THINNING TECHNIQUES APPLICABLE TO *PINUS RADIATA* PLANTATIONS

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ABSTRACT

This paper reviews the various thinning methods and equipment available to the forest manager for a range of silvicultural practices, including thinning to waste.

Considerable increases in the productivity of conventional chain saw-based techniques have been obtained by variations to wood specification, the introduction of forwarders for extraction and the training of the cutter force.

The introduction of more mechanised techniques has commenced but acceptance has been slow. It is considered that the mechanisation of early thinnings is most likely to be economic under favourable stand treatment and terrain conditions, where simpler and less costly machines can be used.

The mechanisation of these operations can be facilitated by increasing the stem size of the trees to be removed or by reducing wood specification to permit multiple stem harvesting.

FELLING ONLY — THINNING TO WASTE

Light-weight Chain Saws

Chain saws of about 40 cc are being increasingly used in this operation, replacing axes and various types of manual slashers. Their merits include ready availability, flexibility in relation to the size of tree to be felled, ease of carrying and their ability to be used for low pruning all or part of the residual stems in a combined thinning and low pruning operation. Disadvantages are largely confined to a concern for the operator who is using this noisy and vibrating tool continuously. However, both these features have been appreciably reduced by the better silencing and vibration-damped mountings of most of the new saws of this type.

Brush Cutters

These are widely used in Scandinavia for clearing and thinning to waste. In Sweden alone approximately 290 000 hectares were so treated in 1969. Svensson (1971) in a study of time functions for cleaning with brush saws in young stands indicated that time consumption per hectare was 7 h 21 min in stands in which an average of 7119 stems/ha were removed and mean height was 3.0 m. Time consumption was very noticeably influenced by the number of trees removed and tree height. By extrapolating this data beyond the limits recommended by the author, the removal of 600 trees/ha at a height of 5-7 m would require a labour input of about 3 hours/ha. This would appear to compare favourably with the chain saw or manual slasher. Possible reasons for the brush cutters not finding an application here are:

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(i) tree sizes are too large and/or
(ii) thinning to waste in Australia tends to be confined to rough terrain and the chain saw may be more easily handled
(iii) brush cutters have not been properly evaluated.

Certainly we usually thin to waste when all attempts to find a market for the materials have failed and tree sizes are too large for brush cutters. However it has been shown by Shepherd (1975) that crop trees can be identified with a high level of confidence at ages as young as two years. Thinning to waste at the point where canopy closure first occurs may permit the use of these saws.

Undoubtedly the best application for this tool is in dense, small material where the saw is used rather like a scythe. It would appear that this technique is applicable to thinning naturally regenerated stands, particularly following fire, and should be further considered for thinning to waste in normal plantations.

Tractor Mounted Thinning Saw

This saw was developed by the Forests Department of Western Australia for selectively thinning to waste in young *P. pinaster* stands. Although it is still being developed, its defects are of a minor nature and it has demonstrated its ability to function very efficiently. The hydraulically driven circular saw of about 12-in. diameter is mounted on a hydraulically controlled arm in front and to one side of a 40 hp

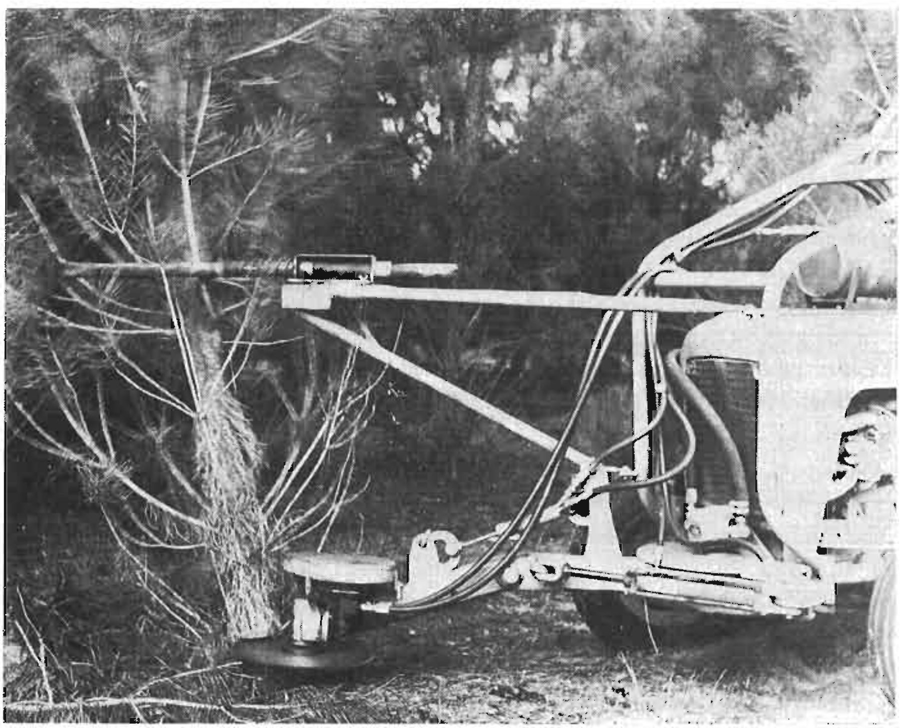

FIG. 1—Tractor-mounted thinning saw moving continuously through a stand of **P. pinaster**.

agricultural tractor (Fig. 1). The tractor moves continuously forward at approximately 2-3 km/h, travelling between the rows. The saw is positioned to fell selected trees and to push the tree away from the machine.

On this basis the machine could treat about 0.60 ha/h while operating. Assuming a 70% availability and an hourly cost of $8 for machine and operator, the cost of treatment would be $19 per hectare, which is extremely favourable.

FELLING AND CONVERSION TO CHIPS OR ROUNDWOOD

Chain Saw-based Techniques

In spite of much activity in the development of sophisticated harvesters and processors, the chain saw is the basic tool used to fell and process 99% of our thinnings material today. Continued development of the chain saw, working techniques, extraction equipment, and changes in wood specification, have enabled significant reduction in labour input to be made. Following limited trials in South Australia, Farrow and Kerruish (1971) predicted that a change from 1.3 m axe-trimmed wood loaded on to truck at the stump to 3 to 5-m wood limbed by chain saw and extracted by forwarder would reduce the labour input by 35-40%. Subsequent experience with this technique on a production basis has supported this prediction. Extensive studies have been carried out in Finland (Tenhola, 1969) on the effect of work technique and varying wood specifications with regard to wood length, accuracy of length and standard of limbing. These showed improvements in cutter output of up to 33% for the cutting of roughly-limbed wood to approximately 3 m lengths as compared to well-limbed wood of exactly 3 m in length.

The most effective version of this technique is the "assortment" method which has been developed in Scandinavia. Using chain saws which incorporate features to facilitate their use for limbing, trees are directionally fallen towards the extraction track with the assistance of a special felling bar. The tree is limbed, measured by tape (if required) and bucked to length by chain saw in one pass along the tree. Pulpwood material is moved to stacks of 0.3 m^3 or more by dragging or turning rather than carrying. Sawlogs are generally left to be picked up individually by the forwarder. Optimal lengths appear to range from about 3 to 5 m and may be fixed at random. It would appear that cutter performance is not greatly influenced by wood length but is by the accuracy to which the lengths are to be cut and in particular, by the standard of limbing and size of stack.

The technique has found wide acceptance in Australia. The need to train fallers has been recognised and training schools are now run by A P M Forests Pty Ltd, Pyneboard Pty Ltd, and a combined forest owners' training team supported by Softwood Holdings Pty Ltd, Sapfor Pty Ltd, and the Woods and Forests Department of South Australia. Nordfor (Aust.) Pty Ltd, a company which specialised in training cutters, introduced the techniques in 1972-3 when training schools were run in South Australia, Victoria and New South Wales.

Chain saw-based techniques are notable for their flexibility and they can be applied to:

(i) a wide variety of thinning treatments, ranging from 2nd to 3rd row nonselective thinnings to the removal of every 10th row and the selective thinning of the rows between

(ii) Felling and converting trees of poor form. In both very high and very low site quality stands of radiata pine the number of deformed trees may be extremely high, at times exceeding 50%

(iii) A wide range of terrain, extraction techniques being the limiting factor

(iv) Recovery of a wide range of assortments including special products such as round timbers.

In spite of this quite formidable list of advantages, the high labour input and the arduous nature of the work makes the introduction of alternative techniques inevitable. Of the total cost of harvesting and transporting pulpwood to mill door, about 70% is direct and indirect labour costs. With the current rate of increase in the cost of labour, significant reductions in labour input are essential if the product is to remain marketable in competition with pulpwood from later operations and mill waste.

The nature of the work is unattractive. The cutter operating in first thinnings works in a confined space with a noisy, vibrating and dangerous tool, under poor footing conditions and often on steep slopes. He may be required to lift or move material in this environment which is in excess of the 50-60 kg maximum suggested by I.L.O. (1964) for more favourable working conditions.

Accident rates are high and this is reflected by the cost of workers' compensation which is in the vicinity of 20-30 percent of wages. Also, it should not be overlooked that a high proportion of work-caused injuries result in strained backs, hernias, and deafness which are not immediately obvious and rarely attributed to the true cause.

There is still some scope for improving the productivity of techniques based on the use of the chain saw, mainly by training and better management, but the more advanced version must now be considered to be fully developed and the major improvements required in labour productivity must come from more mechanised systems.

Feller-bunchers

This machine type is concerned with felling, transporting the trees in a near vertical position and placing them in a bunch to facilitate either extraction or processing. There is considerable variation in the manner in which these functions are performed.

Felling is usually done by shears, the double-bladed shear finding increasing acceptance because blade dimensions can be minimised, thus reducing the force required, the damage to the butt log, and the weight of the felling head. Where frozen wood must be felled to yield sawlogs, shears may cause excessive splitting and this has motivated the development in Canada, the USSR and Scandinavia, of chain saw type felling heads or other kerf cutting tools. These developments have been recently documented by Malmberg (1974).

A feller-buncher capable of extracting the stump as well has been developed by Koch and Rome Industries to operate in the plantations of south-eastern U.S.A. Developmental work is also being done by Osa in Sweden. The concept is particularly appropriate to *P. elliottii* which has a remarkably carrot-like stump and tap-root. Preliminary investigation of the stumps of 12-year-old *P. radiata* in the plantations of APM Forests, Gippsland, suggests that the much heavier lateral roots of this species will require much higher forces to sever the lateral roots. However it is worth further investigation as it has been shown by various investigators that the stump contributes 10-20% of the total fibre produced by a tree. The removal of the stump would greatly facilitate subsequent re-establishment of the stand.

Felling devices that can fell as a machine moves forward continuously have been developed to prototype stage in the Russian LRB-1 and the Propst harvester in the U.S.A. and considerable experimentation is being done in this field. It is argued by Kerruish (1975) that a continuously moving feller-buncher or harvester is essential if stems of less than 10 cm d.b.h. are to be harvested because of the need to reduce the number of decisions required of the operator. Such a concept could find a role in row thinning.

Accumulator-type Felling Heads:

Such devices permit the accumulation of two or more trees in the felling head before they are extracted from the stands (Fig. 2).

This concept was studied in detail by the Swedish Royal College of Forestry with its application to selective thinning in mind. A pilot study by .Bredberg and Moberg (1971) using a dummy felling head on a telescoping boom, indicated the technical feasibility of the concept and suggested that the felling and extraction time per tree could be reduced by as much as 38% if 3 trees were accumulated. A simulation study by Sjunnesson and Santesson (1972) confirmed that the time per tree could be reduced by as much as 33-40% under certain stand and operating conditions.

Accumulator attachments are currently available on Drott, Allen, Morbark and Rome felling heads. Because of the simplicity of the accumulator device, it can be readily incorporated in most felling heads. Such a concept is expected to find a ready application in row thinning.

Types of Feller-bunchers:

There are many different types of feller-buncher and an appreciation of the different design principles involved is required to ensure that the correct type is used; these are described diagrammatically in Fig. 3. The same considerations apply to the felling infeed mechanisms of harvesters.

Felling Head Mounted to Move Through One Plane (Bobcat, Case, John Deere, etc.): This mounting is used on the small skid steer machines (e.g., Bobcat) and crawler-based units which are used for thinning in southern U.S.A. It is also used on the larger Franklin, Siccard feller-bunchers. It appears to work well on the smaller machines, and the compact dimensions and manoeuvrability of these machines enables them to operate in selective thinning operations. With larger machines this mounting is not suited for other than the most favourable ground conditions. As the felling head is positioned on the tree by steering the machine, ground irregularities, side slopes, soft conditions, etc., can make this a difficult function. This mounting is, however, very simple and lends itself to the attachment of felling heads to standard loaders.

Felling Head Moving Through Two Planes (e.g. Windsor and Timberjack RW 30). This type of mounting enables the head to be positioned on the tree independently of the direction of movement of the chassis, enabling the machine to maintain a faster

FIG. 2—An accumulator-type felling head attached by a one-plane mounting to a wheeled loader.

cycle time over a wide range of ground conditions and slopes, than can the single plane mounting. It remains a relatively simple mounting and like the one-plane mounting, is quickly mastered by operators.

Its reach is limited and therefore is not suitable for very soft or rough ground conditions, e.g., the heavy concentrations of felled hardwoods that occur in some of our plantations. As most of our plantations are now being established by mechanical means, this constraint will become less and less of a problem in the future.

Mounting to Permit Movement Through Three Planes (e.g. Drott, Can-Car Clipper, Kockum 880, Volvo): As terrain conditions deteriorate, more complex mountings become necessary. The three-plane mounting has been highly developed in Scandinavia because of the terrain in which large glacial boulders are a regular feature. Relatively

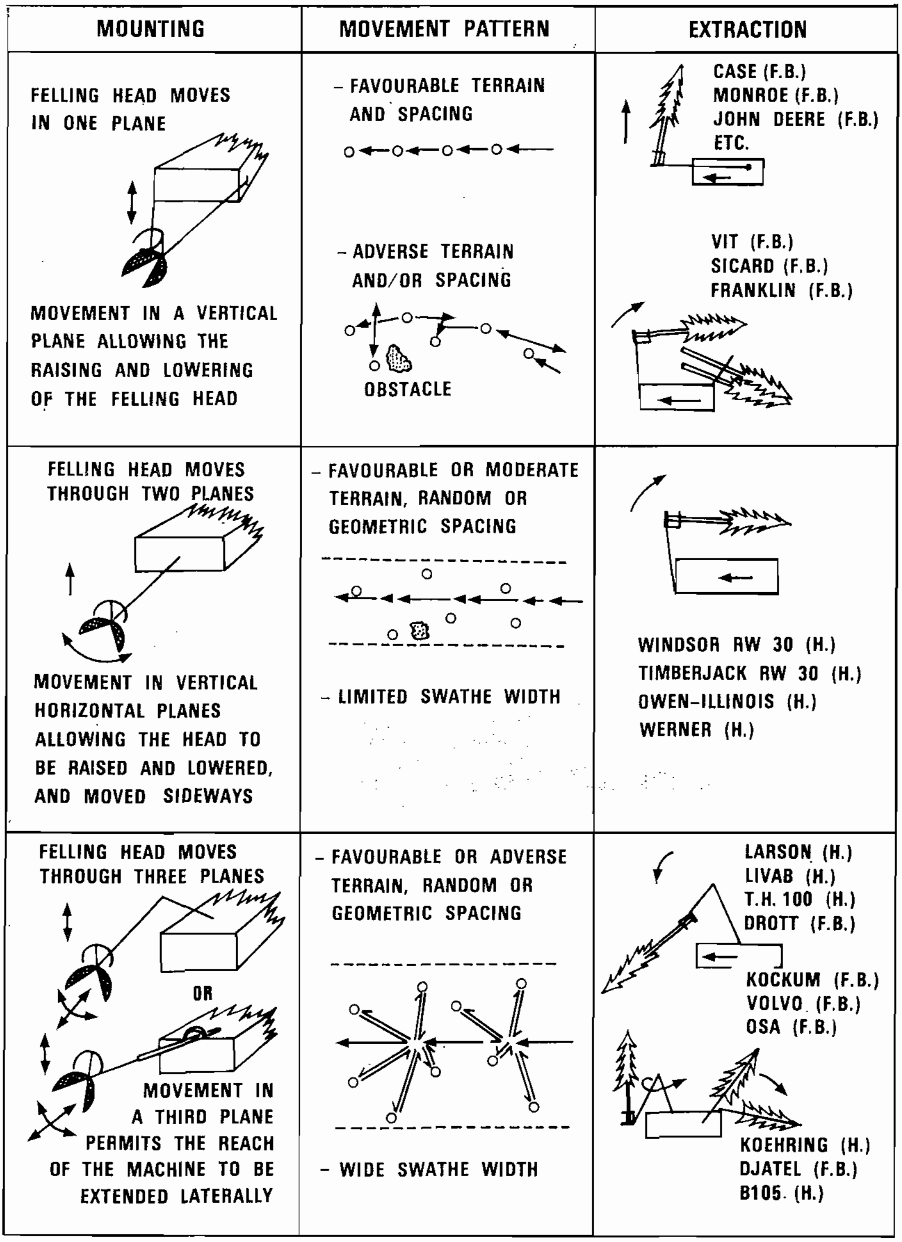

FIG. 3—Mounting of felling heads for feller-bunchers and harvesters.

fast cycle times and improved control have been obtained at the cost of a high level of machine sophistication.

A recent study by Sondell and Svensson (1974) of the Osa 670, which is one of the more advanced machines of this type, indicated that a basic cycle time of 15 to 24 seconds per tree is possible under the conditions described. This fast cycle has been made possible largely because of the recently introduced hydraulic servo control valves (Monsum-Tison) which combine the many functions of such a machine into two control levers, facilitating combined actions and also the use of large hydraulic valves with desirable flow characteristics. Special features associated with the chassis of this machine permit it to be operated on slopes of up to 30°. This type of feller-buncher ranges in cost from $60,000 to $90,000 and they are not currently being used in the thinning of small-diameter stands.

The application of feller-bunchers to radiata pine is currently being examined by the Harvesting Research Group of the Forestry and Timber Bureau. Unlike slash pine in which this machine type is used in the U.S.A., radiata pine has a deep crown. Bunches of felled trees are bulky and difficult to process by chain saw. Also, a higher proportion of the labour input is in limbing and it is this function that must be mechanised. Preliminary investigations suggest that the reduction in labour and costs will be modest.

However the use of this tool will facilitate subsequent conversion of the tree either by processor into roundwood or by chipper and it is ultimately expected to find a wide application.

Limbers and Processors

Many simple devices have been developed which merely limb the felled tree or limb and bunch. They generally utilise the tractor winch or tractor to pull or push one or several trees through the limbing mechanism. Such simple devices have been around for 15 years. Their productivity has generally been considered to be too low and emphasis has been placed on the development of the technically more complex but more productive multi-function machines. But as cost of labour rises, it is possible that these simpler devices may find an application, particularly to small scale operations.

A considerable range of processors is marketed today which convert the felled tree into final log products (e.g. Volvo, Kockum, Valmet and Hahn processors). They are certain to find a role in clearfelling operations and probably in some thinning operations.

Only the Pika and possibly the Tvigg, can be used within the stand. The other machines require prior extraction to landings because of either their dimensions or work method.

The main components are:

(i) infeed device which may be a telescoping or sliding boom, or a standard knuckle boom

(ii) Feeding mechanism: either feed rolls (Volvo, Kockum) or reciprocating type (Logma, Pika, Hahn).

The former is faster, achieving limbing speeds of up to 150 m per minute but is a less positive form of feed. Its performance in radiata pine, with the thick bark and heavy limbing of this species, remains to be assessed.

(iii) Delimbing knives: a considerable variety of delimbing devices have been used in the past for this function and have been described by Myhrman (1970). Virtually all limber-bunchers and processors today use either a knife-belt or one fixed and two moving knives. The knife-belt has advantages in lightly limbed, small dimensioned wood; the three knife design in heavier branched material. Experience with several types of limbing devices suggests that it will be very difficult to achieve a high standard of limbing in radiata because of the wide variation in branching habit, in particular branch angle.

(iv) Bucking to length: this may be done by shears or more commonly by saw. Because many of these machines are designed to produce saw logs as well as pulpwood, bucking by shears is avoided because of the damage done to the log. Where frozen wood is encountered this damage is extensive. It has yet to be determined if this is of economic significance in our radiata plantations. Length determination may be a problem with some of the processors using high speed feed rolls. Our saw logs are usually cut to more specific and exact lengths than is common in Scandinavia.

Whole Tree Chipping

The chipping of trees of the size yielded by our current first thinnings operations and the pulpwood component of later harvesting operations has the following advantages:

(i) much higher fibre yields per hectare can be obtained because of the utilisation of top and branch wood and smaller trees. This may approach 100% if close spacings are adopted;

(ii) harvesting costs do not rise so rapidly with decreasing tree size and/or stem form;

(iii) malformed stems can be more efficiently processed.

Chippers designed specifically for small diameter wood or whole trees can process several trees at once. This characteristic is one of the reasons why the concept has been so rapidly accepted in North America where it is widely used in harvesting cut-over forests which today consist mainly of hardwood species with a high proportion of the volume in very small sizes — down to 5 cm. This technique has resulted in massive increases in fibre yield; up to 100% as compared to normal roundwood yield. Over the past two years approximately 400 whole-tree chippers have been introduced and their acceptance has been much more rapid than that of the multi-function harvesters producing roundwood.

There is considerable scope for the development of chippers better suited to mobile or semi-mobile applications. The bulk of whole-tree chippers in use today use conventional disc chippers which are excessively heavy, involve considerable kinetic and gyroscopic forces and have a high power requirement. Currently there is considerable development work under way on developing the disc chipper for this type of application and also on other types of chippers, in particular, the drum type.

All installations working today on an operational basis are located at major landings and are usually fed with a grapple skidder. However experimental work has been carried out in Sweden (Bygren and Lidberg, 1973) on a forwarder mounted unit that can operate in the outrow for harvesting of thinnings. Ideally the machine would be used to process trees that had been felled and bunched by a feller-buncher.

To date, only the chipping process has proved its ability, on an operational basis, to convert stands of very small diameter trees, particularly if the form is poor. Several multi-stem delimbers have been in operation on a limited basis for several years, but they have not found a wide application.

A considerable research effort is currently being put into whole tree usage. The Canadian Pulp and Paper Research Institute has been working on chip-bark separation and segregation for about 10 years and now claims to have developed its process to the stage where discussions are being held with equipment manufacturers and potential users on its commercial application. Remaining problems largely arise from the need to develop more effective means of treating process effluent and this aspect is currently receiving attention.

The U.S. Department of Agriculture's North Central Forest Experimental Station at Houghton, Michigan, has carried out a considerable amount of work in the area of whole tree utilisation and the segregation of foliage and bark from the woody component. Biltonen, Erickson and Mattson (1973) in an economic analysis of whole tree chipping and bark removal, showed a US$3 per cord (about US$1.2/m^3) cost advantage in favour of that process as opposed to the conventional roundwood harvesting, debarking and chipping process used in their hardwood operations. The debarking process used involves steaming the chip-bark mix and passing through compressive rollers. Foliage and lighter fragments may be removed by screening and air separation if required. Several pulp and paper companies have contributed towards a proposed pilot plant to permit further exploration of the technique.

In Scandinavia a joint inter-Nordic study examined the feasibility of utilising logging waste as early as 1969. Recent movements in fuel costs and the limitations in fuel supplies have prompted renewed interest in Sweden in the chipping of logging waste and small trees. Several pulp and panel product companies are experimenting with the use of such raw materials, some on a mill scale basis. A three year research and development project with a total budget of about two million dollars has recently been announced. Involving the Swedish Pulp and Paper Association, the Swedish Government, the Royal College of Forestry and the Swedish Logging Research Foundation, the project is aimed at increasing the level of research activity into harvesting and utilisation aspects of the whole tree.

The economical harvesting of very small diameter wood and therefore maximum use of the growth potential of a site, is dependent on industry evolving means of using the product of whole tree chipping. That this is recognised is illustrated by the level of activity in this field.

Harvesters

This machine type combines the functions of the feller-bunchers and delimbers or processors. It fells and positions the tree with the range of felling and handling mechanisms described in the section on feller-bunchers. The tree is limbed and converted into wood lengths ranging from 2 m to tree lengths. Some produce and segregate different assortments. The various arrangements of the main components have been categorised by Carlson and Blonsky (1973) who examined recent patent applications in this field. Of the 90 patents considered to be applicable to harvesting trees the following solutions were favoured by the patentees:

1. 50% delimbed at or near the stump
2. 43% move tree through a stationary tool
3. 76% utilise linear feeding
4. 81% process in horizontal position
5. 90% do all the limbing with one tool
6. 90% delimb one tree at a time
7. 61% delimb tree-length material
8. 95% delimb towards the crown.

Like the feller-bunchers, the working pattern is determined by the mounting of the felling head. The following machines can be considered applicable in concept to early thinning in radiata pine. In practice they may have some problems in coping with the form and branching habit, particularly if current wood specifications are to be met. Machine dimensions also preclude their application in closer than 2.4 x 2.4 m spacings.

The Windsor/Timberjack RW 30 with its two-plane mounting can remove the outrow plus selected trees from the adjacent row over a wider range of slope and ground conditions than machines with single plane mounting of the felling head. The felling head can be positioned independently of the direction of movement of the prime mover, unlike the single plane mounting where the machine must be manoeuvred onto, and backed off trees in the adjoining rows. This relatively simple harvester has a demonstrated ability to harvest early thinnings at a cost that compares favourably with chain saw-based techniques.

Those machines with the felling head mounted to move through three planes are still less affected by adverse ground conditions such as residual hardwood. Machines like the prototype John Deere and Livab harvesters are capable of reaching in several rows to selectively remove trees. As the machine is stationary when the felling head is positioned it can be used in rougher ground conditions.

Such machines are, however, both costly to buy and operate in first thinnings where significant increase in the cost of harvesting by such equipment must be weighed against the increase in value to the residual stand that arises from the more selective thinning operation.

However in later thinnings with increased wood size and a yield of saw logs, the cost differences are not so significant.

Two of these machines have been developed as a result of specific projects aimed at mechanising thinning operations. One is the Windsor/Timberjack RW 30 which was developed by A P M Forests Pty Ltd, the Forestry and Timber Bureau and R L Windsor and Son Pty Ltd for thinning radiata. This machine has been evaluated (Powell, 1975) and a thinning operation based on this machine is described by Raymond (1976). Several of these machines are currently working very effectively in slash pine in southern U.S.A. and have been introduced into eastern Canada and Germany.

The Livab G1, which has recently been described by Sondell (1974), is an expression of a concept proposed by Hedbring, Nilsson and Akesson (1968) in 1968 which was subsequently refined by extensive simulation to obtain the best possible solution.

Specific problems associated with the harvesting of radiata pine include poor tree form and variation in branching habit. A high proportion of the trees may include stems of poor form including forks and swept butts. This particularly applies to trees that are selectively removed, they are generally removed because of their poor form. Even if the harvester can process such stems it is impossible to maintain a high standard of limbing.

The main feature of its form and branching habit is variability, both within the tree and between trees, which becomes more evident with improving site productivity. The following indicates the range of branch habit that may occur on stems which would be removed in a scheduled first thinning operation:

Mean branch frequency range:	3 to 12 per metre over the length of the merchantable bole
Branch frequency maximum:	15 per 0.1 metre of stem
Branch diameter range:	0.5 to 8.0 cm
Branch angle range:	10-90 degrees from main stem

Profuse branching occurs during the juvenile phase of the tree's growth which may extend from near ground level to 2 to 3 m in height. Stem form may be characterised by a high percentage of double leaders (forked trees) and marked changes in stem diameter at branch whorls.

OFF-ROAD TRANSPORT

In practice we have three options available for extracting early thinnings. These are forwarders, skidders and cable systems. They will be used in that order of preference, terrain largely being the determining factor.

Forwarders

These machines were introduced into Australia about 1967 with the introduction, by the Harvesting Section, of the MF "Treever", because they were seen as being less sensitive to piece size than existing systems. Over the intervening period and in particular over the past three years following the introduction of the larger Volvo machines, they have rapidly displaced skidders and other methods of extracting early thinnings. They are doing this because they are a highly efficient means of transporting small diameter wood, which can, if required, travel considerable distance from stump to track. They also fit our wood handling system, with their ability to recover different assortments — say pulp and saw logs. They keep the wood clean. From an operational management viewpoint they facilitate good control in that the contractor is prepared to move from his truck seat to the comparable comfort of the forwarder where he has more contact with the operation.

There are some disadvantages: they are costly ($30,000 to $90,000) and complex machines requiring skilled operators and mechanical support. They also have very high ground pressures and can do considerable damage to the soil structure and possibly the root system of the tree. The latter is a consideration that has in part prompted the Scandinavians to keep their extraction tracks far apart. In these countries the rooting system is frequently concentrated in the 20-30 cm of organic soil sitting on top of rock.

It is suggested that in many of our plantations and in particular, those that are prone to bogging, the closer spacing of outrows and the use of medium-sized forwarders may be desirable in that the number of passes over a given route is reduced.

Skidders

The use of skidders for the extraction of early thinnings has been declining in Australia because their production is largely dependent on tree size, and because of the higher level of damage to the residual stands associated with the skidding of long lengths.

However the grapple skidder is an efficient means of moving bunched material over the moderate distances associated with plantation logging. The introduction of feller-bunchers and roadside processing or chipping, or of harvesters producing bunches of tree lengths, could see an upsurge in the use of this machine type.

Investigations carried out in Gippsland indicated that the skidding of first thinnings as full trees was very inefficient. Skidder payload was reduced to half where full trees averaging approximately .085 m^3 were skidded behind a 97 hp machine as a single bunch. Grapple skidders would probably be less adversely affected because the load can be lifted further from the ground, but with the heavy branching associated with higher site qualities, it becomes impossible to assemble a reasonable payload.

Cable Systems

Light skylines have recently been introduced for the extraction of first thinnings. However costs on roadside are approximately twice that for conventional techniques and will find an application only in forests close to pulp mills or where wood supply is limited.

They will, however, find an increasing application in the extraction of larger diameter material either in thinning or clearfellings.

It is extremely difficult to envisage any method of cable extraction that will not remain very sensitive to declining tree size, because of the lack of a mechanised means of felling and bunching full trees or felling, limbing and bunching material at or near the stump.

It is of interest to note that the preferred order in an economic sense is a reversal of that which may be desirable in terms of impact on the site. For example, forwarders exert ground pressures of about 10 to 14 lb per square inch, skidders from 6 to 8 lb, tracked machines from 3 to 7 lb, and cable systems nil.

It is highly desirable that we understand more about the effect of machines on soil,s tree growth, and water quality.

CONCLUSIONS

In the broadest terms there are only three options open to the forest manager who wishes to continue thinning his stands at an early age. He can:

(i) continue current selective thinning practices and chain saw-based harvesting techniques. With small scale operations or those producing special products such as round timbers, this would appear to be the best technical and economic solution for the rest of this decade.

(ii) Modify silvicultural practice and wood specification, e.g., by introducing row thinning and accepting round wood or chips of a lower standard of preparation. Highly mechanised and productive harvesting systems based on relatively simple machines such as row harvesters, feller-bunchers and multiple stem limbing devices on chippers are currently available. Today they are largely confined to plantations established on easy terrain and where the wood or chips are used by large pulpmills capable of utilising this type of material. However it is anticipated that technological developments in both harvesting equipment and wood-using plants will extend the application of these techniques.

(iii) Increase stem size to permit the economic use of the more sophisticated machine systems which can selectively thin and produce traditional roundwood products. This can be achieved by wider initial spacing, thinning to waste or by delaying the first commercial thinning. Machine systems capable of harvesting *P. radiata* on a selective basis are beginning to emerge but harvesting costs will not compare favourably with the two previous options until well into the next decade.

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