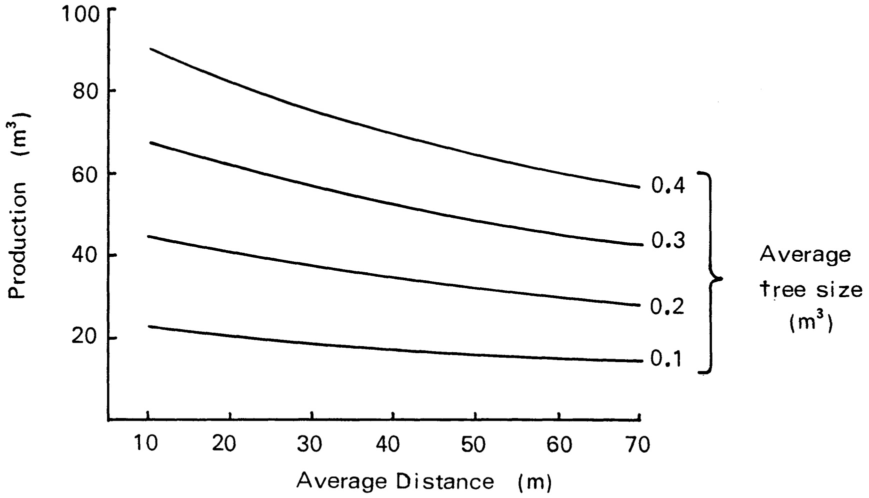

FIG. 3—Effect of tree size and haul distance on daily production (after Mackintosh & Bunn 1976).

TABLE 14—Average felling and extraction costs in radiata pine*

Operation	A$/m^3$	Percentage of clearfelling cost
First thinning	5.50	275
Second thinning	3.60	180
Third thinning	2.30	115
Clearfelling	2.00	100

* Roughana (1981)

Stem Uniformity

The advantages in uniformity of crop size become most significant when mechanised harvesting methods are used. Consistency of size allows for the optimum equipment choice for that average size, with little possibility of stem sizes outside the design limits of the machine. The result is that oversized equipment need not be used for early thinning operations and over-capitalisation, the downfall of many contractors, can be avoided.

Branch Size and Green Crown Depth

The *Pinus* species commonly used in Queensland do not have the large branch and persistent cone problems associated with radiata pine especially at wide spacings (Fenton 1976). As a result, inexpensive grid delimbers and gate delimbers which could not be contemplated in radiata pine areas are used extensively in Queensland, with obvious economic advantages over the more sophisticated delimbing machines.

The basis of most delimbing devices in Queensland is that branches will snap off when the tree or group of trees is pushed through a small opening. The cost saving is not just in the low cost of the equipment but also the ability to delimb more than one tree at a time. With the Boschen system, for example, the feller-buncher places the whole bunch into the "Clever-Hole" delimber where it is delimbed as one unit.

Yield

Studies have shown that up to a limiting point, as yield per hectare is increased at a particular thinning stage, so harvesting and marketing productivity will increase. Table 15 shows the results of separate trials of skidding hoop pine with a wheeled tractor and with a crawler. Indications are that gains in productivity will taper off for the skidding operation, because of the increased ground debris and disorientation of felled stems when thinning yields approach 80 m^3/ha.

If the forest owner does decide to carry out heavier or later thinnings then he will gain through higher tree-marking productivities, i.e., lower costs per cubic metre, and the purchaser will gain through lower skidding costs per cubic metre.

TABLE 15—Effect of yield per hectare on tree marking and tractor productivities in second thinning of hoop pine

Wheeled tractor			
Yield (m^3/ha)	65	50	35
Tree-marking productivity (m^3/man-hour)	8.9	7.7	6.5
Wheeled tractor productivity (m^3/hr)	7.0	6.6	6.3
Crawler tractor			
Yield (m^3/ha)	80	65	50
Tree-marking productivity (m^3/man-hour)	8.3	8.3	5.3
Crawler tractor productivity (m^3/hr)	7.8	7.4	5.3

Row Thinning

Options include outrow only, selection only, or a combination of the two. The preferred system for first thinnings in Queensland is fifth row out with selection between the outrows.

Tree-marking productivity improves in an outrow thinning situation (Table 16). A separate local study found a 3.3% gain in harvesting productivity for outrow thinning compared to outrow plus selection thinning,

$$\gamma\text{SEL} = 115.290\ x + 1.726$$

$$\gamma\text{OUT} = 108.689\ x + 3.131$$

where γ SEL, γ OUT = production rate (m^3/ha) for selection thinning and outrow thinning respectively

x = average stem volume (m^3).

Further trials are planned as outrow thinning does increase access to the compartment and allows the use of wider machines in the forest.

TABLE 16—Relative tree-marking productivities for first thinning in slash pine

Treatment	Tree marking productivity (%)
Third row only	220
Straight fifth row + selection	139
Flexible fifth row + selection	99
Selection	100

CONCLUSIONS

Recognition of the effects various silvicultural practices ultimately (i.e., in some instances via a primary influence on stand characteristics such as average stem volume) have on the productivity of thinning operations has certainly influenced local procedures. We would highlight the following practices as particular examples:

- Use of intensive site-preparation methods to provide a plantation floor free of original forest debris and to increase average stem volume.
- Acceptance of lower initial stockings (1000 stems/ha) and pre-commercial thinning (minimum 600 stems/ha) during the early free growth period to provide increased average stem volumes at all thinning stages.
- Provision for row thinning at the first thinning stage to provide increased unit yields, improved machine and tree-marking productivities, and larger average stem volumes despite a commitment to green crown pruning and a continuing need for some selection thinning.

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