THE PRINCIPLES AND PRACTICE OF PRUNING - By Rowan Reid

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The ideas and words in this liftout are the author’s and do not necessarily reflect the views of any other group or individual.

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PART ONE: WHY PRUNE TREES?

I prune trees. I see pruning as a risk management strategy aimed at growing large logs faster, reducing harvesting costs, and enhancing my marketing options. I believe pruning is appropriate for me - but I’m not fanatical about it (am I?). I try to ensure that my pruning time is carefully allocated and not wasted on trees that will never make a good log. I’m probably more fanatical about thinning, which, as I will illustrate, is a key to making pruning viable.

I share the view of David Hocking, a respected farm forester in New Zealand, who argues: "In my opinion the case for pruning remains overwhelming, especially for small growers. I accept that it is a significant investment. I accept that pruning alone is not a guarantee of wood quality and I accept that future markets cannot be guaranteed. But what is?" ²

In my opinion, a pruned and thinned forest is more interesting to manage, more attractive to live and work in, and a more worthy gift to my children than an overstocked, high risk, unpruned plantation of average wood quality. I also appreciate it is not always the best option for other growers. Before any grower makes such a decision they need to understand the principles and practice of pruning.
Pruning increases log value

The main purpose of pruning is to enhance timber value by increasing the proportion of clearwood®. Knot-free timber commonly attracts a premium price in appearance grade markets for pine®, eucalypt, teak, Douglas-fir® and many other species. Although not often specified, knot-free timber is also preferable in the structural timber market where large or loose knots affect timber strength®.

For pruning to be effective, knots or defects resulting from them must cause significant product downgrade. Sawing trials of unpruned trees by CSIRO (E. globulus®) and Queensland DPI (E. cloeziana®) confirm that knots are the worst grade-limiting defect affecting the out-turn of both appearance and structural grade sawn timber from eucalypt plantations. Waugh and Yang (1994)® of CSIRO actually concluded that, because of knots, "there appeared to be little commercial opportunity for appearance products" from eucalypt plantations in Tasmania.

Sawing trials involving pruned (and spaced) trees suggest that pruning can dramatically enhance sawlog quality in most species including eucalypts (when not prone to excessive kino gum) and softwoods (when not predisposed to large resin pockets). Milling of pruned 13 year old E. globulus in Western Australia® and 10 year old E. nitens in Victoria demonstrated that it was possible to achieve reasonable recoveries of clearwood sawn timber from quite young trees. Ignoring kino, pruned E. fastigata logs produced 30% clears compared to less than 6% for the unpruned top logs from the same trees in a New Zealand milling trial®.

The potential for pruning to enhance clearwood production in Pinus radiata is well-established®. For other softwood species grown in Australia the evidence in favour of pruning is also strong: for example, 17 year old pruned and thinned Cupressus macrocarpa had a recovery of high-grade timber from the pruned butt log of 72% compared to just 15% for the unpruned second log. International research also supports pruning of deciduous hardwoods like poplar® and oak®. Once pruned, the next most significant factor affecting the recovery of clear high-grade timber in almost all studies was log diameter.

Pruning aims to confine branch-related defects to a ‘knotty-core’ within the log. The shape and dimensions of this core will impact on the recovery of clearwood in the form of sawn boards or veneer. The nature of occlusion over a pruned branch stub can lead to an extension of defects beyond the end of the branch stub. These defects include the inclusion of bark, resin, gum, stains or irregular grain. A study® involving Douglas-fir (Pseudotsuga menziesii) reported that the Diameter Over Occlusions (DOO) can be significantly larger than the Diameter Over Stubs (DOS) if the pruned branches are large or if pruning cuts are not smooth. Based on many years of research it has been suggested that in New Zealand the DOO in Pinus radiata will be about 3cm larger than the DOS if pruned as recommended®.

It is often assumed that forest growers who prune will be paid a premium price for their logs. Pruning of hoop pine (Araucaria cunninghamii) in Queensland has been traditionally driven by a steep price gradient that sees the royalty on a cubic metre of log increase almost in direct proportion to the log diameter with a premium of around 50% for pruned logs®. The price gradient for P. radiata across the country is similar, but due to the limited supply, the premium for prune logs is less clear. In New South Wales premiums of as much as 100% are suggested®. In New Zealand, despite a drop in pine log prices off their highs of the late 1990s, the premium for pruned logs is still around 60% on the domestic market and close to 100% for export logs®. Unfortunately, the nature of any price gradients for diameter or premium for pruned plantation logs of eucalypts in Australia can only be predicted from the results of sawmill studies®. However, based on native forest prices (Fig. 2) for veneer logs a premium of at least 50% for pruning alone seems realistic at this stage®.

There is a risk that substitutes, such as medium density fibreboard (MDF), or intensive processing methods (such as finger jointing) will reduce the demand, and hence the premium, paid for clearwood logs. Finger jointing in pine costs about $170/cubic metre of sawn dried timber®. If related back to the log, this suggests that the processor could afford to pay an additional $40 or so for pruned logs (assuming a sawn recovery of 50% of which 50% was knot-free). Finger jointing results in a ‘manufactured’ appearance and MDF is simply not a ‘solid wood product’.

Figure 2: The price gradient for log royalties in Victoria (1995).
Steep price gradients make pruning a more attractive option.
Pruning can halve your rotation time

If diameter growth can be enhanced, the rotation time required to produce a high quality saw or veneer log can be reduced. In unpruned plantations it is knot size and distribution that makes it impossible to take advantage of the rapid diameter growth rates that are possible when trees are open grown. Pruning allows forest owners to space their trees in a way that stimulates diameter growth up to the point at which other problems, such as tree form, wood quality or low volume production per hectare, become a concern\textsuperscript{23}. In the northern hemisphere, where growth rates are very slow, the results can be dramatic. One Canadian report\textsuperscript{5} goes as far as to say: "pruning is the only way to produce clear wood in rotations of less than 100 years". In England, the rotation age for oak sawlogs can be reduced by as much as 60 years (from 150 to 90 years) using quite conservative thinning regimes and pruning - without having a significant effect on wood quality\textsuperscript{23}.

Many authors report similarly dramatic reductions in rotations for plantations of eucalypts, including for *E. nitens* in Tasmania\textsuperscript{24}, *E. fastigata* in New Zealand\textsuperscript{12}, many eastern state temperate species in Western Australia\textsuperscript{26} and a range of sub-tropical eucalypts in Queensland\textsuperscript{25}. Richard Moore\textsuperscript{26} has achieved average diameters of 53cm (*E. diversicolor*) and 57cm (*E. globulus*) within 19 years following early pruning and thinning to 150 st/ha. Pruned *E. fastigata* grown in N.Z. at a stocking of just 76 st/ha grew to a mean diameter of over 65cm in 29 years\textsuperscript{12}. When these and other research results are compared with publicly available data from unpruned eucalypt plantations held at stockings sufficient to control early branch development the difference is stark (Figure 3).

Achieving a large diameter is more critical in eucalypt sawlogs than it is for pine. As well as increasing the width of the clearwood zone, diameter growth dramatically reduces the impact of growth stresses\textsuperscript{54,27}, and allows quarter-sawing techniques (often essential to reduce drying degrade) to be used effectively\textsuperscript{55,27}. A minimum diameter overbark of 60cm is often recommended\textsuperscript{28}. Because of the intolerance of eucalypts to competition this will require much lower final stocking rates. This has a bearing on the number of trees requiring pruning.

Controlling competition between trees (thinning) is an important aspect of pruning. Although a high initial tree stocking can improve growth and form by providing ‘mutual shelter’, at some point the competition will begin to dramatically reduce diameter growth and therefore the benefits of pruning. If some of the trees have been left unpruned in anticipation of a future commercial thinning, these ‘followers’ can end up out-competing the pruned trees suppressing their growth even further. This concern has led some researchers to recommend\textsuperscript{24} limiting the severity of pruning to ensure it does not affect growth rates. In less tolerant species, like most eucalypts, severe competition can occur within conventional plantations (established at over 800 st/ha) within the first 4 or 5 years of growth\textsuperscript{55} when the basal area may be as low as 10m\textsuperscript{2}/ha. This suggests the prospects of a commercial thinning for pulp or small logs part-way through the rotation are remote.

Pruning may make it ‘viable to harvest’

Although automated harvesting equipment removes branches in a single motion, delimbing remains one of the most significant costs associated with manual harvesting\textsuperscript{29}. In fact, manual harvesting may be cost competitive against automated harvesting when log diameters are large, the trees well spaced and butt logs are pruned. This is important since scale of production is a critical factor in attracting automated harvesting equipment and may represent an obstacle to the viability of plantations less than about 20 hectares.

Another argument in favour of pruning is the increased flexibility it offers in light of uncertain future timber markets\textsuperscript{6}. If the species is appropriate, large diameter pruned logs are suitable for almost all timber product options from veneer down to woodchips. They are also suitable for milling across a wide range of processing methods. For example, small diameter eucalypt logs require specialised line bar carriage systems to counteract growth stresses during milling whereas large logs are suitable for most types of mills including small portable mills\textsuperscript{28}. This alone may be a critical marketing advantage for the forest grower in that it increases the number of potential buyers and may allow them to undertake their own value adding.

The common alternative to pruning is maintaining high initial stocking rates to control branch development then undertaking a commercial thinning operation to release the stand. Many, if not most, private plantation owners have had problems finding a market for thinnings and suitable contractors to do the work resulting in the stands being left unthinned for far longer than desired\textsuperscript{50}. Direct regimes, involving pruning and thinning, have far more harvest age flexibility: if markets cannot be found at any particular time growers can wait without placing the plantation under intense stress or risking stand stability.

Pruning enhances non-timber values

Pruned forests, because they can be widely spaced, provide the opportunity to incorporate other values into the design, such as a native understorey for biodiversity or low shelter; pasture for grazing; or even a second commercial tree crop such as bush foods. It may also be possible to begin the next timber rotation prior to the harvest of the first. For example, in north Queensland farmers are successfully growing the more tolerant hoop pine (*Araucaria cunninghamii*)...
under a pruned canopy of wide spaced *E. grandis*. The same can be done with pine under eucalypts in the southern states.

Pruning to reduce the fire risk was once common practice in Australian pine plantations. Pruning removes the 'ladder' of fuel required to maintain a travelling canopy fire31. If fuel levels on the ground can be kept down during the fire season by grazing or other methods, then the risk of tree damage may be minimal. Because wind speeds drive the rate of spread of a fire, and hence its intensity31, closely grazed pruned plantations can actually form an effective firebreak.

The negatives of pruning

Pruning is an expensive, time-consuming and labour demanding job that adds to the already heavy up-front costs associated with plantation forestry6. It is a job that must be done 'on-time' to the extent that missing just one year may result in the plantation being worth less than had it never been pruned at all. Ensuring forests are pruned on-time, every time has created real problems for industrial and small forest owners alike.

High pruning may also increase the risk of wind throw due to the increased exposure and the greater development of heartwood in the stem (see below). Increased light at ground level can exacerbate weed growth increasing the fire hazard, encouraging noxious weeds and making plantations difficult to access. In addition, there is the risk of decay or disease resulting from pruning and the uncertainty as to whether there will be a premium for pruned logs come harvest time. All this comes on top of the many environmental and market risks of any form of commercial tree growing.

These problems simply highlight the need to take care to ensure that the silvicultural regimes adopted match the particular site, grower and market opportunities. There are no short cuts – if growers are to maximise the benefits that pruning can offer, they must understand how pruning affects tree growth and wood quality, be aware of the various pruning methods and strategies available, and be able to make well-informed decisions about when and how to prune.

PART TWO:

**TREE GROWTH AND PRUNING PHYSIOLOGY**

How trees grow

The above ground part of the tree essentially grows in two ways. Elongation of the main stem and branches occurs as a result of cell division by the 'apical meristem' at the growing tips. The corky remnants of this growth can be seen in the stem as the 'pith'. Thickening of the branches and trunk results from cell division by the 'cambium', a thin layer of cells hidden just below the bark.

Both wood and bark are the result of cambium growth. The newly created bark cells form the 'phloem' through which the carbohydrates and hormones generated in the leaves flow down the trunk to the root system feeding cambium growth on the way. As new phloem cells are formed the old ones dry out adding to the protective bark. On the inside of the cambium, newly fashioned wood cells add to the sapwood through which the water and nutrients flow up the tree. The sapwood is also a place to store starch that can be later used to sustain the tree through periods of slow growth or dormancy. Usually, as each new growth ring of sapwood is formed, an inner ring of older sapwood is itself 'retired' (the cells being filled with crystals or resins) and becomes heartwood.

The type and number of wood cells produced by the cambium is determined by the concentrations of carbohydrates and auxin (an important plant hormone) generated by the canopy52. Following rapid shoot growth, high levels of carbohydrate and auxin result in the formation of large 'earlywood' cells. When the levels drop off during dry or cool conditions (or as the trees enters a dormant phase) small thick-walled 'latewood' cells are formed. It is the dense latewood cells that form the growth rings.

Wood formed close to the canopy, where the concentrations of auxin and carbohydrates are high, is known as 'juvenile' or 'crown' wood. Juvenile wood commonly has a lower density, lower percentage of latewood, shorter fibres and a higher amount of spiral grain than mature wood making it unsuitable for many uses35. Because pruning influences the location and amount of canopy on the tree, it has a direct influence on growth rate and wood quality.

**Impact of pruning on growth rate and form**

Pinkard and Beadle (2000)34 suggest that: 'the key criterion (governing pruning) is that there should be no significant reduction in growth rate.' This may seem like a reasonable notion, but is it really a sensible basis for the development of pruning prescriptions? Where only a portion of the trees within a stand are pruned it makes sense to be concerned about the prospect of pruning setting back tree growth, even for a very short time, because it could easily result in the pruned trees becoming suppressed by the more vigorous unpruned trees39. However, where all trees are pruned, or thinning is undertaken in concert with pruning, the risk of loss of dominance is eliminated. In this case, the choice of pruning method and its severity can be based on other criteria, such as wood quality, which are directly related to the reasons for pruning in the first place.

If the timing and severity of pruning is based on critical 'target log specifications' then it may be necessary to prune heavily even if tree growth is affected. What good is a pruning regime that minimises the impact on growth, if it is inadequate to control the size of the knotty core or risks encouraging decay due to large branch size?

**Height and diameter growth**

Almost all studies of stem pruning for clearwood production show that tree height growth remains largely unaffected by pruning. The exceptions are where pruning is extended well above what would normally be required35 or where the trees are growing in direct competition with unpruned trees39. This occurs because the carbohydrates and growth hormones that drive height growth are produced in the upper crown41 quite independently of the lower branches. The also explains why thinning a plantation does not increase its height, despite stimulating canopy growth35.

A number of eucalypt pruning studies undertaken in Tasmania have suggested that removing 50% of the green crown has no significant effect on tree diameter41,45. It is important to appreciate that this research was undertaken in fully stocked stands (near 1000 st/ha) and that the lower branches were probably in the early stages of senescence. For a true picture of the possible impact of pruning on diameter growth, it is important to study free-growing trees. In a Victorian trial, widely spaced (200 st/ha at age 6.5 years) *E. globulus*, *E. grandis* and *E. nitens* were pruned up to a range of stem diameters37. The more intensive the pruning, the greater the impact on diameter growth, with the pruning to 7cm retarding growth more than the 12cm which, in turn, retarded growth more than the 17cm treatments. In Queensland, a similar study25, involving wide spaced *E. cloeziana*, suggested that pruning just 10% of the live canopy of young trees has an impact on diameter growth.

In a Malaysian trial,38 it was found that leaving anything less than 5m of green crown on 3 year old *Acacia mangium* (an Australian tropical wattle) resulted in a significant reduction in diameter growth. Similar results have been reported for *P. patula*39 in Uganda, *P. radiata* in New Zealand40 and many other species45. What is important is the ability of the trees to recover.
Fortunately, well-spaced trees of most species recover quickly from pruning. When part of the canopy of a tree is removed, the photosynthetic activity of the remaining foliage increases providing some compensation. This was confirmed in Tasmania where it was found that an increase in the photosynthetic capacity of young eucalypts occurred within weeks of pruning and was sustained for almost two years. There was also an increase in foliage production, larger leaves and longer retention of existing leaves on the pruned trees. In one South African trial, eucalypts set back by pruning trees fully recovered their diameter increments in less than two years.

**Wood quality**

Concerns over the development of a large juvenile wood core seem to have limited the enthusiasm of some foresters for heavy pruning and wide spacing, even though both the theory and research suggests the opposite is more likely. Stem-pruning not only restricts diameter growth, and hence the size of a young tree, it also reduces the concentration of carbohydrates and auxins flowing down the trunk. Juvenile wood, as mentioned earlier, is produced in parts of the trunk that are close to the actively growing foliage. Slowing early growth and encouraging later growth is commonly mentioned as a way of improving wood quality. Pruning and thinning may provide a means of achieving this ideal.

Unfortunately, the wood density of some species remains low for many years. The wood density across the growth rings of Pinus radiata, for example, increases from the core out to the pith. Although most authors only refer to the first ten years growth of pine as being the “juvenile core” it is not until the trees are around age 20 that they are laying down high quality timber. Although the width of the growth ring in pine has no influence on wood density, concerns are being raised about the strength of pine when harvested under about age 25 years.

The wood density pattern in eucalypts is similar, although for most species this is less of a concern since their inherent density is relatively high anyway. In fact, young eucalypt timber, while retaining the appearance qualities of old-growth trees, may be easier to work as a result of a 20 or 30% reduction in wood density. Ring-porous hardwoods like oak and chestnut actually produce higher density wood when grown quickly. This comes about because in these hardwoods the wood density increases as a result of a 20 or 30% reduction in wood density. Ring-porous hardwoods like oak and chestnut actually produce higher density wood when grown quickly. Although the width of the growth ring in pine has no influence on wood density, concerns are being raised about the strength of pine when harvested under about age 25 years.

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Pruning also reduces the width of the sapwood band. The area of sapwood is related to the water demands of the canopy, so anything that reduces the size of the canopy will lead to a reduction in the area of sapwood in the trunk. If pruning is combined with thinning it is likely that the sapwood area will ultimately increase as the open-grown trees develop larger canopies. The width of the sapwood band at the time of harvest will depend on the level of the open-grown trees. If pruning is combined with thinning it is likely that the sapwood area will ultimately increase as the open-grown trees develop larger canopies. The width of the sapwood band at the time of harvest will depend on the level of competition at that time. If a wide sapwood band is likely to reduce log value it may be possible to pre-determine the stocking rate required to suppress growth just prior to final harvest.

**Log taper**

Taper refers to the rate at which the diameter decreases along the log. The ideal log is one that has no taper – a cylinder. If pruning reduces diameter growth without retarding height growth the implication is that it results in less log taper. This is the finding of a number of pruning studies including one based on high pruned Acacia mangium and another involving Pinus sylvestris (Scots pine).

Pruning (if combined with thinning) reduces stem taper in another way: because the concentration of auxin and carbohydrate defines the position in the stem of maximum growth, many authors note that the largest growth rings are found near the base of the green crown with diameter increments decreasing down the trunk. If, once pruning is complete, the trees are spaced such that competition does not lead to a substantial natural rise in the green crown, then it is only a matter of time until the pruned log assumes a cylindrical shape. This is unlikely to lead to the development of more juvenile wood at the upper end of the pruned log, because of the length of the branches in the lower canopy and the relative inefficiency of their foliage.

**Epicormic shoots**

If the canopy is destroyed by fire or wind (or pruned heavily), ‘epicoric’ shoots may develop up the length of the trunk. The shoots arise from buds that otherwise remain suppressed by the concentrations of auxins available in the phloem. Rapid changes in the light levels, temperature, nutrients or moisture can also induce a similar response. Heavy thinning of fully stocked plantations has the same effect suggesting that there are insufficient buds within the suppressed canopy to provide the leaf area to match the improved conditions. This can be seen in eucalypt plantations, and suggesting that adopting a heavy stocking to suppress branches and then thinning heavily to promote diameter growth, may prove self-defeating.

Epicormic shoots are not true branches and do not have a knot that goes right back to the pith like a normal branch. If removed within the first season, they leave an interesting girdled pattern and rarely cause any serious damage to the clearwood. However, if left growing, they can go on to produce veneer logs to firewood. It may be possible to reduce the risk of epicormic shoots in deciduous trees by pruning when the canopy is active. In very susceptible species (such as poplars, redwoods, cypress etc) pruning of epicormics may be required for one or two years after the final pruned height is reached. Once the canopy develops to its full potential in well-spaced trees it is able to suppress the buds in the stem and the risk of new epicormic shoots is remote.

**Self pruning and the pruning of dead branches**

Self-pruning (the death of lower branches and their subsequent ejection from the stem) is commonly observed in eucalypts. Unfortunately, even in fully stocked stands, self-pruning in eucalypts is unpredictable and variable in its effectiveness and may result in a range of secondary defects. When diameter increments are high, as is common in well-spaced plantations, the dead branches can easily become trapped in the stem before they become brittle enough to fall. Concerns about pruning dead branches on eucalypts have arisen from observations in Tasmania that when small dead juvenile branches of some eucalypts are pruned, the dead stub can get trapped in the cambium and pulled out from the knotty core as the tree grows, leaving a “trace” through the clearwood zone. There are no reports of this being observed in sawing trials of pruned trees in Western Australia or Victoria, nor are there any reports of a similar occurrence in other tree species.

**Pruning and wood decay**

Although pruning of eucalypts does increase the risk of decay-forming fungi entering the tree, the decay is usually limited to the branch stub. The incidence of decay appears to be related to the diameter of the branch, with those over 2cm clearly at higher risk.
Decay is also more prevalent in areas of high rainfall and moist summers. Once infected, the extent of decay is most advanced above and below the branch and towards the pith. No significant movement of decay outwards into the clearwood zone from a branch stub has been reported in any of the studies involving eucalypts. However, the likelihood of decay arising from branches pruned in the second or subsequent pruning lifts flowing down into the clearwood growing over the pruned stubs below is still unclear.

One study of Acacia melanoxylon found that of 147 stubs extracted from 20, 11 year old trees pruned 4 or 5 years earlier only six did not exhibit decay. However, unless associated with insect attack, the decay never extended out into the clearwood zone despite spreading back to the pith and, in one case, up and down the core. Only two stubs were found to have evidence of insect attack through the pruning wound.

New Zealand researchers, who veneered pruned E. nitens, concluded that decay pockets were "confined, in the main, to the caroty and defective compression heart zone of the pruned logs." The same was reported when winter-pruned E. nitens was milled in Victoria, despite decay in the stubs being quite common. Another New Zealand paper, reporting on the milling of pruned E. fastigata states "there was no internal decay associated with the pruning." Pruning-related decay has not been raised as a concern in any of the Western Australian work involving a range of eucalypt species.

Although trees cannot expel decay-causing fungi or heal the damaged tissue, they are able to isolate the infection in order to protect the new wood. The pattern of movement of decay in trees is explained by Alex Shigo's model of 'Compartmentalisation of Decay in Trees' (CODIT). In the tree's best defence, the 'barrier zone', formed in the year following pruning, the tree plugs vertical cells above and below the branch and towards the pith. No significant movement of decay outwards into the clearwood zone from a branch stub has been reported in any of the studies involving eucalypts. However, the likelihood of decay arising from branches pruned in the second or subsequent pruning lifts flowing down into the clearwood growing over the pruned stubs below is still unclear.

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Large branches should first be cut well out from the stem to reduce their weight. If using a saw, first undercut the branch to eliminate the risk of bark stripping. Branches less than about 2.5cm can be cut in a single action with loppers. Even slight damage to the branch collar of *E. nitens* at the time of pruning has been shown to slow recovery and increase the possibility of decay.

Queensland kauri pine (*Agathis robusta*) is one species in which quite large live branch stubs will be eventually ejected cleanly from the stem, suggesting that pruning may simply require cutting of the branches back to 10 or 20cm. Unless diameter growth is very rapid, the stubs will be ejected cleanly. Large branches should be cut as normal.

If the collar is not damaged the wound will heal quickly and evenly with the callus forming a "doughnut" as it grows over the stub.

### Season and frequency of pruning

The most critical factors influencing the choice of season for pruning are the risk of infection and dormancy of the cambium. In temperate areas, late winter pruning of eucalypts is generally recommended. This reduces the risk of bark tearing or 'popping' as the cambium is dormant, while taking advantage of the rapid tree growth in spring to control any decay. Dormant season pruning is also recommended for softwoods as it has been shown to result in less resin flow and hence defects developing over the branch stub.

Although winter pruning of deciduous trees is easier due to the lack of foliage and is less likely to result in bark tearing or decay, poplars are often pruned in late summer while the foliage is still green, so as to provide useful stock fodder. This may also reduce the risk of epicormic shoots developing on the stem.

Fast growing trees need to be pruned more often in order to control the size of the knotty core. Because smaller branches heal faster and are less likely to exhibit decay, annual pruning is preferred where practical. Despite the greater number of visits, annual pruning may be more cost effective because small branches are easier to prune.

### Form-pruning

Early form-pruning provides a means of correcting the shape of young trees, so as to encourage them to develop a single straight stem at least as high as the expected log length. Form-pruning may not be required if there are sufficient vigorous, well-formed trees, evenly spaced across the site - culling the poor trees will immediately improve the form of a plantation. However, where the selection ratio is low, correcting tree form can enhance plantation viability.

Form-pruning may be required within the first year to systems where the planting stock produce more than one leading stem. This is the case in poplars where a number of stems commonly arise from a planted cutting or barbatelle. The best single shoot is chosen no later than during the first winter, and the other removed – select the straighter of the two. Form-pruning of small branches is only required if they are affecting the form of the leading stem.

Form-pruning of young deciduous trees during the dormant season can dramatically improve tree form. It has been shown, for example, that following corrective pruning of dormant black walnut (*Juglans nigra*) the retained leader, if bent, will commonly regain a vertical form. It is also possible to physically constrain a leader into a vertical position for a period after which it will remain straight.

Ian Brown, a keen grower of *Acacia melanoxylon* in New Zealand, advocates summer early pruning of the leading shoots as a means of training the leader. It is very common (Ian argues intrinsic) for the very leading shoot of blackwood to abort early in the season, leaving the lateral shoots free of apical control. If left unchecked, two or three of the laterals may enter a struggle for leadership, resulting in irregular branching. A similar problem is common in black walnut (*Juglans nigra*), in which the first buds to burst in spring are those at the tips of the leader and branches. A late frost can easily kill the leading shoot, leaving the lower laterals to compete for the leadership.

Another type of early corrective pruning involves ‘pinching out’ of the large secondary buds that commonly develop at the base of the branches of some species. The ‘bud-pruning’ prevents branch development and has proved successful in reducing subsequent pruning costs in some tropical rainforest trees such as *Flindersia* species.

A simple method of improving a very poorly formed tree that has suffered from exposure or neglect is coppicing. In species that coppice strongly, cutting them back to ground level (usually in autumn when the reserves of carbohydrate are at their highest) can result in a strong new shoot with much better form than the original tree.

### Stability pruning

On exposed sites, particularly those prone to waterlogging, young trees commonly suffer wind-throw or toppling. Intensive soil cultivation (ripping and mounding) and fertilisation at the time of establishment can induce rapid leaf growth making the trees even more susceptible. Stability pruning involves the lightening of the canopy of young trees in an attempt to reduce their sail area and therefore the risk of toppling. Although it is possible to correct a young wind-thrown tree, an early form-pruning with an eye to tree stability may be warranted on susceptible sites.

### Pre-emptive pruning

Pre-emptive pruning involves the removal of lateral branches earlier than would be the case under a stem-pruning prescription. This usually involves the removal (or shortening) of large branches that may affect the form of the main leader. Pre-emptive pruning can also reduce the costs of later stem-pruning operations and help control the size of the DOS by removing branches before they become very large. Where disease or decay is of concern, the pre-emptive pruning of large branches may be important in reducing the risk of decay.
Annual pre-emptive pruning of Acacia melanoxylon, using a branch caliper of about 2.5cm to identify any branch within the log length that should be removed, has proven to be an effective means of improving tree form and reducing stem-pruning costs, while not affecting tree growth rate.\(^7\)

Stem-pruning regimes

Stem-pruning is aimed at confining the knots and associated wood defects to a relatively uniform cylindrical core up the centre of the pruned log. Because young trees are tapered, it is usually impractical to prune to the full height in one lift, so pruning usually involves a number of ‘lifts’. Prior to the 1980s, most pruning operations were done to a fixed height. For example, first lift to 2m, second to 4m and final lift to 6m. When applied across a plantation this resulted in over-pruning of the small trees and under-pruning of the large ones. For many years the New Zealand researchers advocated pruning to a minimum length of green crown. For *Pinus radiata* it was felt that leaving 3-4m of green crown would maintain growth, while allowing control of the knotty core.\(^15,2\) Taking a few simple measurements made it possible to determine the diameter of the stem at the point 3 or 4m from the top. A pruning calliper, corresponding to this diameter, was then used to guide the pruning operation. This approach introduced the concept of ‘variable lift pruning’, which is now recommended, and should be adopted as standard practice.

More recent research\(^7\) found that, despite variability in the length of green crown retained when using a calliper, pruning to a fixed diameter was actually an effective means of mimicking ‘constant leaf area’ pruning (rather than constant green crown length). This allows forest growers to define their pruning regimes on the basis of the size of the target knotty core, rather than the length of green crown retained. Pruning to a constant diameter on a regular basis is the only effective means of achieving a uniform knotty core.

How hard to prune (pruning gauge size)?

While the smaller the better in most cases, there is little point in achieving a tiny knotty core if the presence of juvenile wood or other defects results in the downgrading of the inner clearwood.\(^13\). There may also be limits to how close to the core the processor is able to cut. For veneer production the ‘chuck diameter’ of the veneer cores will be critical, whereas in sawmilling it may be the size of the ‘boxed heart’.

Based on the volume of the clearwood sheath for a range of log sizes, a knotty core of less than one-third of the underbark log diameter is a useful target (Figure 7). This would result in about 80% of the log volume being clearwood. To achieve a DOO of no more than 20cm up the entire length of the pruned stem may require that no DOS is larger than about 17cm. This allows for 1.5cm all round to cover the wounds and account for sinuosity (bends) in the stem. Pre-emptive pruning of large branches (over, say, 2cm) and annual pruning to a stem diameter of 10cm would be sufficient in most cases to contain the DOS to less than 17cm. For a 60cm log, reducing the knotty core by 5cm to 17.5cm by pruning more severely or regularly would increase the proportion of clearwood by less than 5%.

For *P. radiata* grown on fertile farm sites, a DOS of less than 19cm is a good compromise between the need to restrict the DOO and concern about the impact of heavy pruning on tree growth.\(^2\) On low fertility sites, trees are commonly less tapered and hence can be pruned to a smaller DOS, while leaving plenty of green canopy.

Where the sawwood of a species is unmarketable, the diameter of the heartwood sheath, rather than underbark diameter, should be considered. This would be the case for a wide range of species including Californian redwood (*Sequoia sempervirens*), black walnut (*Juglans nigra*), blackwood (*Acacia melanoxylon*) and even some of the lyctus susceptible eucalypts like *E. nitens*. In such cases it may be worth pruning harder to limit the knotty core to less than 15cm by using an 8cm gauge and spacing the trees wider to encourage larger diameter growth.

Heavy pruning may increase the risk of epicormic shoot development. Unlike branches, which must be pruned carefully to reduce the risk of collar damage, epicormic shoots on hardwoods (like eucalypt, poplar and oak) are easily removed from the ground using a long pole saw. Softwoods (pines and Californian redwoods, for example) tend to produce a multitude of fine epicormic shoots up the stems that are more difficult to remove from the ground. They may require that the tree be climbed so a knife or the back of the saw blade can be used to scrape them off.\(^15\)

![Pre-emptive pruning of Acacia melanoxylon. Any branch within the log length greater than 2.5cm is removed annually irrespective of the diameter of the stem.](image1)

![High pruned Acacia melanoxylon following the final pruning lift. A structure is now in place to grow clearwood.](image2)

![Figure 7. Percentage clearwood in logs of varying diameter (underbark) for different maximum knotty core sizes (DOO = Diameter Over Occlusions).](image3)
Clearwood milling of 10 year old E. nitens using a line-bar carriage and hand saw.
a minimum distance between any two final crop trees of at least 6m. If
this is accepted then, despite having established around 1000 st/ha,
more than a third of the trees would need to be culled on the basis
of spacing alone. This leaves less opportunity to cull on the basis of form,
branching habit or vigour.

An alternative approach is to establish the same number of trees
but in groups of three or four trees at least 6m apart. The best trees
in each group would be selected for the first one or two pruning
lifts. This would reduce the stocking to around 270 st/ha and allow
the final selection of the best 150 or so to be based on form and
vigour alone.

Tools and equipment for pruning

A wide range of tools are currently being used for pruning - almost
as many as there are committed forest growers. Handsaws, pole
saws, loppers, secateurs, chainsaws, motorised pole saws, battery
operated loppers, and many brands of each. For those who are
prepared to climb, there is also a range of ladders some of which
require harnesses. Rather than discuss any in detail I'd simply like to
present some observations.

Handsaws are essential for accurate cutting of large branches, or
those growing at an acute angle to the stem. Loppers are quick and
effective for small branches, but risk damaging the bark if used on
hardwoods during the growing season. Pole saws are effective for
pruning small lateral branches from the ground and controlling
epicormic shoots on hardwoods. Pole secateurs can be useful for
pre-emptive pruning from the ground. Chainsaws are heavy, noisy
and not necessary if the pruning is done on time. Pole chainsaws can
cause an enormous amount of damage to the branch collar and
should never be used. Hydraulic and compressed air pruners are
expensive and cumbersome. Battery operated secateurs look
promising, but may also be dangerous to handle up a ladder.
Pruning platforms are ideal on flat land but obviously expensive.
There is no one tool that is the best for every job.

Ladders are, in my view, essential to allow the pruner to work
close to the branch in order to ensure a clean and accurate cut.
Climbing without a harness is risky and unnecessary. A vertical
climbing ladder, used in combination with a harness (and bicycle
helmet), reduces fatigue, allows the operator to use loppers safely,
and almost eliminates the risk of dangerous falls compared to
conventional ladder pruning.

Documented evidence

Once wood has grown over the branch stubs it is impossible to
determine the size of the knotty core without cutting into the log.
Log buyers may not accept your assurances that the trees have
particularly good form and pruned on-time, every time. Australian Forest
Growers provides a Pruned Stand Certification that is ideal for
those with a relatively large, uniformly managed stand. Other
growers should document all aspects of their management in a
'Tree Diary' and take photographs of the stand immediately after
each pruning and thinning operation as supporting evidence.
Because of insect attack, the spread of decay, and other factors
there will always be uncertainty surrounding wood quality of
standing trees. One option is to harvest a sample of trees to assure
the buyer; otherwise growers could be paid on the basis of
graded output - 'over the saw'. This would help ensure neither the
grower nor the processor carry the financial risk associated with
the uncertainty.

Does pruning pay?

The efficient allocation of pruning time becomes critical to the
viability of the operation. If the forest owner makes a commitment
to high pruning, the cost per hectare is likely to be greater than the
cost of establishment, and possibly even more than the cost of the
land. The return on pruning time can be increased by pruning less
trees per hectare (such that the trees are not directly competing for
site resources), pruning vigorous straight trees with small branches,
and minimising the number of pruned trees that need to be culled
at a later time.

There have been studies comparing the economic returns of
pruned and unpruned silvicultural regimes16-15. In their favour,
regimes involving pruning yield a greater proportion of higher log
grades and shorter rotation lengths. On the negative side, there are
the higher management costs, lower volumes per hectare, loss of
potential income from commercial thinning, lower value logs from
the unpruned section of the tree, and uncertainty as to whether
there will be a premium for pruned logs.

Pruning, by any method, is labour intensive. The time taken to
prune individual E. nitens trees has been reported12 as 3 minutes
for the first lift and almost 5min for the second lift to a final height
of 6.1m. In my experience, skilled operators using a ladder and
harness can prune at least 20 well-formed eucalypt trees per hour.
If it is assumed that for every tree high pruned in three lifts, three
are pruned in the first lift and two in the second; these examples
should equate to a total of no more than 15 min, or less than $10,
per final crop tree. In New Zealand, experienced contractors are
expected to be able to prune between about 10 and 25 pine trees
per hour, whether working from the ground or from ladders15. This
equates to between $4 and $7 per final crop pine tree15.
Pruning costs are higher for heavily branched species or when
pruning is done steep. Steep sites or those infested with weeds will
be more expensive again. Flat grazed plantations on cleared
farmland are often the easiest and cheapest.

The fact that the pruning costs are directly proportional to
the number of trees places a great deal of pressure on final
stocking rates. There are no simple answers. For the softwoods
(Pinus spp, Araucaria spp, etc) final stockings of between 200
and 300 st/ha seem reasonable. For the hardwoods, I prefer
maximum final crop stockings of between 100 and 150 st/ha.

Figure 8 presents a simple model for estimating near 'free
growth' stocking levels for crown shy eucalypts and the more
tolerant pines based on basal area as an indication of the level
of competition. If trees contain no heartwood then the
basal area is proportional to the size of the canopy. As the
trees grow, heartwood (which has no physiological function
in the tree) makes up an increasing proportion of the basal
area of the forest. Hence, the basal area corresponding to
a particular level of competition in a plantation will
increase over time.

If pruned trees are grown free of intense competition the width of
the growth rings, and hence the yield of clearwood, will be greater. If
trees are grown ‘above the line’, diameter growth is likely to suffer due to competition. However, if competition is reduced too much the volume production per hectare will be very low and exposure may affect tree form. Although trees certainly grow faster on better quality sites, the point at which competition reduces diameter increment doesn’t vary as much as might be expected. Concerns about low stocking inducing heavy branching above the pruned section need to be balanced against the higher upfront cost of pruning more trees and the longer rotation associated with higher final stocking.

As a result of the many contributing factors there may be a number of explanations for the differing conclusions reached by various commentators, researchers, forest companies and individual forest growers about the economics of pruning:

- Shorter rotations may be critical to an individual hoping to see a return within their working life whereas government or corporate growers may be comfortable with long rotations as long as they receive an acceptable return on their investment;

- The costs of repeated pruning operations may be very much higher for industrial growers who need to supervise contractors working in isolated plantations for long periods compared to farmers who live near their forest and can do the work themselves;

- Industrial growers may have a choice of value adding in the mill whereas farm foresters usually only have one option - to value add on the stump;

- Varying levels of confidence in the prospects of being able to undertake a commercial thinning. Small, isolated or independent growers may find access to markets for small wood more difficult and hence may be better advised to adopt pruning regimes that are not dependent on the viability of early commercial thinning;

- Being able to sell when you want to is largely dependent on having a product that is in demand. It may be that without any pruned logs there will be no interest.

Having thought about my own circumstances, studied the principles of pruning and had a go myself I’ve decided to prune (and thin) – what about you?

Recommended reading:

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