THINNING PRACTICES IN AUSTRALIA — A REVIEW OF SILVICULTURAL AND HARVESTING TRENDS

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ABSTRACT

Changes in harvesting technology in Australia have been characterised by both the training of a more skilled work-force and the introduction, on an operational basis, of fully mechanised means of harvesting small thinnings. The range of opportunities to sell smallwood has led to considerable divergence in silvicultural practice. Rising costs of handling small thinnings and poor market conditions for these products in some areas have encouraged the development of silvicultural schedules which minimise smallwood in commercial operations. Tasmania and Western Australia have tended towards policies that embrace the more radical approaches stemming from New Zealand, while other States have maintained more conventional schedules.

INTRODUCTION

Previous reviews of developments in silvicultural practice and the associated harvesting of thinnings in coniferous plantations in Australia have been produced by Shepherd (1969), Brown (1976), and Kerruish (1976). The changes which have occurred since the last major review have been influenced by such factors as the rapidly changing world economic environment, marked changes in the Australian market for smallwood, and complex changes in labour availability. The Australian plantation resource is now 6 years older, and so silviculturists and harvesting strategists are less preoccupied with smallwood and are giving more attention to integrated operations in later thinnings. This change in preoccupations has been influenced by substantial changes in the use of sawmill wastes, and by a preference for older wood in some pulping processes. Rapidly changing marketing prospects have also had an influence in that plantation products are beginning to find export markets rather than being used only within Australia.

The plantation land base, in terms of both availability and productive capacity, varies widely throughout Australia with corresponding implications for silvicultural practice. For example, in South Australia an established complex of wood-processing industries is dependent on the continued productivity of a now limited land base. In contrast, the Tumut group of plantations in New South Wales still has considerable scope for expansion in area and is not so threatened by productivity constraints. Pressures for the conservation and use of non-wood products of the forest, such as recreation or water yield, are in some instances imposing constraints on expansion in both area and productivity.

Much greater emphasis may need to be given to biological considerations where the area and potential productivity of the land base are constrained. Several papers presented to the 1975 IUFRO meeting on thinning drew attention to possible problem areas (Butcher & Havel 1976; Heather 1976; Shepherd 1976). During the intervening 6 years a number of these have assumed greater importance in plantation forest management – for example, the problems associated with the spread of the wood wasp *Sirex noctilio* Fabricius (Neumann & Minko 1981) and the long-standing problem of minimising the possibilities of productivity decline in the second rotation (Woods 1976; Squire *et al.* 1979).

There was widely held concern at the time of the previous meeting that it would not be possible to thin our plantations (according to the silvicultural prescriptions then held to be desirable) on the scale required. Of the harvesting techniques discussed, most were based on motor-manual methods (Chandler 1976; Cole 1976; Grayburn 1976; MacIntosh & Bunn 1976). Only the papers of Kerruish (1976) and Raymond (1975) were concerned with mechanical harvesting of thinnings. In the intervening years motor-manual techniques have developed substantially; at the same time, there has been widespread adoption of mechanised harvesting of first thinnings. These developments have made it possible to thin on a large scale as required, so as to be able to meet both forest management and industry needs. What is now required is a critical evaluation of the performance of these systems in economic terms, in relation to aspects of environmental impact and to long-term site productivity. The present meeting will, no doubt, attempt to answer a number of the economic problems and touch on the problems likely to emerge from the use of high levels of mechanisation in intensively managed plantations.

SIGNIFICANT CHANGES IN PLANTATION FORESTRY

The most significant feature of Australian plantation forestry over the past decade has been the continued high rate of annual plantings. The high planting rates of the early 1970s have been sustained (Fig. 1) in spite of less Australian Government support through the Softwoods Agreement Act and recommendations from the Bureau of Agricultural Economics for reduced plantings to meet aims of national self-sufficiency (Bureau of Agricultural Economics 1977; Treadwell 1978).

A number of points of interest arise out of an analysis of Fig. 1 (Table 1). From this we see that almost half of the plantation estate is aged 10 years or less. A second point to note is the relatively small area of plantation aged 30–40 years, a result of the cessation of most planting during World War II, 1939–45. This shortage of mature plantation was accentuated in New South Wales by a moratorium on planting *Pinus radiata* D. Don for a decade from 1935, pending the results of an investigation of the

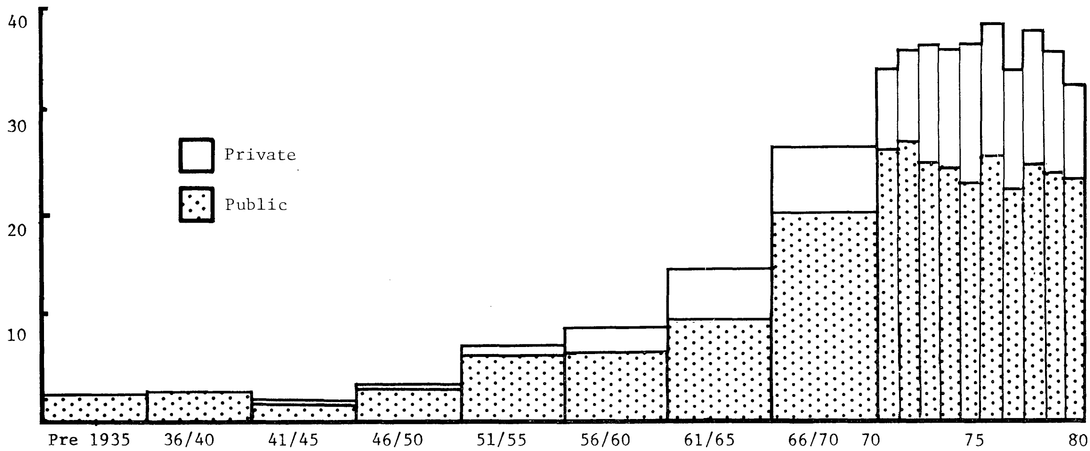

FIG. 1—Areas of coniferous plantation established in Australia (000 ha)
Source: Forestry Branch, Department of Primary Industry

TABLE 1—Australian plantation forest resource (by age-classes)

Age	Area (ha)	Area (%)
< 10 years old	351 467	49.5
10–19 years old	205 432	28.9
20–29 years old	82 317	11.6
30–39 years old	28 864	4.1
> 39 years old	41 638	5.9
Total	709 719	100.0

poor performance of this species in some of the plantings dating back to 1921. Of the total plantation estate some 27.5% is privately owned (as at 30 March 1979), with much of this area administered by three companies – APM Forests Pty Ltd, Softwood Holdings, and Southern Australia Perpetual Forests Ltd.

Of interest also is the species mix represented in the Australian plantation estate (Table 2). Almost 71% of the total area planted is *P. radiata*, with most of this concentrated in New South Wales (21%), Victoria (22%), and South Australia (12%). *Pinus elliottii* Engelm. (14.5%) is the next most important species; most of this is planted in Queensland, as is the *P. caribaea* Morelet (2.3%) and *Araucaria* (6%). In recent years the trend has been towards increased plantings of *P. caribaea* in mid and northern Queensland coastal regions together with somewhat reduced plantings of *Araucaria*. The only other single species of any significance is *P. pinaster* Ait. (4.2%), most of which is planted on the Swan coastal plain north of Perth in Western Australia. Plantings of this species also have declined in recent years.

TABLE 2—Areas (ha) of coniferous plantation established in Australia (by species)

Species	Pre-'35	1936–40	1941–45	1946–50	1951–55	1956–60	1961–65	1966–70	1971–75	1976–80	Total
Pinus radiata	17 885	7 966	6 840	12 211	21 444	29 516	52 428	92 961	127 592	133 847	502 690
Pinus elliottii	485	579	351	1 328	6 675	9 150	9 724	20 949	27 875	25 463	102 579
Pinus caribaea	—	34	5	130	312	459	1 421	2 787	3 647	7 687	16 482
Pinus pinaster	2 288	486	212	435	2 796	2 614	3 830	6 745	6 072	4 397	29 875
Araucaria spp.	2 211	3 413	2 281	3 703	4 132	3 644	4 924	6 787	7 214	4 698	43 007
Other species	2 311	3 980	517	852	1 042	533	1 057	1 819	2 088	887	15 086
Totals	25 180	16 458	10 206	18 659	36 401	45 916	73 384	132 048	174 488	176 979	709 719

Source: Forestry Branch, Department of Primary Industry

A recent development in plantation forestry in Australia has been the clearfelling of first-rotation forest in significant areas with, in most instances, replacement by a second rotation of *P. radiata.* Much of this area is being re-established by planting but significant areas have been allowed to regenerate naturally. By the end of the decade 1970–80 the area being clearfelled annually and replaced by second-rotation crops had risen rapidly from around 800–1000 ha in 1977 to a little more than 2000 ha. From the early 1980s onwards much of the establishment in South Australia for the Woods and Forests Department will be second rotation as relatively little plantable land can now be bought to add to the plantation estate.

A major preoccupation of plantation forestry over the last decade has been to minimise the possibilities of a decline in productivity in the second and subsequent rotations. Such a possibility was first reported from South Australia (Keeves 1966; Bednall 1968) and resulted in considerable research effort being devoted to the problem. Several recent papers have reported the results of this research, notably work leading to the development of the so-called "maximum growth sequence" for establishment in South Australia (Woods 1976) and work in Victoria seeking to minimise site disturbance between rotations by excluding burning of logging debris as a management tool (Squire *et al.* 1979).

Considerable attention has been given to nutritional and fertiliser aspects of plantation practice, both for first and for subsequent rotations (Boardman 1974; Woods 1976; Neilsen & Crane 1977; Flinn *et al.* 1979; Crane & Raison 1980; Boardman & Simpson 1981; Neilsen *et al.* 1981; Waring 1981). Fertiliser is applied at establishment and then later as routine practice in many operations and the placement of that fertiliser has been made very precise to maximise possible benefits to the planted seedling (Woods 1976). Recognition also of the significance of weed competition in limiting these potential fertiliser benefits (Woods 1976; Waring 1981) has led to the widescale use of herbicides as a routine part of establishment practice (McKinnell 1975; Eilert 1979).

A major portion of current plantings in the four main species (*P. radiata, P. elliottii, P. caribaea,* and *P. pinaster*) is with seedlings raised from seed orchard seed. Improvement in a number of economically important characters is assured with such planting stock; these characters include stem straightness, numbers of multiple stems, branch character, and growth (Eldridge 1982). Workers in New Zealand have suggested the improvements in form and growth of genetically improved planting stock are such as to warrant the adoption of wider initial espacement (James 1979). Wider spacings have in fact been adopted generally throughout Australia over the past decade. Improvement of form and growth as a result of tree breeding has undoubtedly contributed towards this change, as fewer trees need to be cut out in thinning to form a desirable final crop. However, the benefits of good soil preparation, the application of fertilisers and herbicide, and the use of good nursery stock have also contributed towards a high standard of establishment which allows the planting of fewer seedlings. One possible change which can provide at least some cost savings, the adoption of rectangular espacement (Incoll *et al.* 1979), has not been widely adopted although slight rectangularity is evident in many plantings.

The result of much of this recent research and development has been the establishment in recent years of very evenly grown plantations on well-prepared sites. These plantations, most less than 10 years old, will be more suited to mechanical harvesting than many older plantations now being harvested.

ECONOMIC INFLUENCES

Previous reviews of this topic have been concerned principally with technical aspects of thinning and harvesting and have taken little note of the economic framework within which these processes were operating. While we do not wish to intrude into areas of economic analysis it will place the discussion which follows in better perspective if some of the more important economic trends are made clear. What is important is that established patterns for a number of the key economic indices have changed markedly during the last decade.

Forest operations are greatly influenced by wage costs and labour availability, fuel costs, the nature and cost of machinery used, and the cost of capital. Average weekly earnings in Australia rose in real terms *vis-à-vis* the consumer price index up until 1975 over a period of several decades (Fig. 2). This established trend influenced a swing into mechanised techniques in forestry, as in comparable industries such as agriculture. However, wages in real terms remained static from 1975 to 1980 and have begun to rise again only since June 1980. Fuel costs, by contrast, having declined in

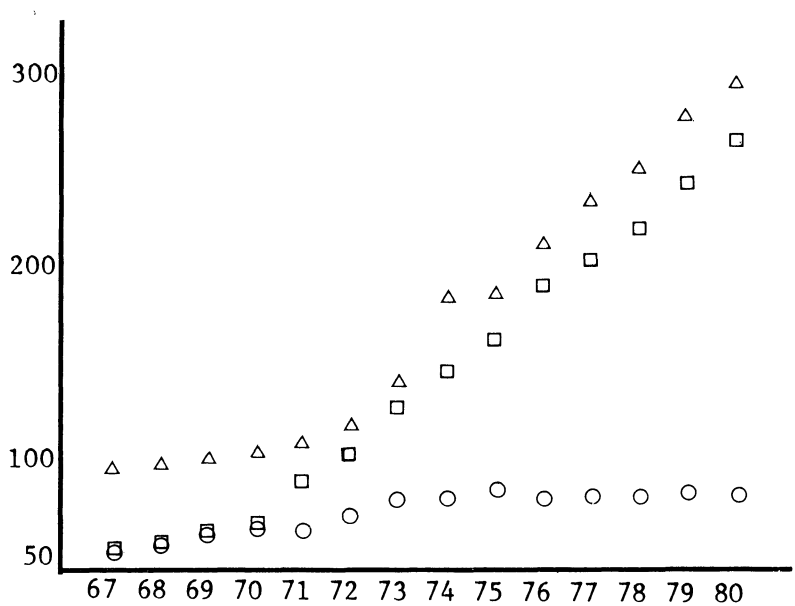

FIG. 2—Australian Consumer Price Index (Δ), original average weekly earnings in dollars (□), and real average weekly earnings (o) adjusted to CPI commencing 1966-67

Source: ABS Monthly Review of Business Statistics, Cat. No. 1304.0

real terms over a lengthy period, surprisingly remained stable in the mid-seventies, only to rise abruptly because of the Government world parity policy (Fig. 3). There are recent indications that the policy of the OPEC countries may be to maintain world oil prices at near current real prices and, if anything, prices recently may even have declined slightly. The cost of capital has risen steeply in recent years (Fig. 4). The interest rate on capital borrowings has increased because of higher rates of inflation. However, there is every indication in Australia that the high demand for capital to finance major developments (particularly in the minerals area) has also placed pressure on the money market, resulting in higher interest rates in real terms than 5 or 10 years ago.

Finally, labour employment deserves some comment. The number of people unemployed in Australia has risen markedly over the past 6 years, as it has in most developed countries in recent times. Yet the number of people employed in forest operations generally, and in logging in particular, has remained relatively static (Dept Primary Industry 1980) in spite of an increase in the volume of wood harvested. This situation is in marked contrast to that of the 1930s when many unemployed workers were readily absorbed into the forest work-force. The reasons for this are no doubt complex. They are probably associated with the perceived expectations of workers today who are not attracted by arduous and often isolated work in the forest. Current levels of unemployment benefits are more generous than they were 50 years ago. A higher level of education and skills is required in harvesting today than even a decade ago so that only a more selective job market is available to a less enthusiastic worker pool. The forest industries have been slow to come to grips with the problems of training a skilled work-force. Notable efforts have been the Logging Industry Training Team (LITT) at Mt Gambier and the TAFE/ANM/Kockums Aust. Pty Ltd operator-training course at Albury. Large-scale industry is dependent on a regular supply of raw material and so managers have elected to invest in mechanisation rather than in what we understand they see as an uncertain work-force.

SILVICULTURAL OPTIONS

There has probably been greater change and divergence in silvicultural approaches to management of Australian plantations during the past 5-year period than in any previously. Until about the end of the 1960s what might be called the South Australian "influence", for want of a better term, had a profound effect on silvicultural practices in relation to thinning in Australia generally. The South Australian approach to silvicultural management of pine plantations, but particularly of *P. radiata,* was expounded by Jolly (1950), and later by Jacobs (1962) and Lewis (1963). Jacobs drew heavily on South Australian experience in teaching silviculture at the Australian Forestry School, as did his successors both there and with the Australian National University. Also, a close link existed between South Australia and the Victorian School of Forestry at Creswick where demonstration forests were modelled in accordance with the ideas of Lewis. Thus, while local factors undoubtedly had modifying effects, the South Australian "influence" was somewhat all-pervasive in silvicultural management of Australian plantations until a little more than a decade ago.

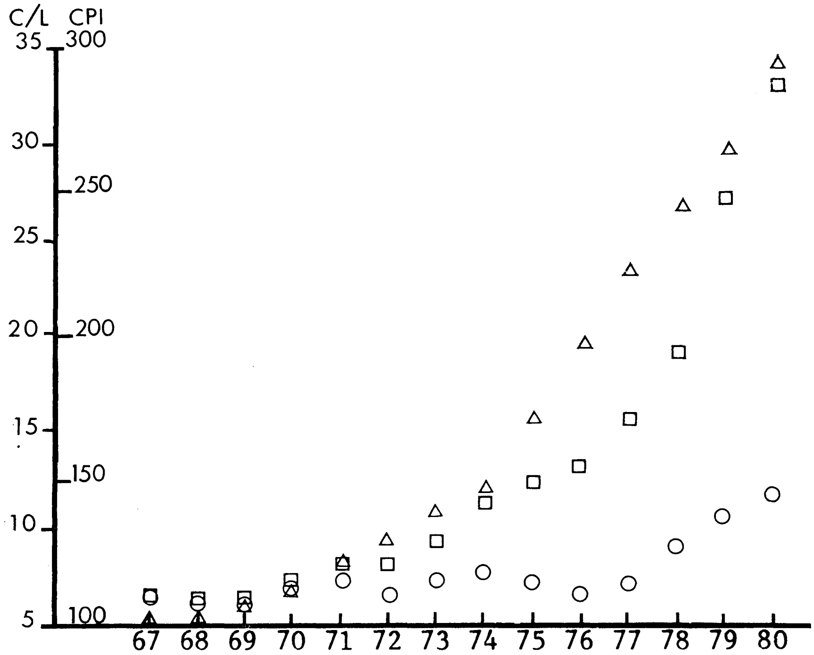

FIG. 3—Australian wholesale prices (Aust. c/l of distillate (□) and real wholesale prices (o) adjusted to the CPI (Δ) commencing 1966-67 (prices for Shell, Adelaide)
Source: South Australian Prices Commission

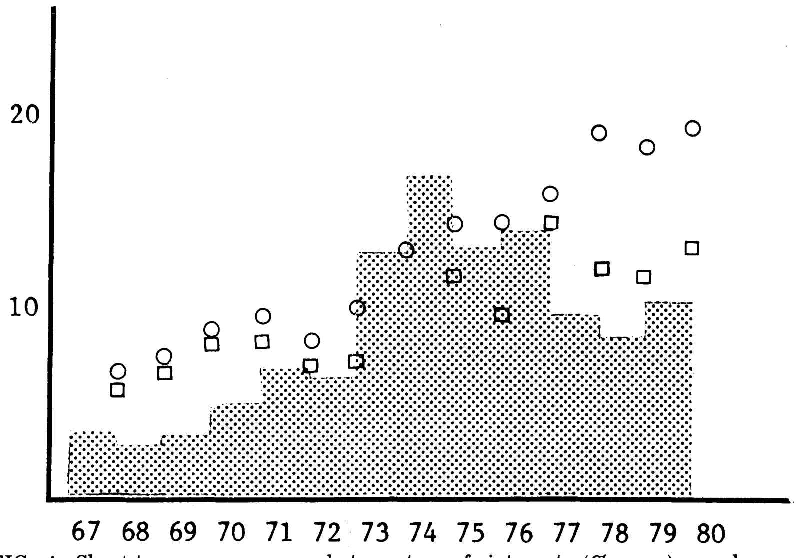

FIG. 4—Short-term money market: rates of interest (% p.a.) on loans in Australia (o) at call maximum, (□) fixed term maximum. Shading shows annual rate of inflation in the CPI.
Source: Reserve Bank, as published in ABS Monthly Review of Business Statistics, Cat. No. 1304.0

South Australian silvicultural management objectives were outlined by Lewis *et al.* (1976) as follows:

(a) Every thinning is expected to produce a commercial yield;
(b) The site is to be used to full production capacity all the time;
(c) The plantations are to be maintained in stable condition;
(d) An average final-crop tree of 50–60 cm d.b.h.o.b. is expected to be produced in a rotation of 50 years.

These objectives were, and still are, suited to conditions which prevail in South Australia. But many forest managers have realised during the past decade that what suited South Australia did not necessarily suit them. One important catalyst for change was undoubtedly the result of the work of the economics group within the New Zealand Forest Research Institute, as exemplified by Fenton & Sutton (1968). Spurred on by some economic analyses of Australian situations (Forrest 1974; Hall 1974; Wilson & Watt 1976; Turner *et al.* 1977) management accepted new approaches to silvicultural manipulation of plantations.

Tasmania has a set of management conditions which probably come closest to those argued as important in determining silvicultural regimes in New Zealand (Sutton 1978). A major part of the yield of the plantations will be sold on mainland markets and smallwood is expensive to harvest and difficult to market. For these sorts of reasons the Tasmanian Forestry Commission has adopted silvicultural regimes closely modelled on those advocated for New Zealand (Neilsen 1979).

Western Australia has adopted a very similar approach to silvicultural management of its plantations but for a quite different set of reasons. Death of trees due to summer drought led to the adoption of what was referred to as "Silviculture 70" (McKinnell 1976; Butcher 1977), later modified as circumstances changed (McKinnell 1981). An assessment of the effects of the very damaging cyclone "Alby" of 4 April 1978 confirmed the worth of wide-spacing silvicultural regimes in terms of wind firmness (McKinnell 1981). The importance of correct thinning practice in maintaining stand stability to wind had been accorded a low priority in evaluating alternative silvicultural strategies generally in Australia, in spite of a number of instances of damaging storms in New Zealand. The potential losses from wind, however, were brought into sharp focus by a major windstorm in the Australian Capital Territory (Cremer *et al.* 1977), and subsequently by cyclone Alby in the West.

Thus in both Tasmania and Western Australia silvicultural regimes have diverged sharply from the more conventional approach in South Australia. Plantations are being established at an initial stocking density of not more than 1000–1200 stems/ha and with non-commercial thinning at around 5–6 years to reduce stocking densities to the range 600–750 stems/ha (to 300 for *P. pinaster*). Further reductions, combined with a carefully managed pruning programme to 6 m, result in the necessity for, at most, one production thinning before clearfelling at age 25–30. The regimes eliminate any necessity to harvest smallwood. There is a substantial loss of production but only in the smaller sizes as the production of large diameter sizes is enhanced and final harvest can be advanced by 10 or more years.

The other two mainland States with large areas of *P. radiata* plantation, Victoria and

New South Wales, fall into another category again. To some extent Queensland can be considered here too. The South Australian influence was certainly strong in the southern States; Queensland tended to follow a more independent, but nonetheless conservative, silvicultural line for the different species grown there (Robinson 1968). These States over the past decade have been placed in something of a dilemma. They could not always thin their plantations at the right time commercially because of a lack of smallwood markets (Ferguson & Shepherd 1979). They were certainly aware of the effects of non-commercial thinning (Incoll & Baker 1980), and could appreciate the advantages of silvicultural regimes which minimised the production of smallwood, as shown by Forrest (1973) and Wilson & Watt (1976). Yet these States have been loath to adopt such regimes, except perhaps in some of the steeper, less accessible areas, because it would have limited their capacity to attract and meet the demands of a major development. Just such a development is that of ANM Ltd at Albury, to be supplied by plantations at Tumut and in the north-east of Victoria. The sensitivity of this dilemma was reflected by the sharp response by Henry (1980) to Ferguson & Shepherd (1979). The initial paper was written in the context of the times and the authors now acknowledge the changed effects the ANM development would bring. However, the general argument is still applicable to plantations remote from Albury-Wodonga or any other market for smallwood.

Silvicultural policies in these States have tended then to be more opportunistic than in South Australia, in the sense that silvicultural management has been modified periodically to meet the exigencies of the times. However, at no stage have these policies embraced the more radical approaches stemming from New Zealand. Experimental thinning has demonstrated the silvicultural flexibility of *P. radiata* as a plantation species (Shepherd & Forrest 1973; Hall 1974, 1981; Cremer & Meredith 1976). Much the same yields can be expected if low, crown, or row thinning, or even thinning from above is employed, provided the severity of the thinning regime is not too great. Plantations thus thinned with moderate severity might not be as profitable as they would have been had more drastic schedules been employed; schedules such as those shown in the economic analyses noted earlier give the highest returns. But these analyses did not take into account possible benefits in a wider context. Such benefits might include the value of older pulpwood for an associated kraft pulp industry (Uprichard 1980) or Government objectives for fostering new industrial development in growth centres such as Albury-Wodonga.

Plantation managers in the eastern States have been very conscious of factors such as these. An important influence has been the level of current demand but always there have been the possible implications of a quantum leap in demand due to major industrial development. Thinning policies have changed during the past decade but remained mostly within a relatively conservative framework which has meant little loss of productivity. The very high demand for smallwood for the ANM plant, combined with highly mechanised methods for harvesting, will likely impose considerable stress on the plantations supplying that wood. It will be interesting to observe in the next decade how well the silvicultural flexibility of *P. radiata* enables the plantations to sustain this stress, especially as the extent of colonisation by *Sirex* is increasing and there is evidence of greater damage from bark beetles.

SIGNIFICANT INNOVATIONS IN THINNING TECHNOLOGY 1975–81

Immediately prior to the 1975 meeting two important innovations occurred with the introduction of advanced motor-manual techniques and formal training at Mt Gambier in South Australia, and the design and construction of the Windsor Harvester for first-thinning operations in APM's Gippsland plantations. The initial Windsor Harvester described by Raymond (1975) was augmented later with two additional machines; the three machines were handed over to contract operations in 1977. These machines removed every third row and could selectively thin the rows adjacent to the row removed.

Since the introduction of advanced motor-manual techniques based on a 5-m wood length and extraction by forwarder, they have been adopted in New South Wales, south-east Queensland, Western Australia, and Tasmania. The volume of material harvested as either tree lengths or short billets has declined. Short billets are still handled in Gippsland (2.0 m), Oberon (2.4 m), and to a minor degree in the Mt Gambier region (2.4 m). The persistence of tree-length extraction in parts of Tasmania is of interest in that the north-west, with its high rainfall and loamy soils, presents problems for forwarders. The Dowling bench appears to have been an important innovation, improving both productivity and the ergonomics of chainsaw work in the very flat forests around Mt Gambier (Bankes 1982).

After the Forest Industries Machinery Exposition (FIME) 1975 the Clark Bobcat feller-buncher was evaluated on an experimental basis (McCormack 1976) and, although not used here commercially, it led to a number of small feller-bunchers being built around industrial tracked front-end loaders. A study by McCormack & Waugh (1975) showed that for *P. radiata* stems of up to 45 cm d.b.h.o.b., the losses in sawn timber after kiln drying were no greater when felling shears were used instead of the conventional chainsaw.

A Volvo-Tvigg processor was introduced in Oberon by Pyneboard Pty Ltd on an experimental basis in 1976 and operationally in 1977, and to Tumut in 1978. This was the first feed-roll type delimbing machine used in *P. radiata* and McCormack (1978) established its ability to handle the moderately heavy branches of Tumut *P. radiata*. A combination of a small, tracked feller-buncher and the Volvo-Tvigg processor was used to remove every fifth or seventh row and selectively thin the intervening bays, demonstrating the technical feasibility of mechanising selective thinning.

In 1976 the first steps were taken to mechanise the thinning of southern pines in south-east Queensland. The Boschen-Windsor system used two separate machines to remove and delimb every fifth row and selectively thin the bays, whereas the semi-mechanised system used conventional felling, the limbs being removed by backing the trees through a grid during extraction (Williams 1981).

Unfortunately the delimbing of *P. radiata* is a much more formidable task. The branches are heavier, branch angles more variable, and the branches extend to ground level, unless the butt has been previously pruned. During 1977 the first John Deere 473 harvester was introduced experimentally into Western Australia and was studied by Melmoth (1978a). This machine, like the Windsor, combines felling and delimbing functions but is capable of selectively thinning two rows either side of the outrow.

Its large, powerful feed-rolls can handle all but the heaviest limbs and this machine has now been introduced commercially into Western Australia (three machines), South Australia (four), and Tasmania (four). In most operations, the wood is converted from tree lengths to 5.4-m billets for extraction by forwarder. This cross-cutting is generally done by a man and chainsaw, but one of the Western Australia machines has been modified locally to produce pulpwood 5.4 m long. Another machine described by Quill (1981) is being used to fell and delimb larger trees and to fell and bunch small trees for subsequent whole tree chipping.

In 1977 a Logma processor was also introduced for evaluation in Gippsland and was studied by Melmoth (1978b). This machine was able to delimb rough *P. radiata* and to remove limbs from the butt of the tree. It could also handle larger trees and more difficult terrain than the John Deere harvester. Logmas commenced routine operations in Gippsland and in Western Australia in 1978; the second machine in Gippsland started in 1980 and 10 Kockums feller-bunchers and Logma processors commenced with ANM Ltd's contractors in 1981, after an extensive training school conducted by ANM Ltd, Kockums (Aust.) Ltd, and TAFE Tumut. This system is being used mainly in first thinnings, removing every fifth row and selectively thinning the bays. The 5.4-m billets are extracted by forwarder. Both operator skills and machine productivity in this operation are being studied by CSIRO in collaboration with ANM Ltd and the Forestry Commission of N.S.W.

A Hydro Ax prime-mover with feller-buncher and flail delimber attachment demonstrated in 1980 at FIME was subsequently studied in a series of experimental operations in both *P. radiata* and southern pines. Moore (1980) reported that this machine had a very high capacity even in small wood dimensions, although dirt on the logs and poor delimbing in *P. radiata* would be negative aspects for many existing mills.

The most recent innovation of importance is the Kato excavator-based system developed by Pyneboard Pty Ltd at Tumut. This system involves the attachment of a locally made shear to a standard industrial excavator, and a Swedish Skogsjen feed-roll processing head to a second machine. Capital investment is half that of the specialised forest machines and ground flotation would appear to be improved. Unlike all other mechanised systems currently in use, wood is well bunched and located in a manner that will enable the productivity of the forwarder used for extraction to be maximised.

As Fig. 5 illustrates, the mechanisation of thinning is expanding rapidly, although it would be dangerous to conclude that the expansion will continue at the rate suggested by extrapolation of the graph. The opening of new mills and expansion of existing ones are recognisable events likely to encourage further mechanisation.

During the period 1975–77 light cable systems were introduced to thin steep plantations and by 1978–79 these systems were being used commercially. Eight were built by Timberlift Pty Ltd in the Australian Capital Territory and a number in New Zealand under licence. This machine draws heavily on Norwegian and United Kingdom experience with light cable systems but is unusual in that it incorporates a knuckleboom crane which enables the cable system to operate continuously, independently of other machines, even on narrow side-cut tracks. The performance of these machines has been described by Galbraith & Sewell (1979) and Melmoth (1979).

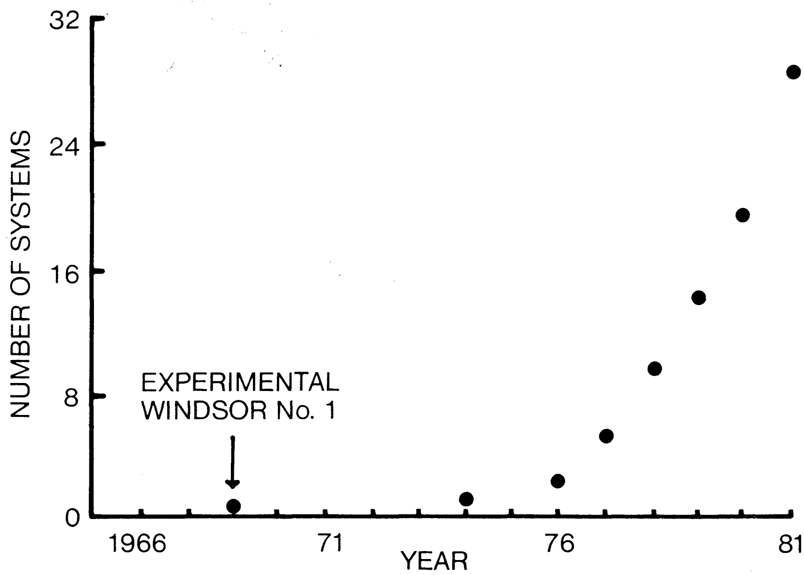

FIG. 5—Number of fully mechanised thinning systems in operation in Australian plantations

In spite of their technical success, however, the use of cable systems to extract thinnings has diminished in Australia and today only two are being used. The cost of thinning by cable system, generally about twice that of conventional systems operating on easier terrain, has been high – often so high as to eliminate any stumpage.

BENEFITS AND COSTS OF TECHNOLOGICAL DEVELOPMENTS

Labour Inputs

Economic development in the late 1960s and early 1970s accentuated the demand for less labour-intensive operations. In 1970, 70% of the costs at mill door of first thinnings were direct labour costs. This was too high a figure for the large-scale operations and capital-intensive mills being constructed and so emphasis was placed on improving labour productivity.

Early studies by Hill (1966) and Kerruish (1967) showed about 1.1 man-hours/m^3 were required to fell, delimb, crosscut, and stack early thinnings of about 0.11 m^3 average stem volume (Fig. 6). These operations involved wood lengths of 2.0 and 2.4 m and extraction in large pallets or stacks required considerable wood handling by the cutter. Farrow & Kerruish (1971) and later Whiteley (1972a) found that somewhat higher inputs of 1.4 and 1.3 man-hours/m^3 respectively were required for cutting and assisting to load 1.2-m wood. Bills (1972) reported inputs of 0.6 and 0.8 man-hours/m^3 for 3- to 5-m length wood from early thinning operations in South Australia, depending on the training and skill of the cutters. This would appear to have been confirmed by Lembke (1976) who reported cutter output to be 35 to 40% higher than for 1.2-m wood, and by Shaw (1982) in an extensive study of first-thinning operations at Tumut.

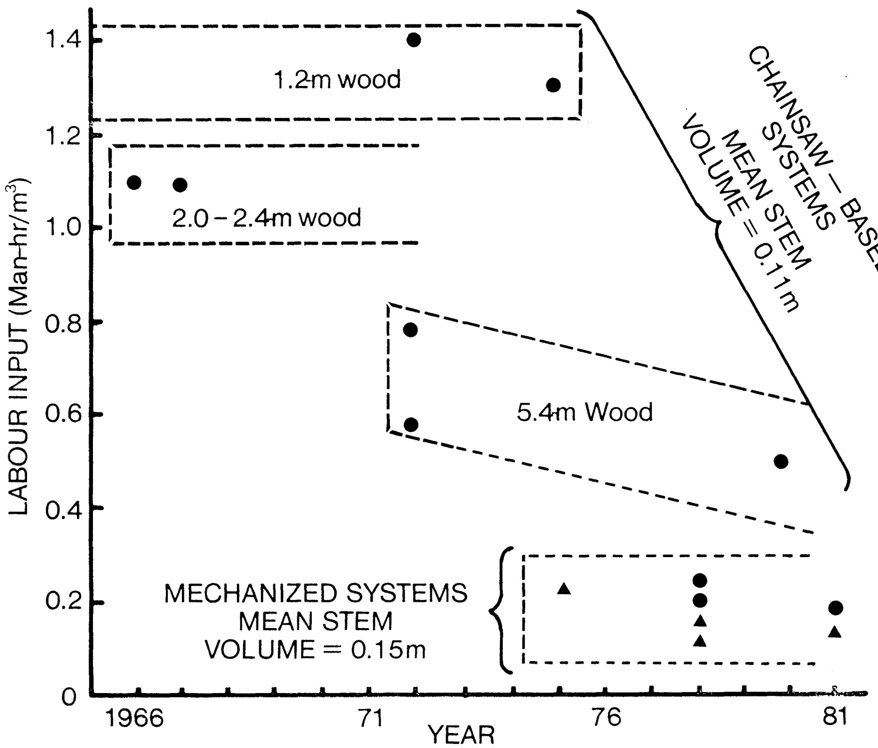

FIG. 6—Labour input for cutting and piling first thinnings (● shortwood, ▲ tree-length wood) according to published studies. The broken line indicates the range of inputs

The fully mechanised systems have further reduced labour input as illustrated in Fig. 6 and by Raymond (1975) and Kerruish & McCormack (1979). More recent unpublished studies by A. Twaddle & R. McCormack on the Kockums Logma system at Tumut support this earlier work.

The gains made possible by mechanisation have not been fully realised because of industry commitment to shortwood systems (for which the maximum billet length is 5.4 m). This has, in most operations, involved cross-cutting of processed wood by motor-manual techniques. However, further machine development, as exemplified by the incorporation of a cross-cutting saw on the John Deere harvester, or the use of multiple-stem slashers or roadside chipping, can be anticipated.

Compared with cutting, labour inputs involved in extraction are minor. Whiteley (1972b), in a study of a number of methods of extracting billets 2.0 and 2.4 m long, reported inputs ranging from 0.05 to 0.15 man-hours/m^3. R. McCormack (pers. comm.) in a series of studies of modern forwarders extracting 2.4- and 5.4-m lengths indicated inputs of about 0.07 man-hours/m^3.

Most of the above data were obtained from detailed studies and may differ substantially from gross results over a year, depending on a number of factors.

Capital Inputs

Over the last decade, the capital invested in the harvesting of early thinnings has escalated in an almost spectacular manner, due to the increased size and complexity of the machines and the mechanisation of additional harvesting functions. Table 3 shows the relative average capital investment per tonne of wood produced over the period in question.

TABLE 3—Average capital investment per tonne of annual capacity (1981 machine prices)

System	Typical of period	Investment (A$)
2.0- or 2.4-m lengths, 4 × 4 forwarder	1972	3.5
5-m lengths, 6 × 6 forwarder	1979	3.8
Harvester + half a 6 × 6 forwarder		
(a) 1 shift	1981	17.5
(b) 1½ shifts	1981	11.6

The increased cost of the larger forwarders used today has been offset by their greater annual capacity. The Table also indicates that the high capital investment per tonne of wood produced associated with fully mechanised operations is substantially reduced if the machines are operated on more than one shift; most mechanised systems being used today are operating on an extended shift basis. The potential to further reduce the capital investment per tonne of wood produced by fully mechanised systems is of special interest. Australian plantations in general are on favourable terrain and, as noted earlier, plantation establishment has become very intensive. It should be possible to use machines simpler than those now in service because such machines were developed for clearfelling in the natural forests and rough terrain of Scandinavia. While *P. radiata* may not afford opportunities for the use of the simple machines adopted in Queensland and the southern United States for the southern pines, there is considerable scope to use componentry made primarily for other industries. Such components are produced on a large scale; Table 4 compares the purchase price for specialised forest machines from Scandinavia with that for industrial machines made in large numbers in Japan. While the performance, particularly the mobility, of the industrial machines may be less than that of the more specialised counterparts, this is not always important in plantations where large volumes may be harvested per hectare and the terrain is commonly favourable.

TABLE 4—Cost of specialised harvesting and industrial machinery (1981 prices)

	A$/kg	A$/kW
Harvester	14	2300
Processor	12	2150
Industrial excavator	5	1000

Work Environment

Advanced work techniques have substantially modified the nature of the work involved in motor-manual operations. Safety features of chainsaws, protective clothing, and less handling of wood have reduced the hazards associated with early thinning operations. Bankes (1982) has shown that these factors have been significant in reducing the frequency and severity of accidents at least in his region.

The physiological inputs required of some workers in Australia are in excess of the international 8-hour standard, suggesting a possible combination of excessive work-load and poor work technique. The physical work capacity of individuals has not generally been considered by industry when recruiting. Fibiger & Henderson's (1982) study of cutters in the Australian Capital Territory shows the extent to which inefficient work technique can persist today, especially in the absence of effective training. Although improvements in motor-manual techniques have occurred, problems persist; protective equipment, helmets, ear protection, and leggings, are not designed for our warmer climate (Henderson 1980).

The highly repetitive nature of the work and poor ergonomic design of the machines used are problems with some mechanical systems, in particular the first generation of systems which often involve improvised machines and components.

Site Impact

There can be little doubt that higher levels of mechanisation are causing increased damage to both stand and soils on other than favourable soil and slope conditions. Damage is occurring in the form of:

- Bark removal from residual trees;
- Damage to root systems;
- Soil compaction;
- Physical displacement or rearrangement of soil horizons.

Bark removal is not a new problem. The use of forwarders to extract correctly positioned wood has, in fact, reduced this form of damage. But many of the mechanised systems used today are not thinning systems – they are composed of machines designed for clearfelling and their dimensions and, more particularly, their placement of processed wood in the outrow, result in damage to the residual stems during extraction by forwarder. Operator skill and experience have also been shown to affect levels of stem damage. Investigations into the possible biological and economic losses arising from stem damage to young *P. radiata* (Johnson 1968) suggest that except where damage to the stem is massive, the end result is resin-impregnated wood and callus tissue, both of which cause some loss of wood value, but that loss is confined to the proximity of the damage. Less understood are the effects, if any, of damage to root systems, soil compaction, and the physical displacement of soil. Root damage has caused some concern in Scandinavia where the root system is often confined to a shallow humic soil over rock and considerable effort has been put into developing long-reach cranes (up to 15 m) to maximise the permissible spacing between tracks.

Wingate-Hill & Jakobsen (1982) discuss some aspects of soil damage. It seems likely that the use of logging machines under soil moisture conditions that result in a combination of root damage and severe soil damage must reduce the proportion of a given site which is available to the root system of a stand, at least on a temporary basis. This reduction may be substantial. With every fifth row removed, as is common practice today, as much as 25% of the site may be removed at least temporarily from production. This is clearly a topic deserving of more research.

New Processes

Most of the developments described involve the mechanisation of various processes which had previously been executed manually or semi-manually. As discussed by Kerruish (1977) in examining the implications of technological developments in harvesting on short rotation crops, the mechanisation of a process *per se* is unlikely to change the relationship between tree size and harvesting cost.

Two systems, however, have been introduced involving components which have mechanised operations and introduce new processes. One is the John Deere/Morbark system used by Softwood Holdings and described by Quill (1981). The second is the Hydro Ax feller-buncher and chain-flail delimber described by Moore (1980). Both incorporate accumulator-type felling heads which allow several small trees to be handled simultaneously and, more significantly, conversion processes which permit more than one tree to be processed at a time. As a consequence these two systems have a theoretical capacity to reduce the effect of declining tree size on costs, an important consideration influencing the age of thinning. Both these systems are limited in their immediate application by the form of their output – whole-tree chips which include bark, branches, and some foliage in the John Deere harvester/Morbark operation and roughly delimbed tree lengths in the Hydro Ax flail system.

Kerruish & Moore (1982) show that adoption of multiple stem and continuously moving processes can bring major reductions in energy, capital, and labour inputs into the harvesting of early thinnings, particularly if row thinning can be adopted.

CONCLUDING REMARKS

We have noted the situation which prevailed in Australia in 1975 when the last IUFRO Project Working Group met to discuss thinning and harvesting in plantations. Since then there has been a 50% increase in the plantation estate in Australia. Harvesting has progressed to the stage where significant quantities of later thinnings and clear-fellings are now available but because of the age-class distribution of the estate the emphasis still remains on early thinnings. The expanding harvest has been accompanied by a significant growth in processing capacity, particularly plants drawing on first thinnings and notably the ANM plant at Albury. Most of the resource from the larger plantation groupings is committed to industry whereas smaller, more isolated, plantation developments still have difficulty in selling smallwood. In spite of much change over the 1970s silvicultural policies have remained flexible so as to take advantage of prevailing conditions.

A perceived constraint in 1975 was the capacity of what was then a labour-intensive harvesting sector to cope with the sheer volume of raw material likely to become available to improve the productivity of thinning operations. Two separate avenues were explored – advanced motor-manual techniques, and fully mechanised systems for thinning. The fear that the logging sector of the industry could not cope has been largely allayed over the past 5 years as a direct result of the success of those two developments.

Sir Rutherford Robertson, in his keynote address to the 1977 Adelaide Conference of the Institute of Foresters of Australia (Robertson 1977), noted with some trepidation as a biologist the mechanisation taking place in forest operations and its associated energy inputs. He made a plea that "scientific understanding and management be applied to the totality of our technological efforts". Nowhere in forestry is his remark more relevant than in relation to the harvesting of smallwood in plantations, for nowhere else in forestry has there been a comparable swing to mechanical solutions to overcome a problem. These mechanised systems have met industry requirements by ensuring reliability of supply and the capacity to thin large areas of plantations.

However, this solution has been achieved at considerable capital cost per unit of wood harvested. It has also somewhat increased our dependence as an industry on liquid fuels as a source of energy, as shown by McCormack & Wells (1982). The labour content in harvesting has declined markedly but this fact has been somewhat obscured as the volume of the harvest has been continually increasing. Plantation forestry will not, therefore, be an employer of labour on the scale envisaged a decade ago. But the high physiological inputs associated with motor-manual techniques in first thinnings (Fibiger & Henderson 1982) and the high cost of accidents which occur even with training and advanced work techniques (Bankes 1982) render such work unattractive.

The real problems of increased mechanisation are with the associated environmental impacts as we do not yet fully understand the interactions between machine, environment, and biological productivity. While we share Sir Rutherford Robertson's concern over the implications of the mechanisation of industrial plantation operations, increased mechanisation is a fact of life and a trend not likely to change. We must therefore seek ways to minimise the problems. In agriculture the first attempts to mechanise complex operations were relatively inefficient and some time elapsed before engineering technology and agronomy came together to produce efficient systems. In forestry the process may well take longer but the papers to this meeting do indicate a significant rate of change in the nature of the technology being evolved. These changes are leading not only to more efficient machines in terms of capital and fuel needs but also to lighter machines, and hence machines potentially less likely to cause damage to the site. Maintaining productivity of plantation land should remain of paramount importance if the long-term investments in both forest and associated industry are to be protected. Hence, it is important that machine developers take environmental impact into account as well as mechanical reliability and efficiency.

For the first century of plantation forestry in Australia the forester was overwhelmingly concerned with biological productivity to the point where Australia can now boast some of the finest plantations in the world. The decade of the seventies has seen the beginning of a marked swing to mechanisation in those plantations but with less than due regard for the biological, and even perhaps socio-economic, consequences.

What we must now have is a coincident evolution of both silviculture and harvesting technology with the dual aim of maintaining the long-term biological productivity and economic viability of the plantation estate.

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