GIPPSLAND FORESTRY HUB
Promoting the Forestry Industry

MID ROTATION MANAGEMENT FOR SMALL-SCALE PLANTATIONS

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Glossary

Feller buncher refers to a harvest head that is designed to cut one or more trees at a time and bunch them together. Feller bunchers do not debark, delimb or cut logs into set lengths.

Forwarder refers to a piece of heavy forest machinery that picks up logs after they are felled and debarked (processed) and transports them on a bunk to a loading area.

Mid rotation management refers to activities undertaken to commercially thin a plantation approximately halfway through its rotation. This operation normally removes logs for sale into a suitable market.

Non-commercial thinning refers to activities undertaken to thin a plantation in the first quarter of its rotation with logs not being extracted to a market.

Out-rows refers to removing an entire row of trees at a set number of intervals in plantation thinning as opposed to selecting individual trees across all rows.

Single-grip harvesting head refers to harvest heads that are designed to grip (cut and process) one tree at a time.

Skidder refers to a piece of heavy forest machinery that is used to collect whole trees in a log grab after they are felled and drag them to a loading area for further processing.

Small-scale plantations are those that are privately owned and generally under 20 hectares or unable to provide at least 1,000 tonne of resource in a thinning operation.

EXECUTIVE SUMMARY

In Gippsland, mid rotation management is difficult to achieve in small-scale timber plantations. This is due to several factors including restricted market access, high operational costs, difficult terrain, and lack of contractor suitability and/or availability. Barriers to mid rotation plantation management are a major threat to the success of private forestry in the region.

There are a range of factors that impact the quality and productivity of mid rotation management operations. The type of thinning system has a profound impact on the cost. Systems that remove entire out-rows are undertaken with greater speed and ease of operation, although they are less suited to hardwood sawlog plantations compared to selective thinning. Site characteristics such as slope, aspect and understory vegetation can impact mid rotation management productivity, in addition to plantation characteristics such as tree size, tree form, species and stocking.

A broad range of small and adapted forestry equipment is used internationally for mid rotation management. In Australia, very little of this equipment is used due to low demand and a lack of manufacturer support. In Scandinavia, the nexus of forestry machine development and small-scale forest ownership, medium size purpose-built forestry equipment is most popular for mid rotation management operations.

Haulage systems in Gippsland have relied on truck modifications such as piggyback trailers and central tyre inflation to reduce road building costs and to extend seasonal operational windows. In contrast, self-loading trucks are the backbone of the European forest industry, which allows haulage to work independently from the harvest operation.

Case studies in this report have identified the value of purpose-built forestry equipment and the impact of tree size on thinning productivity. While the capital cost of small forest harvesters and adapted forwarders is significantly less, the harvesting cost was ultimately found to be approximately three times greater compared to mid-sized purpose-built forestry equipment.

The size of Gippsland's existing private forestry estate suited to mid rotation management is approximately 2,400 hectares of small and medium-scale plantations. The dominant species are blue gum, yellow stringybark and spotted gum. These plantation resources are predominantly located in the Wellington and Latrobe Shires with approximately 20% established on steep terrain. This resource is located on 81 sites with an average plantation area of 30 hectares.

There are limited market options for thinning resources extracted from plantations in Gippsland. These include firewood, small sawlogs and some niche markets for poles and posts. Larger markets for wood chip export require transport to Eden or Geelong now that the Maryvale paper mill (Opal) is no longer available. Future markets are emerging in Yarram for veneer and bioenergy.

Most of the world's forest plantations have been assisted by subsidies of one form or another either directly or indirectly. Subsidies can be used to help overcome barriers, impediments, and constraints. Subsidies should be tailored for different stages of plantation development such as initiation, acceleration, and maturation. In the short-term, subsidies could be used to encourage non-commercial thinning and to offset harvest and haulage costs to enable growers to undertake commercial thinning. Incentives could also be used to assist the firewood industry to transition to plantation resources more rapidly. In the longer term, support is required to develop local markets seeking to utilise small logs and to support contractors seeking to invest in suitable harvesting equipment.

Overcoming mid rotation management challenges in Gippsland requires; (i) a viable resource being secured; (ii) a suitable harvesting system being used; (iii) the right management steps being implemented; and (iv) appropriate subsidies made available while (v) support is offered to help grow emerging local markets for the longer term.

INTRODUCTION

Forest harvest and haulage systems in Gippsland were originally formed around large resources, such as the public native forests and the vast plantation resources of Australian Paper and the Victorian Government plantation estate. These resources were often significant in area, volume, and tree size, necessitating harvest and haulage equipment with industrial capabilities.

While mid rotation thinning operations have historically occurred in these Gippsland Forest Estates, they have generally been undertaken on favourable terrain and where tree size and/or total volume has been sufficient to create a net positive return (Figure 1). Gippsland has benefitted from having a large paper mill (Opal - formerly Australian Paper) centrally located and historically purchasing both hardwood and softwood logs for paper production. However, the mill door price has always been comparatively low[a], meaning that large volumes and low-cost harvest and haulage systems were needed to make thinning operations viable. In addition, harvest and haulage rates in Gippsland are comparatively high compared to other forestry regions like The Green Triangle. This is due to the difficult terrain, high roading costs, restricted transport capacities[b] and short operational windows due to the climate and soils.

Figure 1. Pine thinning operation for Heartwood in Gippsland

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[a] Proven by the fact that hardwood chip exports via Geelong and softwood log exports via Melbourne often paid competitively higher prices.

[b] For example, there are significantly fewer approved roads for Higher Mass Limit vehicles in the Gippsland region compared to The Green Triangle

Small-scale plantations face a significant challenge successfully operating within this setting. With small areas and volumes, the cost of relocating industrial harvesting equipment and preparing adequate extraction roads can quickly amount to a significant loss on any proposed mid rotation thinning operation. Furthermore, access to markets and contractors is often out of reach for small private plantation owners. Local markets are often locked into contracts with the larger plantation owners, preventing them from buying other private wood. Contractors are also compelled to take long-term harvesting contracts to justify the large capital outlay for their equipment. This usually precludes them from undertaking thinning operations in small private plantations.

Even if a contractor and market can be lined up by a small-scale private plantation owner, a proportion of higher value logs (e.g. sawlogs, veneer or preservation) may be needed to make the operation financially viable. This can be difficult to achieve in practice. Not all contractors have modern harvesting heads capable of meeting tight log specifications and/or log optimisation. Even if so, multiple loads of each product would be needed to justify the large amount of work required to establish each market agreement. This is unlikely in small thinning operations as markets are not inclined to manage the administration around one or two loads of product. Especially where certification, chain of custody and safety create large paper trails.

Growers unable to meet these conditions often see their higher value logs downgraded to chip logs or firewood thereby eliminating any opportunity for a commercial return on their thinning operation.

It is against this background that a report has been requested by the Gippsland Forestry Hub Inc. to investigate opportunities for efficient, cost-effective mid rotation plantation management in small-scale plantation resources.

THE NEED FOR MID ROTATION MANAGEMENT

In forests managed to produce solid wood products, thinning is probably the most important operation carried out between canopy closure and the final harvest. Thinning removes trees of poorer quality and size so that growth is concentrated on the better trees remaining (Figure 2). This sustains health and vigour in the forest and enables the retained trees to generate diameter growth at low levels of competition. At the sawmill, thinning has been linked to higher timber recoveries, less drying degrade and lower growth stresses[1]

Figure 2. Eucalypt thinning operation for Heartwood.

Thinning must be carefully planned and executed. While there is an ideal time to thin forests from a physiological perspective, this timing doesn't always align with the ideal time economically. Early thinning is often done to 'waste' where the culled trees are left on the forest floor and the operation is a cost to the investment. Delayed thinning may result in larger trees being removed and sold for a profit, providing a commercial return to the investment. However, the delay may have a negative impact on the forest health and vigour and compromise diameter growth. Furthermore, delayed thinning can make forests more vulnerable to wind damage post-thinning or to reactions such as epicormic stem growth in *Eucalyptus* species (Figure 3).

Thinning also impacts branch development. Forests thinned too heavily promote heavier branches, whereas those thinned lightly and more gradually, maintain smaller branches as a result of reduced sunlight. Heavier branching leads to knots, which reduce wood quality and limit the potential use of the timber.

Figure 3. Epicormic regrowth in silvertop ash

For small-scale plantations in Gippsland, thinning is imperative. Without thinning, logs are primarily of low value and only suited to markets such as pulpwood and firewood. Furthermore, harvest costs are significantly higher for smaller diameter trees compared to larger diameter trees. Research undertaken in Western Australia[11] noted clearfall harvest costs in a 10-year-old blue gum that was thinned to 400 trees per hectare at age 3.2 years being approximately half the rate of the unthinned treatments. The combination of low value logs and high harvest costs has led to many small-scale growers being unable to progress their forestry ventures.

Nevertheless, a well-planned and thinned plantation can provide a very good outcome for small-scale growers, however, thinning is often difficult to achieve even if it is commercial in theory. For many small-scale growers, market access is unachievable, or contractor availability is unattainable, resulting in the only option being to pay for non-commercial hand thinning to maintain long-term value.

Even if a market and contractor can be secured, a financially viable outcome may only be achieved with a compromise. Traditional thinning strategies in southern Australia have been based around radiata pine, which uses out-row-removal thinning to reduce costs and enable larger machines access to the forest to cut and extract logs. With over 100 years of genetic development, plantations of radiata pine can be thinned this way successfully. The development of genetics in *Eucalyptus* species is far less advanced. Outside of the mainstream pulpwood species, form and vigour are far less uniform and the removal of entire out-rows can eliminate many of the best trees, devaluing the plantation. The situation is even more detrimental where pruning has been undertaken within the rows being removed.

The solution is to identify methods for thinning small-scale plantations that are cost-effective and adaptable to the needs of Gippsland growers seeking to invest in (predominantly) hardwoods for high value log products.

HARVESTING SYSTEMS

BACKGROUND

Australia currently hosts a range of commercial forestry harvest and haulage systems, which have been outlined in various reports[2,3,4]. In Gippsland, the primary harvest systems include tracked or rubber-tyred (wheeled) harvesters, using either single-grip harvesting heads or feller bunchers to fall trees (Figures 4a & 4c). Once fallen, trees are transported as cut-to-length logs on forwarders, or as whole trees using skidders (Figures 4b & 4d). Haulage is undertaken using single-semi trailers or B-double trucks where permitted. Gippsland forest harvesting operations do not utilise in-field chipping or A-double road trains, which are prominent in areas like The Green Triangle. However, Gippsland does host several cable harvesting systems for operations on extremely steep slopes. The cost of harvesting in Gippsland varies for each site and system.

Large operations can justify multiple harvesters and forwarders or skidders operating on each plantation to maximise productivity. A simple system may include one buncher to fall the trees, two skidders to transport the trees to a landing where a processor with a single-grip harvesting head is used to debark, delimb and cut the logs into preferred lengths. A dedicated loader is then used to load the logs onto log trucks for transport to the mill. An alternate to this system might contain two rubber-tyred single-grip harvesters falling and processing trees at the stump with one or two forwarders collecting the wood and loading the trucks. Operations of this size require crews of four or five people plus trucks. It also requires four or five separate float (relocation) costs to be absorbed in the harvesting fee. In large plantation resources, where many months of work are being undertaken, this does not have a major impact on the harvest rate.

Figure 4. Collage of mainstream timber harvesting equipment

a. Single-grip harvester

b. Forwarder

c. Feller buncher

d. Skidder

In smaller plantation resources, a more likely configuration involves just two pieces of machinery being a single-grip harvester to do both falling and processing, and a forwarder to extract the logs and load the trucks. While this configuration reduces float costs, it does elevate other costs in the process. Using single-grip harvesters to fall trees is more expensive than a feller-buncher[5]. It also requires a higher skill level from the operator, particularly in thinning operations, to avoid hang ups and damage to retained stems. Likewise, forwarders are generally more expensive to transport logs than skidders and are less capable on steep terrain[5].

Very small operations may use just one machine and a hand faller. In this scenario, each tree is hand felled with a chainsaw and then delimbed. An excavator is used to drag the tree to a landing area where the bark can be removed using the point (beak) of the log grab. The tree is then measured and cut into product sizes with the chainsaw before being loaded onto a log truck with the excavator.

IMPACTING FACTORS

SAFETY AND COMPLIANCE

There are many harvesting systems internationally making use of small-scale equipment for mid rotation thinning operations such as small excavators, tractors and even quad bikes. While such equipment reduces capital costs and often utilises equipment that has multi-purpose uses, there is restricted application for such equipment in Australia from a safety perspective. Equipment working in forest harvesting operations in Australia generally require the following:

- Falling Object Protection System (FOPs) – if being used under canopy.
- Roll Over Protection System (ROPs).
- Operator Protective Guarding (OPG).

Each of these safety requirements are required to meet Australian Standards. Therefore, an agricultural tractor used for forestry operations requires guarding across the roof and windows and potentially screens replaced with margard polycarbonate (19 mm on front and 12 mm on sides) to protect operators (Figure 5). While these modifications are achievable on most equipment, they add a significant capital cost to the forestry operation.

In addition, the need for operator training cannot be ignored. All forestry operations in Gippsland must comply with the Industry Standard Safety in Forestry Operations (2007), Occupational Health and Safety Act 2004 and the Victorian Code of Forest Practices for Timber Production 2014.

Figure 5. Valtra Tractor Modified for Forestry Operations

Plantation Characteristics

A range of plantation characteristics can impact the productivity and cost of mid rotation thinning operations. The largest of these is the tree size, often referred to as piece size or tree volume. Other influences include tree form, bark type and stocking[6,7]. Each of these factors can affect the time taken for wood to be extracted and the risk of damage to retained trees.

The minimum average tree size for a viable thinning operation varies depending on the cost to harvest and the market value of the resource. Research in walnut and alder plantations in Italy[8] identified 12 cm as the minimum average diameter at breast height (DBH) for economically viable thinning to occur. A further finding was that the thinning cost decreased by 60% when the DBH doubled from 10 cm to 20 cm DBH. Research into the thinning of conifers in Croatia identified 19 cm DBH as the average tree size where thinning operations started to accrue profits[9]. However, with a 18% increase in market price, this dropped to 15cm DBH. Research into harvesting systems for native forest thinning in Australia noted that DBH was the main productivity driver on harvest costs[10] and that thinning costs increased exponentially when DBH dropped below an average of 21 cm. Research into thinning of *Eucalyptus globulus* plantations in Western Australia noted that tree size accounted for 78% of the variation in harvester productivity[11]. Ultimately a larger trees size leads to a lower rate of harvest and a higher likelihood of a commercial outcome from each thinning operation.

In similar research in Western Australia, tree form was found to account for as much as 20% of harvester productivity[12]. Research has also noted harvesting productivity impacts due to different tree species and the type of bark they host. Heavier barked eucalypts like stringybark and ironbark are inherently more difficult to debark. The time taken to remove bark is due to the bark-to-wood bond on the different eucalyptus species[13]. Further research suggests that climatic and seasonal conditions can also play a significant role in the strength of this bond, due to varying moisture content[14].

Site Characteristics

Slope is a key site factor impacting the productivity and hence cost of mid rotation thinning operations[15]. Research assessing harvesting productivity in eucalyptus plantations in Brazil found that there was a direct relationship between slope and felling productivity[16]. On steeper terrain, log extraction is also impacted. Forwarders and skidders are both rubber-tyred machines, which are more limited on slopes than tracked harvesters. In very steep terrain, the tracked harvester is often required to “shovel” the logs to a more accessible location for the forwarder or skidder to collect. In other cases, additional tracks (side cuts) may need to be created for the forwarder or skidder to traverse. In some soil types, side cuts carry environmental risks and should be avoided. Fundamentally, each of these approaches impacts the overall cost of harvesting by either reducing productivity or creating additional roading expenses.

Site aspect is another factor, with plantations located on south and east aspects often experiencing wetter, slipperier soils, and narrower windows of opportunity for the safe and environmentally appropriate operation of thinning equipment. The Gippsland region hosts a significant proportion of its plantation resources on the slopes of the Strzelecki Ranges, creating significant challenges for harvesting operations outside of the traditionally dry months of January to April.

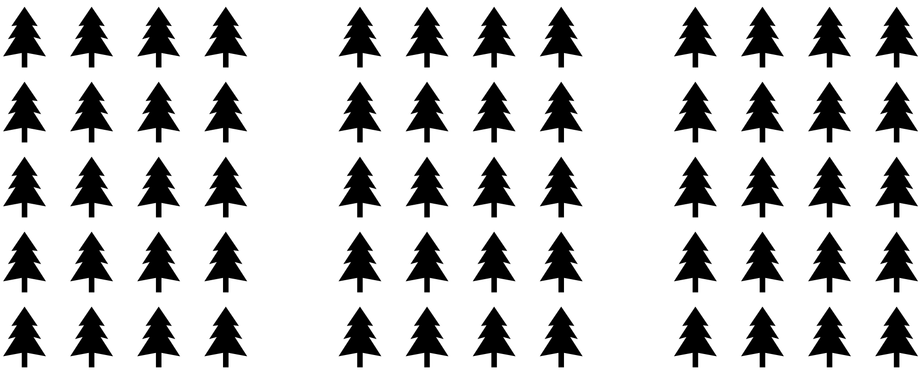
Understorey vegetation is often found on higher rainfall properties in the Gippsland region. Whether in the form of noxious weeds, such as blackberry, or native vegetation such as dogwood or tea tree, this vegetation can reduce thinning productivity due to reduced vision for tree selection and additional complexity for operators navigating the uncertain terrain beneath.

THINNING SYSTEM

The system of thinning a forest can have a significant impact on the type of equipment that can be used and therefore the productivity and cost of the operation. As previously mentioned, thinning in Australian plantations has predominantly used an ‘out-row’ removal system. Thinning is achieved by removing certain rows, either the third, fourth or fifth (Figure 6) depending on the original planting configuration. This system immediately reduces the plantation stocking by either 33%, 25% or 20%. While the rows are being harvested, some forest managers will also opt to remove trees within the rows being retained (bays). This further reduces the stocking, but more importantly, targets the poorer trees specifically.

The main benefit of the out-row-removal system is the speed and ease in which the thinning operation can be achieved. The operator moves the harvester in straight lines and is not required to select trees. The process also creates significant space to ensure falling, processing and extraction are carried out with minimal damage to the retained trees. The downside of the system is that dominant trees of good form are sacrificed in each row removed. Therefore, the system relies on high planting stockings and advanced genetics to ensure enough good quality trees can be retained for the long term. Follow up thinning operations can continue to use the same rows and select trees from the retained rows either side, or to take out additional rows as preferred. The out-row-removal system works well in conifer plantations, which are more tolerant of competition. This means that thinning can be delayed until trees are of commercial size.

Figure 6. Fifth row out-row thinning



While the out-row removal system works well on flat ground and gentle slopes, modifications are required on steeper terrain. Firstly, steeper terrain is generally planted along the contours to reduce erosion however, harvesting is generally undertaken up and down the slope for safety and stability reasons. Therefore, thinned out-rows must be created perpendicular to the original planting rows. This requires more time and operator skill to achieve and results in a decrease in harvest productivity and hence increased cost. Where slope becomes too steep and outside of the operational limits of forwarders and skidders, thinning with log extraction is generally not undertaken.

Plantations of *Eucalyptus* species grown for sawlog production are far less advanced in Victoria. In Gippsland, species such as shining gum (*Eucalyptus nitens*) and mountain ash (*Eucalyptus regnans*) have been grown for sawlog and pulpwood products. However, the relatively low returns from pulpwood and the high cost of harvesting in often mountainous terrain, have limited the amount of thinning undertaken.

In small-scale private plantations, species with less advanced genetics are more common such as spotted gum (*Corymbia maculata*), yellow stringybark (*Eucalyptus muelleriana*) and sugar gum (*Eucalyptus cladocalyx*). The out-row removal system is problematic in these plantations because a sub-set of the best trees are generally pruned to improve form and value of the final sawlog. To remove entire rows in a thinning operation can significantly compromise the plantation quality and economics by effectively taking out some of the pruned trees[c]. Planning pruning operations around thinning is also difficult unless the plantation is systematically laid out on flat terrain, furthermore there is often far fewer good quality trees to choose from in plantations with underdeveloped genetics. In these plantations either non-commercial thinning is required or thinning between rows. The latter is achievable where row spacing is 5 metres or on narrower spacing with small-scale equipment.

HARVESTING EQUIPMENT

Numerous studies have been undertaken to assess different equipment options for mid rotation thinning operations in small-scale plantations[3, 17, 18]. A significant amount of this research has been undertaken in Scandinavia, where small plantations are the dominant forest resource. For example, in Finland there are estimated to be over 600,000-forest owners and 50% of these owning less than 5 hectares. Private forests contribute 80% of the forest industries raw wood material. Harvest areas are on average 1.5 hectares[19].

Adapted Equipment

Mid rotation thinning operations are undertaken with a broad range of harvesting equipment. This includes adaptations for tractors and small excavators (Figures 7 & 8), which make use of equipment already owned by many landowners. Adapted forestry equipment is common in many parts of Europe where forest resources are primarily located on private land with mixed farming and forestry enterprises.

Figure 7. Valtra tractor adapted for tree harvesting

[c] Pruning to 6.5 m can cost approximately $6 per tree.

Figure 8. Komatsu PC70 6.5 tonne excavator with harvesting head

Small Purpose-built Forestry Equipment

In addition to the many mid rotation thinning operations using adapted harvesting equipment, Scandinavia is also host to several manufacturers of purpose-built small-scale harvesters. These machines are generally less than 12 tonne in weight and are suited to first and second thinning operations. The Malwa 560H is a popular machine in this size class, being able to fall and process logs up to 30 cm in diameter (Figure 9). Research has demonstrated that small purpose-built forestry equipment has a lower productivity level compared to medium purpose-built forestry equipment (those up to 22 tonne in weight). However, this is balanced by a significantly lower capital cost resulting in a very similar cost per cubic metre of wood extracted[20]. There are very few small purpose-built forest harvesting machines in operation in Australia largely due to low demand, lack of manufacturer support and untested capabilities on eucalyptus species.

Figure 9. Malwa 560H 5.7 tonne purpose-built harvester.

Medium Purpose-built Forestry Equipment

Despite the small areas and the prominence of alternate equipment, the vast majority of thinning operations in Scandinavia have historically been cut with mid-sized, purpose-built, single-grip harvesters[21]. One of the main reasons for this is that, while smaller adapted equipment has a lower capital cost and can be operated at a competitive cost in first thinning operations, this advantage quickly evaporates with increased tree size[22]. Forest harvesting contractors can achieve much higher productivity levels with purpose-built mid-sized equipment, plus have the flexibility to work in forests with larger trees as required.

In recent years, the most popular harvesters registered in Scandinavia were the Ponsse Scorpion (Figure 10) and John Deer 1270, which have a mass of 20-22 tonne.

Figure 10. Ponsse Scorpion 22 tonne purpose-built harvester

Combination Forestry Machines

Combination machines or "harwaders" were developed in Scandinavia in the 1990s in an attempt to reduce harvesting costs in small-scale plantations. Using one machine for both cutting and extraction reduces capital equipment cost, relocation costs, and effectively creates a one-person operation. While various companies built proto-type machines that could cut and load with one machine (Figure 11), the most common combination machines operate as a harvester then, with some equipment changes, transform into a forwarder.

Research suggests that these machines are most competitive in small plantations with short forwarding distances, small diameter trees and uneven log markets (biofuel or energy wood)[23,24,25]. Research has identified a potential saving of up to 3% in certain forest types[23].

The downside of combination forestry machines is that they have been designed around a system that uses self-loading trucks for transport between the forest and market. If the combination forestry machine is also required to co-ordinate truck loading – as is the system employed in Australia - it would lose the small advantage that it holds over a traditional two-machine system of harvester and forwarder. Additionally, some of the 'quick change' attachments are temperamental on combination machines, which can lead to significant downtime if issues with hydraulic integrity occur due to frequent change overs.

Figure 11. Komatsu Combination Forestry Machine

Log Extraction (Forwarding and Skidding)

Forwarding is a key component in the process of mid rotation thinning operations. Like harvesters, forwarders vary in size and productivity. Larger forwarding distances require a higher load capacity to be cost-effective[21]. Small-scale plantations by nature, generally have short forwarding distances.

In small-scale plantations in Scandinavia, mid-sized forwarders are used to undertake most log extractions in mid rotation thinning operations. In 2018, the most popular forwarder registered was the John Deer 1510G (Figure 12), which has a load capacity of 15 tonne[26]. The width of the forwarder log bunks is an important consideration for mid rotation thinning operations. Forwarders with narrow bunk designs will minimise damage to retained stems while moving between tree rows to extract logs.

Figure 12. John Deer 1510G forwarder 15 tonne load capacity

There are also many small purpose-built forwarders and forwarder trailers that can be connected to forestry tractors for log extraction (Figure 13). While these systems of forwarding can be quite cost-effective, they have serious limitations with respect to ground speed, stability (stabiliser legs need to be extended prior to each collection), crane extension, grapple size and extraction on slopes. It should also be noted that forwarder trailers require a reverse-steer tractor for effective operation.

Figure 13. Valtra reverse-steer tractor with forwarder trailer

Skidders are used effectively in log extraction operations to drag whole trees from the forest to a landing area for debarking, delimbing and processing into size classes (Figure 14). Compared to forwarders, skidders have the advantage of a generally lower extraction cost, higher slope limit and (often) the benefit of a blade at the front of the machine, which can be used for minor road works and the removal of debris and undergrowth vegetation. Skidders by nature have a larger impact on the forest soil and the potential for higher levels of damage to retained stems in mid rotation thinning operations. This is because the product being extracted is generally longer (whole tree) and there is less control of the load compared to forwarders, especially when navigating around corners. Skidders are rarely cost-effective in small-scale thinning operations for the fact that they form part of a harvesting system that requires 3-4 additional machines to function effectively.

Perhaps the exception for skidders in small-scale thinning operations are adaptations to agricultural tractors making use of winches and log grabs to extract logs (Figure 15). While the cost of these units is quite low in comparison to a forestry skidder, they have limited manoeuvrability and lower ground speed and slope thresholds compared to a fully articulated six-wheel drive skidder.

Figure 14. Conventional forestry skidder

Figure 15. Tractor-based skidder

Harvest Heads

The type of harvesting head used is particularly important in any forest harvest operation. Light weight heads are required for small or adapted forestry equipment. The size of a harvesting head is limited by the power and hydraulic flow of the host machine and the ability of the boom to carry its weight at full extension. Light weight harvesting heads can effectively fall and process trees to a certain size, however the speed and accuracy at which this is achieved is highly varied. This is particularly the case where log markets require debarking and specified log lengths. The main drawback for small harvesting heads is their ability to delimb and debark trees in one direction only. This requires the operator to put down the tree, turn the harvesting head by 180 degrees, grip the tree again and move the tree back through the feed rollers[20]. This process is particularly time consuming in some eucalypt species, where bark removal can require two or three passes through the feed rollers. The smallest roller-feed harvesting heads can weigh as little as 350 kg (Figure 16) and can cut and process trees up to 25 cm.

Figure 16. Small forest harvesting head 350kg by Kesla

Multi-processing or accumulator harvesting heads (Figure 17) are popular in Europe for mid rotation thinning operations for biofuel or energy wood markets. In these markets, bark does not have to be removed from the trees and measured log lengths are generally not required. Multi-processing harvesting heads have an additional set of grapples to enable the operator to collect several stems at once. This has the potential to improve the processing efficiency of small diameter stems by up to 30%[19]. Multi-processing heads use either a chainsaw felling system or hydraulic shears to cut each stem. They have limited use in Australia given the undeveloped biofuel industry.

The same accumulator concept is also used in feller buncher harvest heads, where larger trees can be felled and grouped into bundles. Feller bunchers use either a chainsaw felling system or a continuous circular saw ('hot' saw) (Figure 18) to cut each stem. Feller bunchers are popular in Australia in both hardwood and softwood, primarily for clearfall operations. Feller bunchers have excellent stability and can achieve directional falling of trees. Their main disadvantage is the removal of bark, crowns and branches from the forest (removed at the log landing), which takes important nutrients from the site and creates a residue at the roadside.

Stump spray units are a very important addition to forest harvesting heads, particularly for use in thinning or clearfalling of certain *Eucalyptus* species. These systems are fitted to harvesters and delivered via the harvesting head to kill trees at the stump and prevent coppice regeneration post-harvest. Stump spray systems deliver herbicide and dye onto the stump via valves in the chainsaw blade. This system can also be used in mid rotation thinning operations, with care taken to use herbicides and rates that do not have an impact on retained trees (flash back). Stump spray units are a very important component of small-scale mid rotation thinning operations as they provide a saving in the order of $500-$700 per hectare by eliminating onerous post-harvest coppice treatments.

Figure 17. Accumulator forest harvesting head

Figure 18. Feller buncher with continuous circular 'hot' saw

HAULAGE

Haulage systems in Gippsland utilise semi-trailer (28 GMT load capacity) and B-double (45 GMT load capacity) log trucks. Transport companies also use variations in between such as mini-B-doubles, to maximise load capacity on smaller roads.

Figure 19. Semi-trailer log truck piggyback

Figure 20. B-double log truck piggyback

Haulage Modifications

Modifications such as 'piggyback' trailers are common in Gippsland where roads are often windy, narrow and unsurfaced. Piggy backing the trailer or 'jinker', reduces wear and tear on tyres and roads. In addition, it enables trucks to turn around in a smaller area than that required with a full trailer behind them, which significantly reduces road construction costs. Piggyback systems have been developed for semi-trailers (Figure 19) and B-doubles (Figure 20).

Central Tyre Inflation

Another important modification to log trucks in Gippsland is the fitting of Central Tyre Inflation (CTI) systems. The CTI system enables truck drivers to alter the tyre pressure while driving to improve traction on slippery unsealed roads (Figure 21). CTI is an important technology improvement that also reduces roading costs and extends the window for haulage operations on wet surfaces.

Figure 21. Central Tyre Inflation (CTI) System

Gippsland Haulage Factor

It should be noted that log haulage in Gippsland is often significantly more expensive than other forestry regions in Australia. The need for bluestone rock on many sites to cope with the steep slopes and high rainfall across the Strzelecki Ranges, creates a high cost for roads and an additional cost on truck tyres. In addition, narrow access roads restrict B-double truck use, which is particularly costly for transport to markets outside of the local region. As previously mentioned, Gippsland has comparatively fewer designated B-double routes compared to other forestry regions like The Green Triangle.

Self-loading Trucks

Self-loading trucks are the fundamental backbone of wood supply chains in Europe[27] (Figure 22). Their use creates a fundamental shift in the whole harvesting system. Harvest systems in Australia are 'hot' such that log harvest, log extraction and log haulage are all dependant on one another. While log haulage cannot operate without a forwarder or log loader, in the same way, the harvest and extraction operation rely on the haulage operators to weigh and deliver each load to the market before payment can be achieved. The system in Europe is 'cold'. Harvest and extraction operations work without dependence on haulage operators. In Scandinavia, harvest operations are coordinated by the Timber Companies (or Associations) who pay the forest owner a royalty, whereas in countries like Spain, it is the contractors who coordinate the operations and undertake transactions with the forest owners.

The key to these two systems is the point of measurement. In Scandinavia, harvested logs are measured by the harvest contractors. This is done using technology in the harvesting heads to quantify each grade of log being cut. Forest owner payments are based on the quantity of each product processed through the harvesting head. This rewards growers for every grade of log extracted. In Australia, the point of measurement is the weight of each truck load. Forest owner payments are generally based on the number of truckloads of each product. The exception being some of the more advanced softwood markets that pay on scanned log intake.

There are numerous advantages to the Scandinavian system:

- Trucks are regularly full and rarely make separate trips for half loads (or leave half a load on the landing) because they can pick up logs from more than one site.
- Trucks can load more than one product, minimising the need for half loads or the need to down grade products to economise loads.
- Trucks can collect logs on a time frame that suits the driver rather than needing to fit in with forwarder operators for loading.
- Harvesting contractors can move to the next site without remaining on site to load trucks.
- Trucks can unload at any mill or port without dependence on machinery to remove logs, reducing delays and improving efficiency, and
- Haulage operators have loading/unloading operating options depending on budget, truck size and target tare weight. Controls can be operated from behind the truck cabin, at the middle of the truck and trailer or, in some cases, detached from the back of the truck. Operators can be seated in a full enclosed cabin or in the open air, although the latter would not pass safety standards in Australia.

Despite these advantages there are some important factors that would need to be addressed if self-loading trucks were to be successfully introduced into Australia:

- Safety – open air operation is unlikely to meet current forest safety measures. Enclosed cabin screens would need to pass the Australian Standards.
- Registration – self-loading trucks are common in the building industry; however, they are not currently established for log transport in Gippsland. VicRoads and Work Safe approvals would be required prior to use.
- While the existing 'piggyback' system could not be used with self-loading trucks, hybrid setups have been employed in other countries like New Zealand, where trailers have been lifted onto the back of the prime mover with the crane to reduce length and tyre wear (Figure 23). Further investigation would need to be made into the possibilities of employing such a system in Gippsland, to ensure the advantages of self-loading trucks are not negated by extra roading costs.

It should also be noted that there are some disadvantages with self-loading trucks that require further investigation.

- The extra cost of having a loader is one obvious one, however the loss of load capacity may also be defining depending on truck configuration and approvals.
- From an operator's perspective, there are also some issues. In Australia, truck drivers can utilise the time they are being loaded as a recognised rest break. However, operating a crane is likely to count as work time, and therefore reduce the available time allowed for driving. In Europe, where self-loading log trucks are common, restrictions on driving time do not always apply to alternate work duties.
- While self-loading trucks provide significant advantages in Europe, their impact in Australia would be limited given the forest industry is organised around weighed deliveries of each product.
- One of the primary advantages of self-loading trucks is to free up the forwarder. However, this advantage is diminished in mid rotation thinning operations where harvesting productivity is low (due to small piece size) and forwarders have ample time for loading trucks

Figure 22. Large self-loading truck Scandinavia

Figure 23. Self-loading log truck with carried trailer, Rotorua New Zealand.

Other Factors

There are several other factors that impact the productivity and cost of mid rotation thinning operations:

Market Price

The price paid for logs from thinning operations has been noted as having the most significant impact on the viability of mid rotation thinning operations[11]. Research in Italy[8] found that for a mill door price of €85, a 19 cm average tree diameter was needed to make the thinning operation profitable using a feller buncher and farm tractor adapted for skidding. When the mill door price was increased to €100 (18% increase), the average tree diameter could drop to 15 cm (21%). In Gippsland, a firmer understanding of market prices and average log diameters is needed to help drive mid rotation management decisions.

Product Mix

The mix of log products is another key factor in the cost-effectiveness of mid rotation thinning operations. While pulpwood markets are ideal for small logs of multiple sizes and diameter classes, these markets are dwindling across Victoria. Therefore, a higher importance is being placed on thinning operations producing poles, peeler logs and small sawlogs to be cost-effective. However, with these markets comes specifications for diameter classes and lengths, which require harvesting heads with a certain level of technology and operators of experience with such systems. In addition, sorting and handling multiple log products is known to increase the cost of thinning. Research in Finland found that for every additional log product, harvester productivity reduced by 1% and forwarder productivity decreased by 3%[21]. The introduction of additional products also increases the likelihood of retained stem damage. This is due to a higher number of crane movements being required for harvesters to cut and sort multiple products in a cramped space between retained trees.

Operators

Despite all the attention to machinery, operators can have one of the largest influences on the productivity and quality of harvesting operations. Harvesting trials have found there can be up to a 40% difference in productivity between experienced and inexperienced operators[28]. These differences become even more pronounced as working conditions become more difficult. In Finland, these productivity differences have been identified. Therefore, harvesting operators are well trained in government subsidised courses over a three-year period. Courses teach all aspects of machine operation including the use of simulators. Other subjects include mechanics, safety, mapping, and environmental issues. Operators are valued, and responsible for a significant proportion of the harvest operation. This may include relocation of equipment, dealing with the landowners or landowner cooperatives, liaising with markets, downloading maps and uploading log data from each harvest operation, managing environmental issues, and selection of the trees and product optimisation during thinning operations[19].

Booms

The strength, reach and configuration of booms on harvesters and forwarders can have a significant impact on the productivity and damage to retained trees during mid rotation thinning operations. Traditional 'knuckle' booms on excavators have difficulty falling and processing (debarking and delimbing) trees during thinning operations where stockings are high. The 'telescopic' booms, used on most purpose-built harvesters and forwarders, are far more efficient and effective in reaching across rows to fall and collect trees (see Case Study 1). The ability of a harvester and forwarder to reach multiple rows in each pass has a significant impact on the productivity of thinning operations as well as on soil compaction.

Tracked verses Rubber Tyre Machines

Gippsland hosts both tracked and rubber-tyred harvesting equipment. Slope is generally the largest determinate of machine preference. The Industry Standard for Safety in Forestry Operations (2007) stipulates that harvesting equipment shall not be operated on slopes that exceed the maximum specified by the manufacturer. In reality, very few manufacturers publish slope limits for their machinery. Research in New Zealand noted that (as a general rule) rubber-tyred machines should not operate on slopes that exceed 18 degrees and tracked machines should not operate on slopes that exceed 22 degrees[29]. The introduction of winch-assist has allowed conventional slope limits to be challenged for harvesters and forwarders, however this comes with significant additional cost with the requirement of an additional machine (to anchor) and are therefore unlikely to be viable in small-scale plantations.

Relocation Costs

The cost of floating (relocating) forest harvesting equipment is significant for small-scale plantations. Large harvesters and forwarders can incur additional costs due to the need for a float with a four-axle dolly. The transport cost for these machines can often exceed $200 per hour. It is not uncommon for relocation costs to amount to a minimum of $1,000 per machine (one way) for a large harvester or forwarder. Furthermore, oversized machines often require a pilot as stipulated by the National Heavy Vehicle Regulator (NHVR), which adds further costs. In contrast, small purpose-built forest harvesting equipment, like the Malwa (Figure 9), can be relocated with a tray truck for a considerably lower cost.

Furthermore, complications are often experienced when floating larger harvesting equipment in the Strzelecki Ranges. While log trucks can ‘piggyback’ their trailers enabling them to turn around more easily in the forest, floats are low to the ground and do not have the ability to ‘piggyback’. This can result in the need to ‘walk’ equipment long distances, adding additional costs to the relocation.

SUMMARISING HARVESTING SYSTEMS

- Gippsland hosts a range of harvesting systems from large, multi-machine operations to two-person crews using hand falling and an excavator for debarking and loading.
- Safety is a significant factor preventing the use of adapted harvesting equipment that is popular internationally.
- The productivity and cost of mid rotation thinning operations can be impacted by various plantation characteristics including tree size, tree form, bark type and plantation stocking. The largest impact is tree size, accounting for 78% of harvester productivity.
- Site characteristics are another key factor impacting mid rotation thinning operations. Slope has been found to have a direct relationship with harvesting productivity and places limits on the operation of rubber-tyred machines. Site aspect and understorey vegetation can also have an impact on productivity of mid rotation thinning operations.
- The type of thinning system has an impact on productivity. Systems that remove entire out-rows are undertaken with greater speed and ease of operation. They create space so that larger equipment can be used with little impact on the retained stems. The out-row removal system must be modified for moderate slopes, where rows are along the contour. The out-row removal system of thinning is less suited to *Eucalyptus* plantations grown for sawlogs. In these plantations, lower quality genetics and the preference for pruning the best trees, leads to a significant compromise in quality and economics if out-rows are removed.
- A broad range of adapted forestry equipment and small purpose-built forestry equipment is used internationally in mid rotation management of plantations. In Australia there is very little of this equipment due to low demand and a lack of manufacturer support. Medium purpose-built forestry equipment (20-22 tonne) is the most popular option in Scandinavia for mid rotation management in small-scale plantations. One of the main reasons is the higher productivity levels and flexibility to work across thinning and clear fall operations as required.
- Combination forestry machines were developed in the 1990s to achieve both harvesting and forwarding with one machine. They reduce capital costs, labour requirements and float costs. Combination forestry machines are most competitive in small plantations with short forwarding distances. However, they require use of self-loading trucks to be most effective.
- Forwarders are an important component in the process of mid rotation thinning operations. Larger forwarding distances require higher load capacity to be cost-effective. Small-scale plantations by nature have short forwarding distances. The most popular choice of forwarder in Scandinavia is a mid-sized machine with a 15-tonne capacity. Tractors with forwarder trailers provide a low capital cost option, however they have serious limitations with respect to speed, slope, stability, reach and grapple size.
- Skidders are an alternative machine to extract logs, however they are rarely cost-effective in small-scale thinning operations for the fact they form part of a harvesting system that requires 3-4 additional machines to function effectively. Like forwarders, tractors with adaptions to winch and grapple logs are sometimes used as skidders in small-scale thinning operations. While they have low capital cost, they have limited manoeuvrability and lower ground speed and slope thresholds compared to purpose-built skidders.
- The type of harvesting head has a profound impact on the overall productivity of a harvesting operation. Light weight heads are useful on smaller equipment but have limits in speed given they can only debark and delimb

in one direction. This can be particularly time consuming in some *Eucalyptus* species. Multi-processing or accumulator heads provide processing efficiency gains of up to 30% in small diameter trees but cannot debark. Feller bunchers use a similar accumulator concept with either a chainsaw or continuous circular saw but are most suited to clear fall operations and operations where directional falling is important. Both accumulators and feller bunchers remove important nutrients from the forest.

- Haulage systems in Gippsland have relied on modifications such as piggyback trailers and central tyre inflation to reduce tyre wear, minimise roading costs and extend the window for haulage operations. In general, haulage costs are higher in Gippsland compared to other regions because of the higher cost of roads, the impact on tyres and the restricted B-double use.

- Self-loading trucks are used extensively in Europe for log transport. Their major advantage is independence from the harvest system, which is significant in small-scale plantations. However, there are potential challenges meeting Australian Standards and gaining approvals for use in the forest industry with Work Safe and VicRoads. They are less suited to thinning operations where harvesting productivity is low and forwarders have additional time for loading trucks.

- Other factors impacting the productivity and cost of mid rotation thinning operations include the market price offered for the logs, the number of products being cut, the operator's skill level, the type of boom used on the harvester, whether tracked or rubber-tyred machines are being used and the machinery relocation costs.

CASE STUDY 1: EXCAVATOR-BASED HARVESTER VERSES PURPOSE-BUILT RUBBER-TYRED HARVESTER FOR MID ROTATION THINNING IN BLUE GUM

LOCATION

The trial was designed in a 13.5-year-old blue gum (*Eucalyptus globulus*) plantation based in the Glenelg Shire in southwest Victoria. The plantation was originally established at 1000 trees per hectare on rows at four-metre spacing. The plantation was uniform in growth with a standing volume of 211 m^3 per hectare. The average diameter at breast height (DBH) was 18.2 cm. The terrain was flat with sandy soils.

EQUIPMENT

The trial design was set up to assess variations in thinning productivity and retained stem damage using two different harvesting machines. The first machine selected was an excavator-based Caterpillar 320 with a Waratah HTH620 harvesting head (Figure 24). The second machine was a rubber-tyred, purpose-built Valmet 911 harvester with a Valmet 965 harvesting head (Figure 25). A Timberjack 1840 forwarder (Figure 26) was used across the entire trial. Machine widths have been outlined in Table 1.

Figure 24. Caterpillar 320 harvester with HTH620 Waratah head

Figure 25. Valmet 911 with Valmet 965 harvesting head

Figure 26. Timberjack 1840 forwarder

Table 1. Machine widths

Machine	Width (m)
Caterpillar 320	2.80
Valmet 911	2.95
Timberjack 1840 Forwarder	3.02

TRIAL DESIGN AND METHODOLOGY

The trial assessed various thinning treatments for each machine (Table 2). Measurements were made against the various levels of stocking, piece size, and total volume being removed in each plot. Each treatment was 0.25 hectares in size and replicated three times to create a trial size of 2.25 hectares per machine (Figure 27.). Each treatment consisted of 4 rows of trees (or a total of 16 metres in width) by 156 metres in length. Tape and indicator posts were used to mark the end of each plot. A two-row buffer was used to create separation between parallel plots.

The harvesting process involved each machine traversing the middle (centre inter-row) and extracting trees from the two rows either side – note that no out-row was taken. The forwarder followed the same path as the harvester. The volume and piece size of trees in each plot per treatment is outlined in Table 3.

Each treatment was marked in the field as per standard Heartwood procedures, selecting the poorest and worst form trees for each thinning treatment. All trees in the trial were then measured for diameter at breast height (DBH). A total of 23 trees outside the trial were then harvested and intensively measured to develop a relationship for merchantable under bark volume as a function of diameter at breast height over bark.

Table 2. Thinning Treatments

Treatment	Original Stocking (trees/ha)	T1 Stocking Outcome (trees/ha)	T2 Stocking Outcome (trees/ha)
1	786-916	600	400
2	786-916	500	300
3	786-916	400	200

Figure 27. Trial Layout

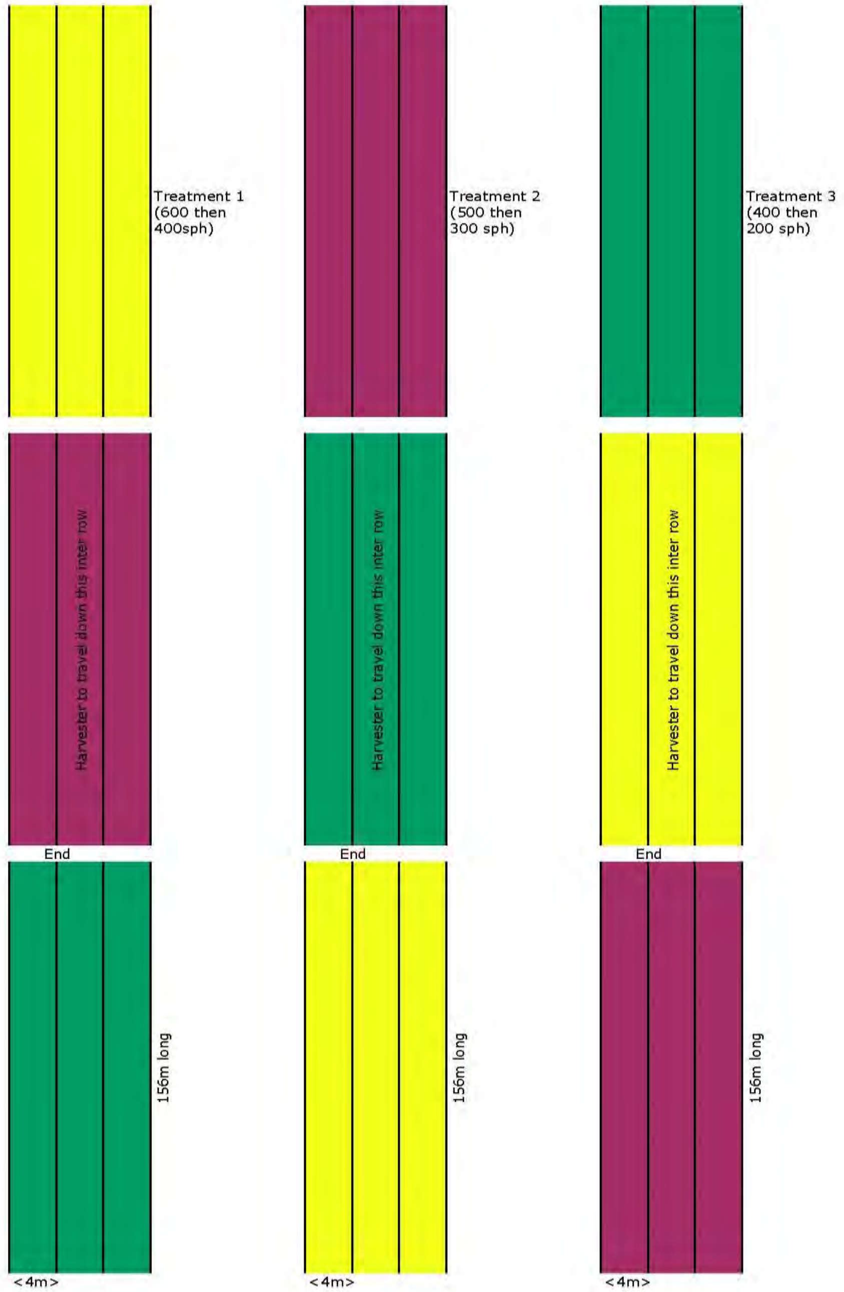


Table 3. Merchantable volume and average piece size of wood per treatment

Harvester	Plot	Trtmnt	Original Stocking (Trees/ha)	1st Thin to Stocking (Trees/ha)	Measured 1st Thin Vol (m^3/ha)	Average Piece Size 1st Thin (m^3)	2nd Thin to Stocking (Trees/ha)	Measured 2nd Thin Vol (m^3/ha)	Average Piece Size 2nd Thin (m^3)
Valmet 911	1	3	904	400	95.6	0.17	200	59.2	0.31
Valmet 911	2	2	820	500	44.8	0.13	300	50.0	0.24
Valmet 911	3	1	792	600	24.8	0.12	400	41.2	0.20
Valmet 911	4	2	808	500	34.8	0.10	300	42.0	0.20
Valmet 911	5	3	896	400	90.8	0.17	200	63.6	0.31
Valmet 911	6	1	860	600	39.2	0.13	400	50.4	0.22
Valmet 911	7	2	824	500	40.8	0.12	300	47.6	0.21
Valmet 911	8	1	828	600	29.2	0.11	400	42.4	0.21
Valmet 911	9	3	792	400	50.0	0.14	200	54.8	0.22
Cat 320	10	3	824	400	74.8	0.14	200	58.8	0.29
Cat 320	11	2	812	500	38.8	0.11	300	48.0	0.24
Cat 320	12	1	780	600	18.0	0.09	400	37.2	0.17
Cat 320	13	2	828	500	46.8	0.14	300	51.2	0.24
Cat 320	14	3	860	400	59.6	0.12	200	50.8	0.25
Cat 320	15	1	848	600	30.4	0.11	400	50.4	0.20
Cat 320	16	2	916	500	55.6	0.13	300	48.4	0.24
Cat 320	17	1	856	600	32.8	0.11	400	34.0	0.16
Cat 320	18	3	768	400	60.0	0.15	200	67.2	0.34

Each operator had at least 6 months experience on their respective machines and more than two years' experience in forest harvesting. Both operators had experience in softwood thinning.

Each operator was given a 0.15-hectare mock area to warm up and practice in before commencing the trial. Once this was completed, each operator commenced harvesting in the trial area. Machines were timed for all operational activities. Down-time for mechanical problems was not recorded.

Operational Guidelines and Specifications

Operators were instructed to harvest and debark all marked trees under "commercial conditions", taking care to minimise retained stem damage, while aiming to maximise productivity. In addition, operators were given the freedom to process and stack logs on either of the adjacent out-rows (unlike the pine system where logs are processed on one side, creating a slash layer, and stacked on the alternate side).

The first thinning operation was undertaken using the following specifications for chip log:

- A minimum small end diameter of 7.5 cm under bark;
- A minimum length of 3.7 m, maximum length of 6.0 m;
- Curve and sweep not to exceed diameter of the log over any 2.4 m length; and
- The diameter of any limb shall not exceed 50% of the centre diameter of the log.

The second thinning operation was undertaken with the above specification for chip log plus a specification for small sawlogs as follows:

- A minimum small end diameter of 15cm under bark;
- A minimum length of 3.7 m, maximum length of 6.0 m;
- Branch stubs are expected to be flush trimmed, but a maximum length of 35 mm will be permitted in mechanically processed product;
- Logs should be reasonably round with no pronounced nodal swelling;
- Sweep tolerances on logs between 150-800 mm diameter is to be no more than ± 100 mm at the centre of the log;
- Unacceptable defects include: large knots, abrupt changes in diameter, double leaders, butt swell, splits or butt tears; and
- Decay, charcoal, pith rot and dead wood not acceptable.

At the completion of the first thinning operation the forwarder collected all processed logs ready for the second thinning to be undertaken. The forwarder was timed for all loading activities within the plots. Given that each plot was located at a different distance from the landing, an average time figure was used for transporting log loads to the landing, unloading and returning to the plots.

Retained Stem Damage

A simple system of recording retained stem damage was employed across the plots. This included:

1. A record of the most likely cause of damage; and
2. The intensity of damage.

The type of damage was recorded as either 'M' for machine chassis damage, 'B' for boom damage, or 'T' for damage from trees because of processing or falling. These were generally easily assessed given by the relative height of the damage on the tree.

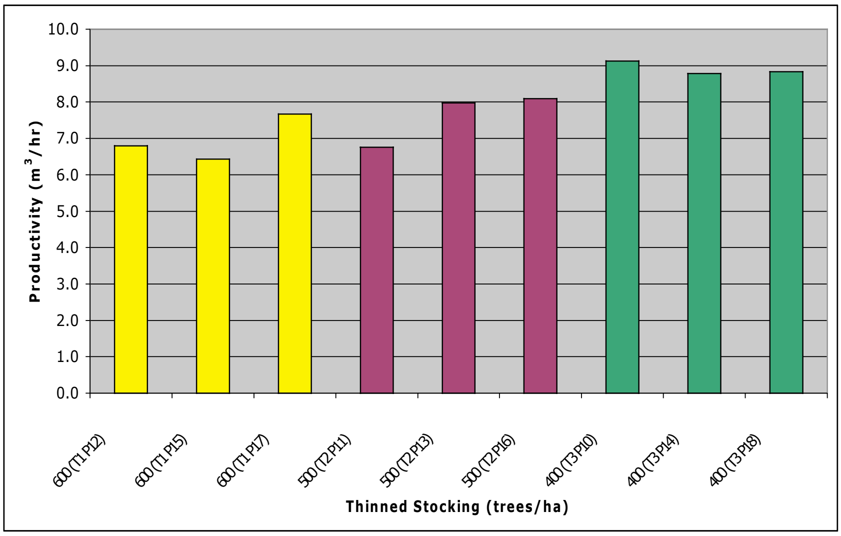
Damage intensity was rated from 1-3, with 1 indicating light damage and no cambium penetration. A score of 2 (Figure 31) indicated that some cambium damage had occurred which would most likely impact tree growth and wood quality. A score of 3 indicated damage had occurred that would either kill the tree or significantly reduce its future value. Level 3 damage was usually where trees had snapped or been pushed over.

RESULTS

Caterpillar 320 First Thinning

The results indicate that the strongest relationship was between the harvest productivity and the volume extracted (R^2=0.81). The chart in Figure 28 supports this finding, in that there is a noticeable trend towards higher harvest productivity as the extracted quantity of trees increases from Treatment 1 through to Treatment 3. The lowest productivity in the first thinning for the Caterpillar 320 was 6.4 m^3/hr and the highest was 9.1 m^3/hr.

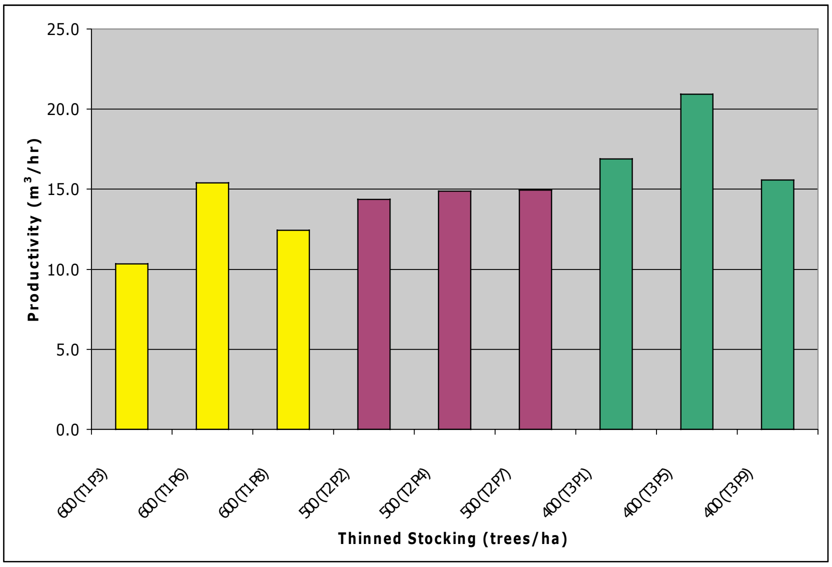
Figure 28. Caterpillar 320 first thinning productivity by stocking



Valmet 911 First Thinning

First thinning operations undertaken by the Valmet 911 demonstrated a moderate relationship between productivity and average piece size (R^2=0.64). However, as per the chart in Figure 29 and like the Cat 320, a stronger relationship was found between the harvest productivity and the quantity of trees being extracted (R^2=0.76). The lowest productivity in the first thinning for the Valmet 911 was 10.3 m^3/hr and the highest was 20.9 m^3/hr.

Figure 29. Valmet 911 first thinning productivity by stocking



Forwarder First Thinning

The forwarder's productivity was highly variable. However, like that of the harvesters, the data demonstrated a noticeable trend towards greater productivity as the treatments increased in thinning intensity and/or level of stocking being removed (Figure 30). The lowest forwarding productivity was 20.6 m^3/hr and the highest was 49.3 m^3/hr.

Figure 30. Forwarder first thinning productivity by stocking

Retained Stem Damage First Thinning

The Caterpillar 320 caused significant damage to retained stems from the tail swing of the machine (Figure 24). The amount of damage appeared to be heavily impacted by row width and the distance between stems on the travelled inter-row, rather than the treatments. Where tree lean or butt sweep reduced the inter-row access, damage was higher.

The majority of damage from the Caterpillar 320 was caused by the machine chassis coming into contact with the trees either side of the inter-row travelled. In contrast, the Valmet 911 recorded no machine damage and very few instances of boom damage or damage from falling trees.

The width of the machines is presented in Table 1. Several measurements were made along the inter-rows to identify the width available to the machines during travel – given that this varies depending on (i) the original mound distance; (ii) what side of the mound the trees are planted; and (iii) whether the trees contain butt sweep or lean. The width (from tree face to tree face) was found to vary significantly between 3.4 m and 4.3 m. On average the gap was 3.7 m.

Tail swing proved to be the largest restriction for the Caterpillar 320. This was measured to be 1.05 m outside the track width and caused most of the tree damage. In comparison, the Valmet 911 and Timberjack 1840 forwarder are articulated machines with only boom extension occurring outside of the tyre widths.

Figure 31. Typical Level 2 Retained Stem Damage

Caterpillar 320 Second Thinning

In the second thinning operations undertaken by the Caterpillar 320 there was only a moderate relationship between productivity when measured against average piece size (R^2=0.54) and the volume harvested (R^2=0.50). The lowest productivity was 10.0 m^3/hr and the highest was 14.4m^3/hr. Figure 32 demonstrates the gradual trend toward higher productivity with lower stocking.

Valmet 911 Second Thinning

Second thinning operations undertaken by the Valmet 911 harvester demonstrated virtually no relationship with average piece size (R^2=0.03) and a poor relationship between productivity and volume harvested (R^2=0.22). The lowest productivity was 16.2 m^3/hr and the highest was 26.0 m^3/hr. There also appeared to be little correlation between harvesting productivity and initial stocking (Figure 33).

Forwarder Second Thinning

The forwarder productivity in the second thinning had a range from 28.2 m^3/hr to 50.9 m^3/hr. As for the first thinning operation (although less obvious), there was a trend towards greater productivity as the treatments increased in thinning intensity and/or lighter stockings were encountered (Figure 34).

Figure 32. Caterpillar 320 second thinning productivity versus initial stocking

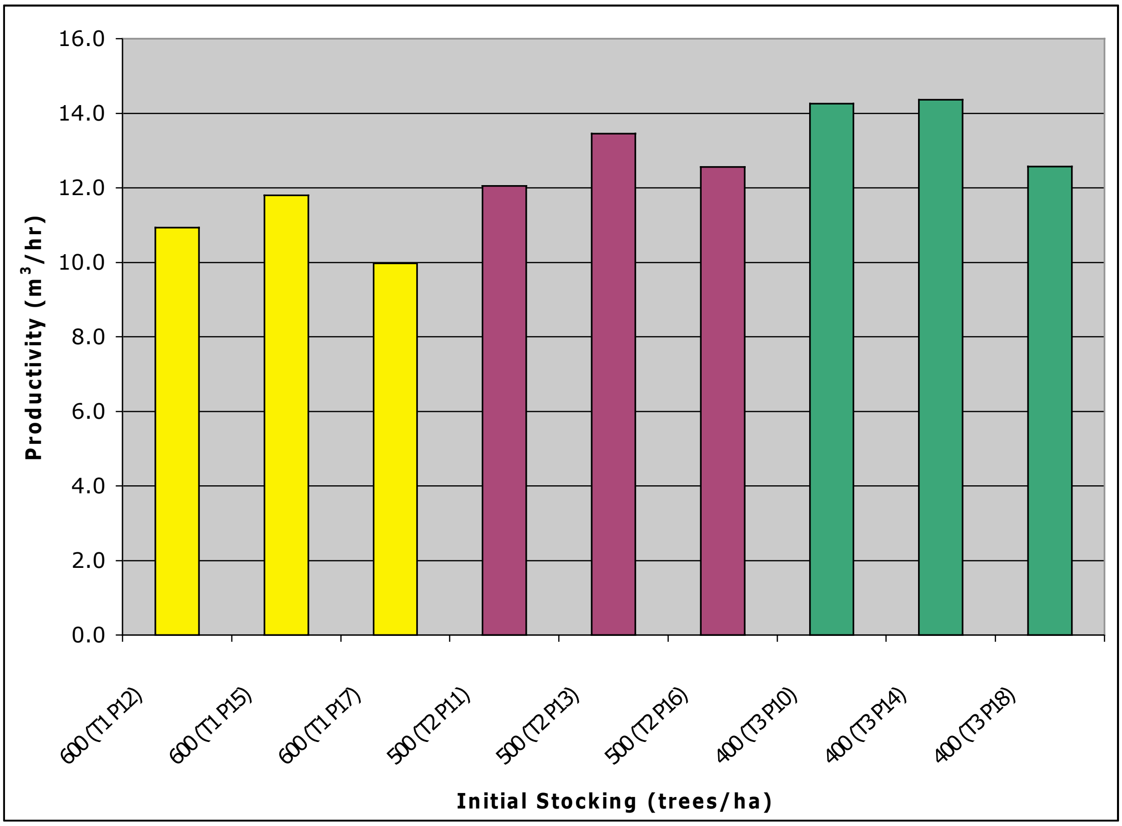


Figure 33. Valmet 911 second thinning productivity versus initial stocking

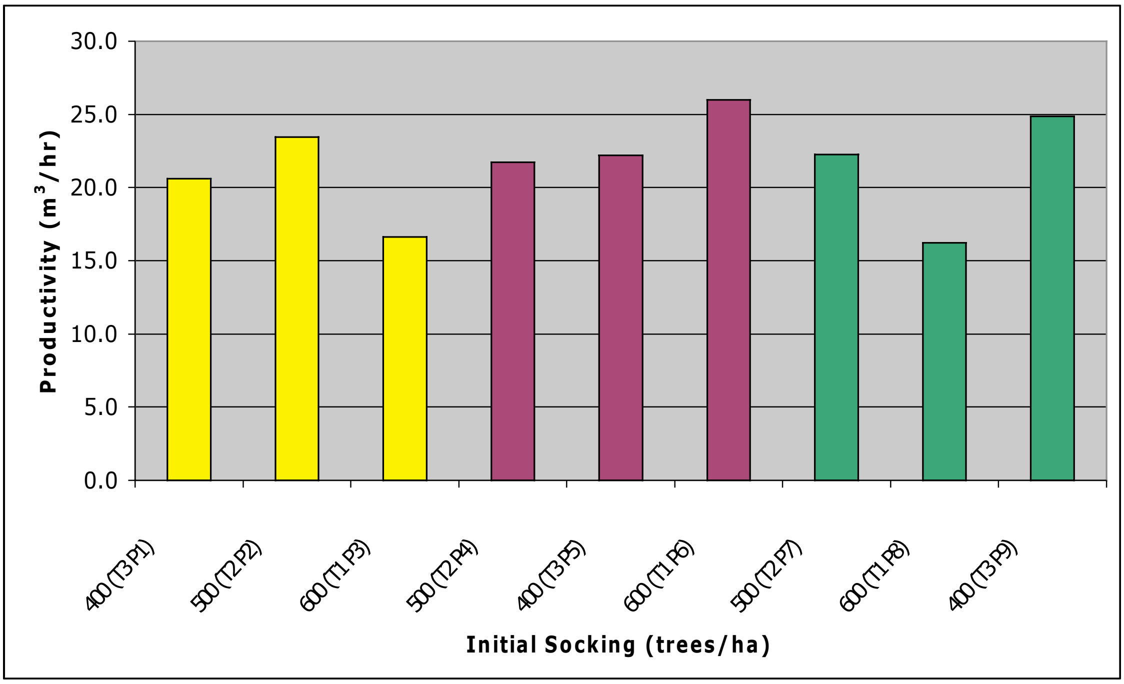
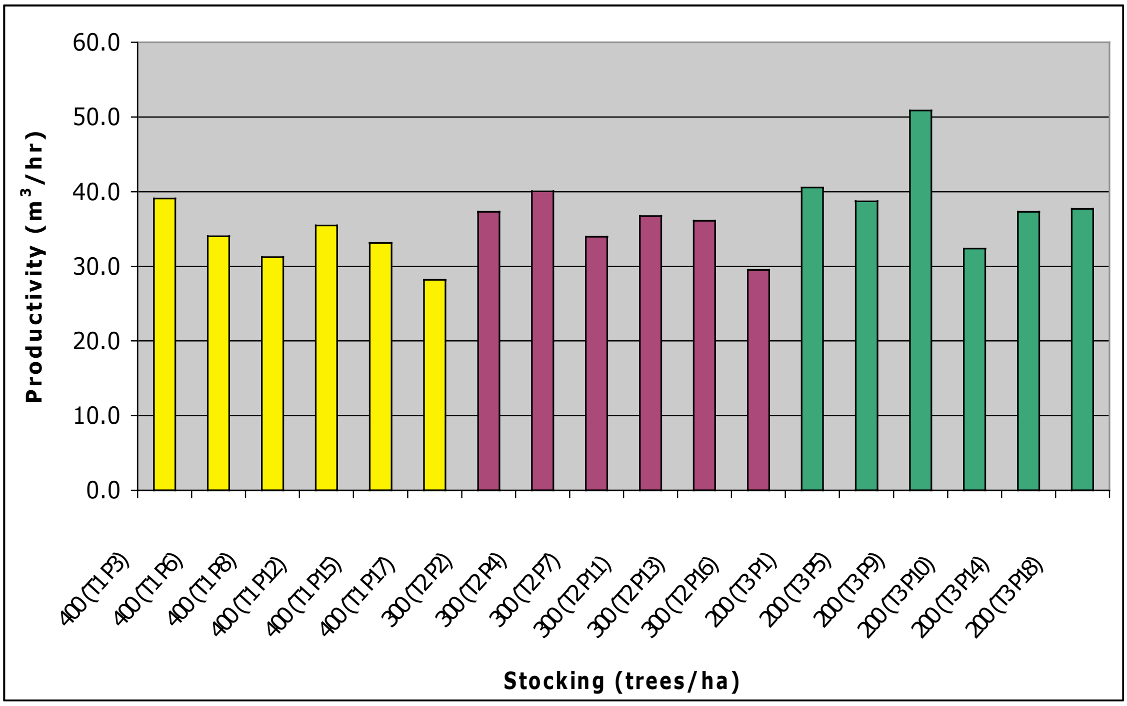


Figure 34. Forwarder second thinning productivity per stocking



Discussion

First Thinning

The Caterpillar 320 was severely limited in its ability to undertake the first thinning operation. The nature of excavator-based harvesters, to swivel and extend a knuckle boom to the base of each tree (Figure 35), caused significant retained stem damage. A significant proportion of this damage was Level 2, indicating that many of the retained stems would be downgraded in value. In addition, the productivity of the Caterpillar 320 was considerably lower than the rubber-tyred Valmet 911 harvester. In Treatment 3 – the most productive of the treatments – the average productivity was just 8.9 m^3/hr (0.14 m^3 ave. piece size). In contrast, the Valmet 911 achieved an average of 17.8 m^3/hr (0.16 m^3 ave. piece size) in the same treatment with little or no retained stem damage (Table 4).

The Valmet 911 proved to be a far superior machine in the first thinning operation. Its narrow chassis, zero tail swing, rubber tyres and telescopic boom enabled it to comfortably fall and process trees across all four rows (Figure 36).

Figure 35. Caterpillar 320: tail swing causing considerable difficulty perpendicular to the direction of travel.

Figure 36. Valmet 911 with no tail swing when working perpendicular to the direction of travel.

The data presented in Table 4 suggests that there is an improvement in harvesting productivity of the Valmet 911 with larger average piece sizes. This trend was also observed for total volume increases but was strongest in relation to the number of stems being harvested. This suggests that the main limiting factor for the Valmet 911 is the number of times it has to grab, fall and process a tree when the average piece size falls between 0.10 m^3 and 0.17 m^3.

Using the Caterpillar 320, the strongest parameter was found to be the volume. The number of stems being removed was also influential on the productivity, however observations suggest that it was more important where the stems were located than how many were to be extracted. Trees to be removed in the rows either side of the inter-row travelled were far easier to fall and process. When trees needed to be removed from the adjacent rows (as demonstrated in Figure 35), the Caterpillar 320 often needed to undertake significant manoeuvring of boom and chassis to avoid damage. In some situations, this required trees to be felled from one position, released, and with further manoeuvring, picked up and processed from a more favourable position where less damage would occur to retained stems. The Valmet 911, in contrast, rarely needed to take any such precautions in its harvesting routine. The strong relationship between the Caterpillar 320's productivity and the volume extracted is explained by the fact that when higher volumes are removed, greater space is created. With more space there is a reduction in the amount of manoeuvring required, and in turn the productivity is increased.

From a treatment perspective, the data summarised in Table 4 indicates that the average productivity achieved in Treatment 1 was 12.7 m^3/hr (0.11 m^3 ave. piece size) for the Valmet 911 harvester. In Treatment 2 this average had increased to 14.7 m^3/hr (0.12 m^3 ave. piece size), which was a 16% increase. Treatment 3 achieved an average of 17.8 m^3/hr (0.16 m^3 ave. piece size), which was a 21% increase on productivity from Treatment 2 and a 40% increase on productivity from Treatment 1. In general, the average harvesting productivity of the Valmet 911 was found to be between 81% (Treatment 1) and 100% (Treatment 3) higher than the Caterpillar 320.

Table 4. Average harvester productivity levels across first thinning treatments

Trial	Treatment	Average Productivity (m^3/hr)	Standard Deviation	Average Piece Size (m^3)
Valmet 911	1	12.7	2.5	0.11
	2	14.7	0.3	0.12
	3	17.8	2.8	0.16
Cat 320	1	7.0	0.6	0.11
	2	7.6	0.7	0.13
	3	8.9	0.2	0.14

Forwarding productivity was difficult to fully represent from the data collected. There is a poor relationship between forwarding productivity and any of the parameters assessed. The operator suggested that the spread of logs was more important than piece size, volume or stocking. When processed logs are well grouped the operator can generally fill the grapple with a single movement, maximising productivity. When logs are spread out, several boom movements are required to fill the same grapple load. On some occasions, the equivalent of a full grapple load may only be recovered after several individual collections. Ultimately, low volumes spread over large distances provide the lowest forwarding productivity. The outcome and advantage of the thinning design employed in this trial is that an even spread of the poorest and worst form trees are removed from the plantation. It is likely, therefore, that forwarding productivity will be reduced in comparison to an out-row system, given the observations discussed.

The forwarding productivity averaged 29.7 m^3/hr in Treatment 1, 33.3 m^3/hr (+12%) in Treatment 2 and 37.5 m^3/hr in Treatment 3, which was a 13% increase on productivity from Treatment 2 and a 26% increase on productivity from Treatment 1. General observations and discussion with the operator suggested that there was no significant influence from any of the measured parameters (piece size, stocking or volume) on the forwarder productivity while driving to the landing and unloading – although no measurements were taken to verify this claim[d].

[d] An average time of 7.55 minutes was used for each return forwarder trip and unloading.

Table 5. Average forwarder productivity levels across first thinning treatments

Trial	Treatment	Average Productivity (m^3/hr)	Standard Deviation
Both Harvesters	1	29.7	5.6
	2	33.3	4.4
	3	37.5	6.2

Second Thinning

From a treatment perspective, the data summarised in Table 6 indicates that the average productivity achieved by the Valmet 911 in Treatment 1 was 19.6 m^3/hr (0.21m^3 ave. piece size). In Treatment 2 this average had increased to 22.5 m^3/hr (0.22 m^3 ave. piece size), which was an increase of 15%. Treatment 3 achieved an average of 22.6 m^3/hr (0.28 m^3 ave. piece size), which was only a 0.4% increase on productivity from Treatment 2. This suggests that the changes in stocking and piece size between Treatment 2 and Treatment 3 have had a very low impact on harvest productivity. This pattern can also be observed for the Caterpillar 320 where an increase of 1.8 m^3/hr or 17% was recorded between Treatment 1 and Treatment 2 (0.17 m^3 to 0.24 m^3 ave. piece sizes). However, between Treatment 2 and Treatment 3 (0.24 m^3 to 0.29 m^3 ave. piece sizes) only a 1.0 m^3/hr or an 8% increase in productivity was recorded.

In general, the average harvesting productivity of the Valmet 911 was found to be between 80% (Treatment 1) and 65% (Treatment 3) higher than the Caterpillar 320 in equivalent treatments. During first thinning, this gap was 100% for Treatment 3, suggesting that the factors restricting harvest efficiency on the Caterpillar 320 are diminishing as the stocking is reduced and the piece size is increased.

Table 6. Average harvester productivity levels across second thinning treatments

Trial	Treatment	Average Productivity (m^3/hr)	Standard Deviation	Average Piece Size (m^3)
Valmet 911	1	19.6	5.5	0.21
	2	22.5	0.9	0.22
	3	22.6	2.2	0.28
Cat 320	1	10.9	0.9	0.17
	2	12.7	0.7	0.24
	3	13.7	1.0	0.29

In addition to the reduced productivity gap observed between harvesters, the factors influencing harvesting productivity were also found to have reduced their impact. For the Caterpillar 320, poorer relationships with the parameters of average piece size and volume harvested were evident in comparison to the first thinning. In the same way, the trend towards increased productivity from Treatments 1 through to 3 was not as pronounced as the first thinning operation. This suggests that, while these parameters remain to be important in second thinning conditions, their impacts are reduced. The Valmet 911, in contrast, had little or no evidence of a relationship between harvest productivity and any of the parameters graphed.

Before drawing any conclusions on the second thinning data, however, it is worth considering a combined data set (first and second thinning) on each of the machines to explore the broader trends occurring.

Combined Data

Figures 37 and 38 demonstrate the strong relationship between harvesting productivity and average piece size for both machines across the total data set (T1, T2 and CF[e]). However, the relationship appears to be non-linear. Thinning studies in Finland[30] across four different harvesters reported a steady linear growth in harvesting productivity with piece size up to 0.50 m^3. However, as average piece sizes exceeded 0.50 m^3, the smaller harvesters slowed down abruptly. For the larger harvesters in the trial, such as the Timberjack 770, productivity dropped off markedly when piece size exceeded 1.00 m^3. It could be argued that productivity would be more likely to drop off sooner in eucalyptus forest given the higher density of wood and greater weight being handled in comparison to the softwoods harvested in Finnish trials. Figure 12, with the benefit of additional data (from clearfalling the remaining plots), suggests that above average piece sizes of 0.35 m^3, the productivity is less responsive. Therefore, it could be assumed that the harvest productivity of the Valmet 911 is approaching the point of maximum efficiency when the average piece size exceeds 0.35 m^3 under second thinning and clearfall operations. In reality, more data would be required to confirm this trend.

For the Caterpillar 320, it appears that productivity flattens out above average piece sizes of 0.25 m^3 in second thinning (Figure 11). It is uncertain whether this is a result of the machine's power limitations in comparison to the Valmet 911, or whether the data set is incomplete and further sampling is required.

Forwarder productivity had little correlation to the measured parameters under first thinning conditions. Table 7 indicates that these correlations are diminished further in second thinning. It would be expected that, other than heavily stocked first thinning operations, forwarding productivity would not be significantly impacted by the parameters explored in this trial.

Table 7. Average forwarder productivity levels across second thinning treatments

Trial	Treatment	Average Productivity (m^3/hr)	Standard Deviation
Both Harvesters	1	33.5	3.7
	2	35.6	3.6
	3	39.6	6.2

[e] A timed clear fall was completed at the end of the trial to provide additional data.

Figure 37. Caterpillar 320 productivity per piece size for all operations

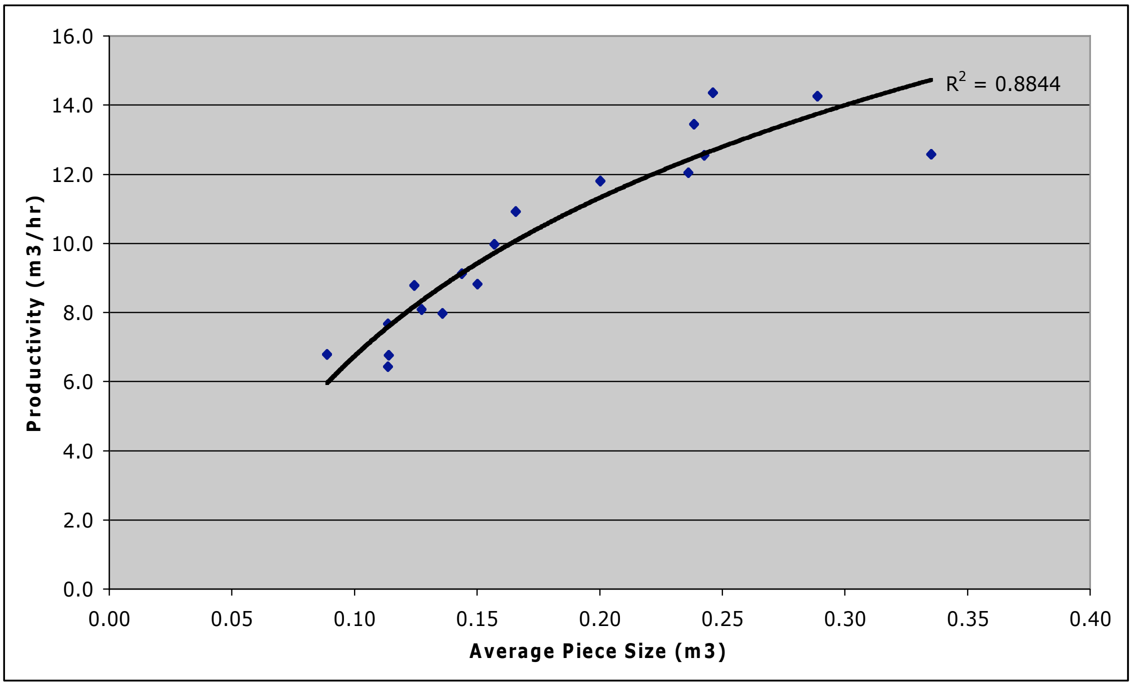
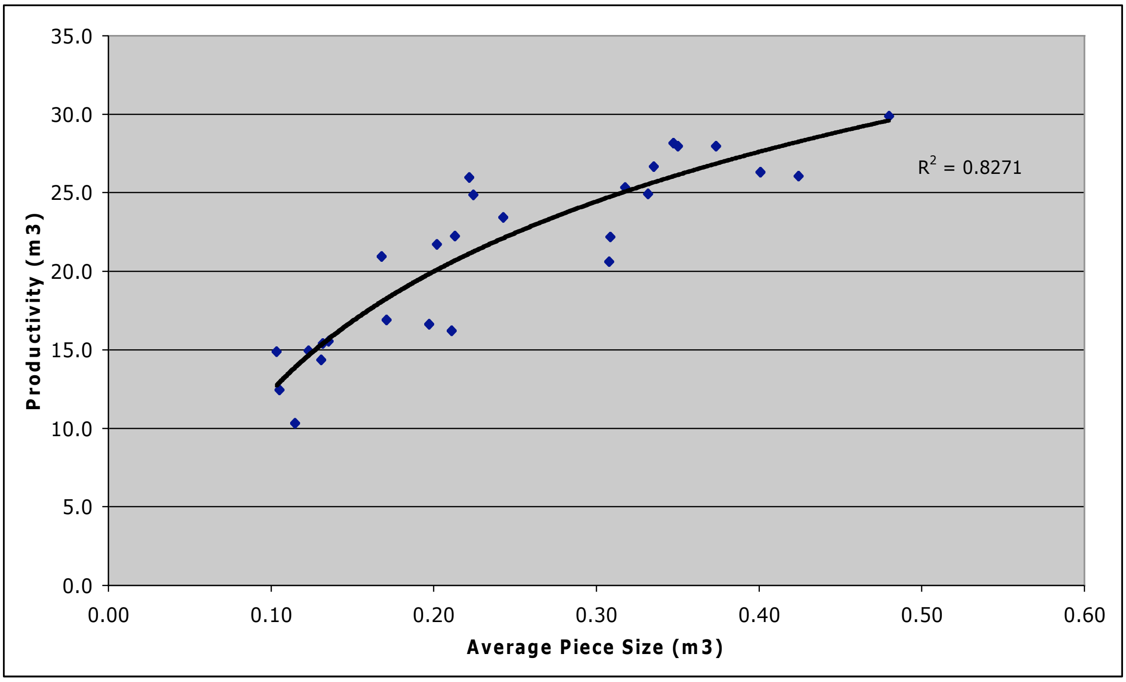


Figure 38. Valmet 911 productivity per piece size for all operations



Thinning Costs

Determining thinning thresholds for small diameter plantation eucalypts requires information about the delivered value of the wood, the cost to transport it to market/port and the cost to harvest. The harvesting cost is the most contentious of these figures given the lack of research into this space, particularly thinning *Eucalyptus* species. If the harvesting rate can be established, informed decisions could be made about the timing and economic viability of thinning operations.

Using an hourly machine rate[f], the cost for first thinning can be established for both harvesting and forwarding (Table 8). The Valmet 911, despite having a 10% higher hourly rate, remains the cheapest option for harvesting across all three treatments with a cost between $16.85 and $23.62 per tonne. The Caterpillar 320 was 65-82% more expensive with a harvest rate between $30.64 and $38.96 per tonne across the three treatments. Forwarding costs were between $7.15 and $9.03 per tonne.

Therefore, at the lightest thinning (Treatment 1) using the Valmet 911, a total harvest and extraction cost of $34.65 would apply, allowing for a $2 per tonne truck loading fee[g]. In contrast, using the Cat 320 would incur a cost of $49.99 per tonne.

At the heaviest first thinning (Treatment 3) using the Valmet 911, a total harvest and extraction cost of $26.00 would apply. In contrast, using the Cat 320 would incur a cost of $39.79.

Table 8. Cost of first thinning treatments

Trial	Treatment	Average Productivity (m^3/hr)	Hourly Rate ($/Hour)	Conversion to Tonnes/Hr (m^3x1.1)	Cost Per Tonne
Valmet 911	1	12.7	$330	13.97	$23.62
	2	14.7	$330	16.17	$20.41
	3	17.8	$330	19.58	$16.85
Cat 320	1	7.0	$300	7.7	$38.96
	2	7.6	$300	8.36	$35.89
	3	8.9	$300	9.79	$30.64
Forwarder	1	29.7	$295	32.67	$9.03
	2	33.3	$295	36.63	$8.05
	3	37.5	$295	41.25	$7.15

[f] The contractor was contacted to provide current rates for similar machines given the initial study was undertaken in 2007.

[g] Loading of trucks was not included in the original forwarding time trial and therefore an industry standard rate has been applied.

The cost for second thinning was also established for both harvesting and forwarding (Table 9). The Valmet 911 remained the cheapest option for harvesting across all three treatments with a cost between $13.27 and $15.31 per tonne. The cost of second thinning was 21-35% lower than the first thinning. The Caterpillar 320 harvest rate was between $19.91 and $25.02 per tonne across the three treatments. This was 35-40% lower than the first thinning. Forwarding costs were between $6.77 and $8.01 per tonne, which was only a 5-11% improvement on the first thinning rate.

Therefore, at the lightest thinning (Treatment 1) using the Valmet 911, a total harvest and extraction cost of $25.32 would apply, allowing for a $2 per tonne truck loading fee. In contrast, using the Cat 320 would incur a cost of $35.03 per tonne.

At the heaviest first thinning (Treatment 3) using the Valmet 911, a total harvest and extraction cost of $20.04 would apply. In contrast, using the Cat 320 would incur a cost of $26.68.

Table 9. Cost of second thinning treatments

Trial	Treatment	Average Productivity (m^3/hr)	Hourly Rate ($/Hour)	Conversion to Tonnes/Hr (m^3x1.1)	Cost Per Tonne	Diff from 1st Thin
Valmet 911	1	19.6	$330	21.56	$15.31	35%
	2	22.5	$330	24.75	$13.33	35%
	3	22.6	$330	24.86	$13.27	21%
Cat 320	1	10.9	$300	11.99	$25.02	36%
	2	12.7	$300	13.97	$21.47	40%
	3	13.7	$300	15.07	$19.91	35%
Forwarder	1	33.5	$295	36.85	$8.01	11%
	2	35.6	$295	39.16	$7.53	6%
	3	39.6	$295	43.56	$6.77	5%

Although the harvest productivity (and hence cost) has proven to be impacted primarily by average piece size, this factor alone cannot be used to determine rates of harvest, since they were achieved under varying stocking levels and a range of extracted volumes. Nevertheless, where thinning operations are carried out under similar treatments to those in this trial, the piece size can be used as a guide for the likely harvesting productivity of the operation, assuming similar harvesters are used.

There are other limitations that need to be considered with this trial and the data that has been produced. In addition to the influence of stocking, volume and piece size, factors such as operator skill, tree form, bark (including species and seasonal variations), harvesting head, and terrain can play a significant role in determining harvesting productivity. Tree form impacts, bark variations and terrain have not been measured in this trial. The harvesting heads will also play a significant role in productivity, however, the largest gains are generally made in the process of debarking. To minimise this difference both operators were instructed to run the logs through no more than twice in each direction (4 times over the stem) regardless of whether the bark was totally removed. Essentially, this provided acceptable bark removal for the Waratah HTH620 head on the Caterpillar 320. The Valmet 695 harvesting head did not remove 100% of the bark due to the softwood rollers fitted. It was decided that changing over to hardwood rollers would be an unnecessary expense given that the harvesting heads were not the subject of the trial.

The standout harvester in this trial was the Valmet 911 due to its higher productivity and the considerable damage caused by the Caterpillar 320. Clearly, the excavator-style machine is not suited to this form of harvesting because of the tail swing damage. Therefore, it is difficult to make genuine cost comparisons between the machines. In addition to the retained stem damage, consideration would need to be given to the damage to the root zone identified with the excavator-based machine. Figure 39 shows some of the regular root zone damage that occurred as a result of the excavator tracks cutting into the side of the mounds. It is unknown what impact this damage would have on retained stems in the long term.

Figure 39. Evidence of root zone damage by the Caterpillar 320

Before eliminating the excavator-based harvester as an option for the thinning of eucalypts without an out-row, an additional trial would need to be undertaken with a narrower tracked machine (2.6 m or less) with zero tail swing. With such a machine, hosting an equivalent 965 Valmet harvesting head, a genuine comparison of productivity and harvesting costs could be made. However, the indications from this trial suggest that rubber-tyred machines with telescopic booms hold a significant advantage over tracked machines for non-out-row thinning operations on flat terrain.

It should be noted that an improvement to this trial would have been the ability to accurately weigh the wood extracted from each plot. The complexities and cost involved in doing this meant that all harvesting times had to be assessed against the measured standing tree merchantable volume, rather than the actual volume extracted on the forwarder.

CONCLUSION

This harvesting trial demonstrated the clear advantage of using a rubber tyred, purpose-built harvester with a telescopic boom to undertake eucalypt thinning operations. The Valmet 911 achieved up to 100% higher productivity in first thinning operation and up to 80% in the second thinning operation compared to the excavator-based Caterpillar 320. In addition, the Valmet 911 produced very little retained stem damage despite no out-rows being removed.

The average piece size of the trees being extracted had the primary influence on harvesting productivity when all treatments were assessed together. The stocking, number of stems being removed, and the total volume being removed also influenced the productivity. However, this influence diminished in the second thinning – particularly for the Valmet 911.

Forwarding productivity increased with the intensity of the first thinning, however, this increase was also diminished in the second thinning. Forwarding productivity did not appear to be strongly correlated to any of the parameters measured in the trial.

The Valmet 911's harvesting rate for first and second thinning operations was found to be most efficient in Treatment 3. In this treatment the original stocking of 768-896 trees/ha was thinned to 400 trees/ha then 200 trees/ha at an average rate of 17.8 m^3/hr (0.16 m^3 ave. piece size) and 22.6 m^3/hr (0.28 m^3 ave. piece size) respectively. This correlated to a cost of $20.43 and $16.09 per tonne respectively. In contrast, the Caterpillar 320 first and second thinning rates in Treatment 3 was $25.54 and $16.59 per tonne respectively. The cost of forwarding was lowest in Treatment 3 for both first and second thinning, amounting to $8.48 and $8.03 per tonne respectively.

CASE STUDY 2: SMALL PURPOSE-BUILT HARVESTER AND ADAPTED TRACTOR-FORWARDER FOR MID ROTATION THINNING IN DURABLE EUCALYPTS

LOCATION

The trial was undertaken across a range of durable hardwood plantations managed by Heartwood Unlimited, based in the Wellington Shire in Gippsland Victoria. The sites had long-term annual rainfall between 650 and 750 mm per year. The plantations were between 10 and 15 years of age and had received one non-commercial thinning at approximately age 4 years. Sites 1, 2 & 3 were located within 30 km of the Radial Timber Australia Sawmill in Yarram, which was the destination for the logs being extracted. Site 4 was located 130 km from Yarram.

EQUIPMENT

The trial design was set up to assess the productivity and cost of mid rotation thinning using the proposed harvesting system. Tree falling and log processing was undertaken using a small purpose-built Rottne H8 (10.2 tonne) rubber-tyred harvester (Figure 40). Log extraction was completed using an adapted reverse-steer Valtra 6400 tractor (approximately 100 hp) and KTS 10 tonne forwarding trailer (Figure 41).

Figure 40. Rottne H8 harvester

Figure 41. Valtra 6400 tractor and KTS forwarding trailer at Site 3.

TRIAL DESIGN AND METHODOLOGY

The thinning trial was undertaken across three properties and four compartments (sites). Within these compartments three species were thinned being southern mahogany (*Eucalyptus botryoides*), spotted gum (*Corymbia maculata*) and yellow stringybark (*Eucalyptus muelleriana*). The plantations were originally established at 1000 trees per hectare on rows at four-metre spacing, except for one site, which was a second-rotation site replanted on three-metre rows. The terrain was flat on all sites except for Site 4 which contained a gentle slope. Table 10 outlines the plantation data for each site.

Table 10. Trial Sites and Plantation Data

Site	Property	Species	Age (years)	Area (ha)	Ave. DBH (cm)	Ave. Height (m)	Volume (m^3/ha)	Stocking (trees/ha)
1	Alberton W.	Southern mahogany	10	14.1	18.2	15.5	67	465
2	Alberton W.	Spotted gum	13	13.5	21.4	16.8	115	529
3	Woodside	Yellow stringybark	14	10.0	23.3	16.4	129	538
4	Bengworden	Yellow stringybark	15	10.0	24.1	15.8	100	419
Ave			**13**	**11.9**	**21.8**	**16.1**	**103**	**539**

The harvesting process involved each machine traversing the middle (centre inter-row) and extracting trees from the two rows either side – note that no out-row was taken. The forwarder followed the same path as the harvester. Each plantation was thinned for two products being posts and firewood. Trees were selected by the operator with the instruction to thin approximately 40% of the stocking, removing the trees of poorest growth and form.

The firewood specifications were as follows:

- Minimum length 4.0 metres.
- Minimum small end diameter 100 mm.
- All bark to be removed.
- No sweep limit.

The post specifications were as follows:

- Length requirements are 4.2, 4.8 or 5.4 metres.
- Minimum small end diameter 150 mm.
- Branch size less than 25% diameter.
- All bark to be removed.
- No sweep.

Each of the operations were timed so that a productivity rate could be calculated per compartment. Down time for repairs were not included. The final extracted volume was estimated based on the number of forwarder loads extracted from each compartment.

Results

The harvesting and forwarding data collected for each plantation compartment has been summarised in Table 11. The pre-harvest and post-harvest stocking levels have been presented in Table 12. The estimated cost of each operation has been summarised in Table 13.

The cost per tonne for each machine was calculated using the commercial rates, being $250 per hour for the Rottne harvester, and $175 per hour for the Valtra tractor and forwarder trailer. Figure 42 compares the cost of harvest, forwarding and total thinning on each plantation.

Table 11. Thinning trial data per compartment

Site	Area	Harvester Time (hours)	Forwarder Time (hours)	Logs Extracted (tonnes)	Harvester Productivity (tonnes/hr)	Forwarder Productivity (tonnes/hr)
1	14.1	36.0	56.0	204	6.3	4.1
2	13.5	67.0	86.5	402	6.0	4.6
3	10.0	39.5	56.0	237	4.3	4.2
4	10.0	25.0	29.0	150	5.8	5.2
Ave.	**11.9**	**41.9**	**56.9**		**5.5**	**4.4**

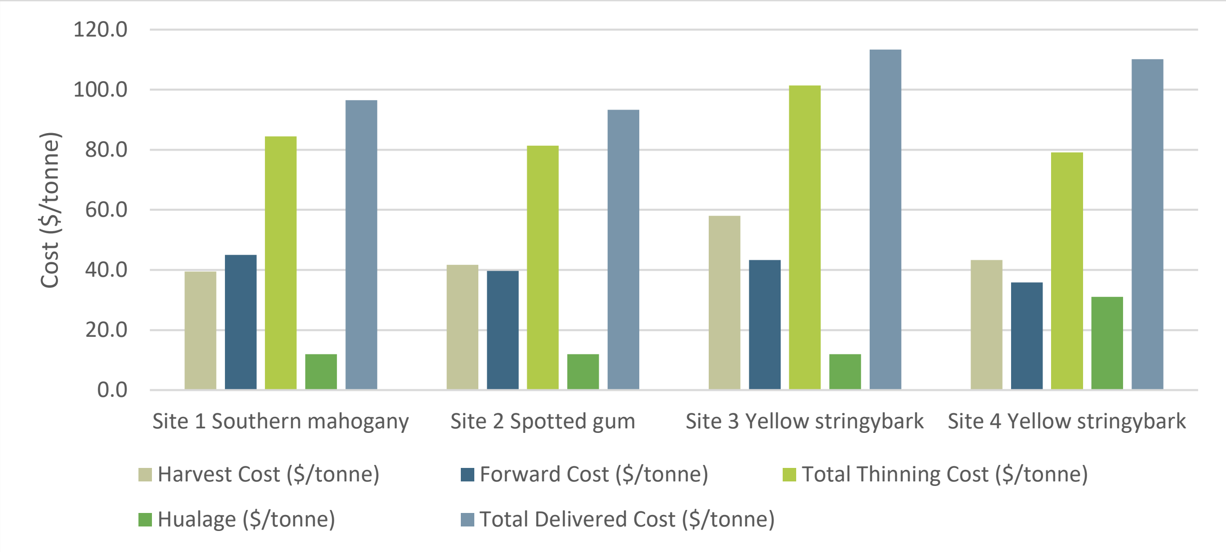
Table 12. Pre-harvest and post-harvest stocking data per site

Site	Stocking Pre-harvest (trees/ha)	Stocking Post-harvest (trees/ha)	Removed Proportionally	Removed (trees/ha)	Piece Size of Removed Trees (m^3)
1	668	465	30%	203	0.14
2	529	365	31%	164	0.10
3	538	300	44%	238	0.16
4	419	224	47%	195	0.18
Ave.	**539**	**339**	**38%**	**200**	**0.15**

Table 13. Thinning trial costs per operation

Site	Volume Thinned (tonne/ha)	Harvest Cost ($/tonne)	Forwarder[h] Cost ($/tonne)	Total Thinning Cost ($/tonne)	Haulage ($/tonne)	Total Delivered Cost ($/tonne)
1	16.2	39.5	45.0	84.5	12.0	96.5
2	29.8	41.7	39.7	81.3	12.0	93.3
3	23.7	58.0	43.4	101.4	12.0	113.4
4	15.0	43.3	35.8	79.2	31.0	110.2
Ave	**21.2**	**45.6**	**41.0**	**86.6**	**16.8**	**103.3**

Figure 42. Cost of harvest, forwarding and total thinning by plantation



[h] Includes an additional $2 per tonne for truck loading, to compare with standard rates.

DISCUSSION

The lowest thinning productivity was achieved on Site 3 (Table 11). This plantation was established on a second-rotation site previously hosting a pine plantation and was planted on three-metre row spacings. The Rottne harvester has a width of 2.2 metres, nevertheless working in tight confines and negotiating old stumps clearly restricted operational speed of both harvester (4.3 tonne per hour) and forwarder (4.2 tonne per hour). While there was little difference between the species, southern mahogany (Site 1) and spotted gum (Site 2) provided better harvesting productivity compared to the two stringybark sites (Sites 3 & 4).

The average thinning cost across these plantations was $86.60 per tonne (Table 13). One of the key reasons for the high cost was the poor recovery of wood. Site 4 had the worst result. Despite having a measured standing volume of 100 m^3 per hectare (equivalent to 110 tonne per hectare) the thinning only recovered 15 tonne per hectare even with 47% of the stocking being removed (Table 12). This suggests that the majority of wood was left on the forest floor due to its form or size not meeting the commercial specifications. Additionally, the operator complained of extreme difficulty removing the bark on the yellow stringybark in this plantation. *Eucalyptus* species in the stringybark group tend to be very difficult to debark, especially after periods of dry weather. Further exacerbating the issue was the small harvesting head on the Rottne H8. Given its limited size and power, debarking could only be achieved in one direction. The persistence of stringybark required the operator to run the log through the debarking rollers several times. After each run, the operator would be required to release the log and rotate the harvest head 180 degrees, slowing the process significantly compared to larger heads where debarking can be achieved in each direction.

By including the haulage cost for delivery to the Radial Sawmill at Yarram, the total average delivered cost was $103.30 per tonne across Sites 1-4 (Table 13). This does not include any fees for management or roading. Local firewood is purchased at approximately $80 per tonne for these species. Therefore, the thinning operation would make an average loss of $23.30 per tonne. While a specification was given for extracting posts, so few were cut that it was deemed uneconomic to separate them into a different product class.

Between the sites there was an obvious higher delivered price for the two stringybark sites (Figure 42). In addition to difficulties removing the bark these were due to row spacing (Site 3) and long haulage (Site 4). These factors have created a 21% higher delivered cost for Site 3 and a 18% higher cost for Site 4 when compared to the spotted gum thinning at Site 2. These issues highlight the financial impact of species, plantation layout and location on a plantation thinning exercise.

While a loss is not an ideal result, the total cost of the thinning would be significantly higher if it were non-commercial. At an average cost of $23.30 per tonne and an average yield of 21.2 tonne per hectare (Table 13), the thinning cost amounts to $494 per hectare to remove 38% of each plantation on average. This includes the Rottne's stump spray application applied during the thinning to eliminate coppice. Non-commercial thinning on trees of this size has been undertaken at a rate of $1,300[i] per hectare plus at least $500 per hectare for follow up coppice control.

Each of these plantations received a non-commercial thinning to approximately 540 trees per hectare at age 4 years at a cost of $500 per hectare. Ultimately, given the poor genetics in these species, a higher non-commercial thinning would have created more space and created a larger tree size and less waste during the operation. This would have amounted to higher productivity and recovery and perhaps a higher proportion of posts that could have been sold at a higher price. While a higher level of non-commercial thinning would have its own cost to the plantation investment, this would need to be assessed against the improved productivity and higher recoveries in the thinning operation at age 10-15 years.

[i] Non-commercial thinning was undertaken by chainsaw to achieve a similar result as the Rottne H8 - being all felled trees put into every second inter-row to maintain access. Falling alone could be achieved for approximately $500 per hectare.

This trial found that the cost of harvesting and forwarding were quite similar in these thinning operations with the equipment used. This is an unusual outcome[j]. As an adapted tractor-forwarder, loading and unloading is quite slow. The size of the log grab restricts the forwarder from picking up more than a couple of logs at a time. The limited power of the boom, particularly at full reach, reduces the number even further. It was also found that if the harvester did not leave logs nicely grouped, the forwarder productivity was significantly impacted. The process of stopping the tractor, spinning the seat 180 degrees, extending the stabiliser legs, and extending the boom is significant. If this is repeated for every log collected, it has a major impact on productivity.

This trial has also highlighted the impact of haulage. The haulage rate for Site 4 at 130 km from the market was more than double the cost compared to Sites 1-3 (Table 13) at 30 km from the market. While a haulage rate of $12 per tonne[k] was achieved for Sites 1-3, few plantations are located within 30 kilometres of a viable market.

CONCLUSION

This trial demonstrated the capabilities of a medium-sized purpose-built harvester and an adapted tractor-forwarder to thin several Gippsland hardwood plantations aged between 10-15 years.

Average harvesting and forwarding productivity were very similar at 4.3 tonne per hour and 4.2 tonne per hour respectively. An average thinning cost of $86.60 per tonne was achieved across the four plantations. The average number of trees removed per Site was equivalent to 200 trees per hectare or 38% of the initial stocking.

The main impacts on productivity were poor recovery, narrow row width and difficulties removing bark. The poor recovery was due to many of the removed trees being unable to meet firewood and pole specifications. Site 4 achieved just 15 tonne per hectare of extracted wood meeting specifications, despite 47% of the plantation being thinned with an estimated pre-thin standing volume of 110 tonne per hectare.

Including haulage, the average delivered cost of the logs extracted was $103.30 per tonne. This amounted to a loss of $23.30 per tonne with firewood priced at $80 per tonne at the nearby Radial Sawmill. The outcome amounted to a thinning cost of approximately $494 per hectare removing an average of 38% of the standing trees including stump spraying to control coppice.

Improvements in the harvesting productivity could be achieved with heavier non-commercial thinning at an early age to create space, remove more of the non-merchantable trees and increase log recovery. This would lower the harvest cost and generate more products of higher value. A purpose-built forwarder has the potential to reduce the forwarding costs significantly. Haulage costs more than doubled from 30 kilometres to 130 kilometres from the market.

[j] Forwarding was approximately 50% of the cost of harvesting in Case Study 1.

[k] As paid at time of the thinning operation in 2019

COMPARING AND CONTRASTING THE CASE STUDIES

It is difficult to draw conclusions when comparing and contrasting harvesting operations when the forest, terrain, machines, and operators are different. Furthermore, the studies were measured quite differently. While Case Study 1 assessed the piece size of each tree being removed, Case Study 2 used average data from permanent sample plots. Therefore, Case Study 1 was able to provide an accurate assessment of the productivity of every tree cut and processed, whereas Case Study 2 only provided productivity figures relating to those trees that met specifications and were extracted from the forest. Nevertheless, some broad observations can be made.

While there were some similarities in the level of stocking being removed in the treatments within Case Study 1 and 2, the main driver of productivity was the piece size (volume) of the trees being removed. Case Study 2 had a piece size range between 0.10 and 0.18 m^3 (Table 12) and this was similar to the range for the first thinning in Case Study 1 being 0.11 to 0.16 m^3. In that assessment the Valmet 911 achieved a harvest productivity between 12.7 and 17.8 m^3 per hour (Table 4) compared to the Rottne H8 achieving between 4.3 and 6.3 m^3 per hour (Table 11). The Timberjack 1840 forwarder in Case Study 1 achieved a productivity between 29.7 and 37.5 m^3 per hour (Table 5) compared to 4.1 and 5.2 m^3 per hour (Table 11) for the Valtra and KTS forwarder trailer in Case Study 2.

While it is difficult to assess the harvesters given that it is not known what number of trees were removed by the Rottne H8 and left on the forest floor due to poor form or insufficient size, there is a more accurate comparison between the forwarders. Despite operating in a higher stocking level, the Timberjack 1840 purpose-built forwarder achieved a productivity more than seven times that of the adapted tractor-forwarder.

With respect to price differences, the cost of first thinning[l] using the Valmet 911 in Case Study 1 ranged from $26.00 per tonne to $35.65 per tonne. In Case Study 2 this cost ranged from $79.20 per tonne to $101.40 per tonne. Therefore, Case Study 2 using the small purpose-built harvester and adapted forwarder, had a cost approximately three times that of Case Study 1.

While the comparisons must remain broad given the differences in these Case Studies, the gap in productivity and cost is confronting. These studies have highlighted what has been long understood in Scandinavia, that premium efficiency is achieved in mid rotation thinning operations with mid-sized purpose-build forestry equipment.

[l] Including truck loading but without haulage

QUANTIFYING THE GIPPSLAND RESOURCE

The history of private forestry in Gippsland has occurred in several waves, often in response to initiatives from governments and markets such as the Australian Paper mill (now Opal). These initiatives have included wood supply agreements, grants, and loan schemes.

A report completed for the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) in 2022 assessed farm forestry on a national scale[31]. A total of 2,600 hectares of commercial farm forestry plantations were identified in Gippsland. Of this resource, 700 hectares was identified as softwood. This report also noted that just 20% of the existing farm forestry in all of Victoria (2,100 hectares) has been established since the year 2000.

A significant component of the more recent plantations in Gippsland were established on the back of initiatives such as the Victorian Government's Plantations for Greenhouse grants. Most of these plantations were hardwood plantations, grown with a view to producing sawlogs. Data retrieved from this State Government program provides the information in Table 14.

Table 14. Summary of Plantations for Greenhouse Scheme, Gippsland

Region	1998-2000		2000-2002		2003-2005		Total	
	Area (Ha)	Sites	Area (Ha)	Sites	Area (Ha)	Sites	Area (Ha)	Sites
East Gippsland	25	1	23.1	2	23	3	71.1	6
West Gippsland	8.2	1	40.8	4	93	7	142.0	12
Total							**213.1**	**18**

A further Victoria Government scheme in 2006 provided additional plantations under the Sawlogs for Salinity initiative. No data has been able to be retrieved for this program although several of these plantations were established by Heartwood or have been identified and included in the assessment for this report.

In 2022, Heartwood undertook a reconnaissance of viable private plantations across Victoria on behalf of Radial Timber Australia. This project identified approximately 700 hectares of plantations in the Gippsland region that had no current market destination and potential for hardwood sawlog production. The average size of these plantations was 15 hectares, and the most dominant species was blue gum (*Eucalyptus globulus*), which amounted to 32% of the resource (Figure 43). The plantations were at least 10 years of age and required those exceeding 20 years to have already completed some form of thinning. Plantations older than 20 years with no prior management were not recorded given the unlikelihood of being able to respond to mid rotation management. Plantations that had very poor form or non-commercial species were also excluded.

The commercial plantations established and managed by Heartwood Unlimited are additional to those found through the reconnaissance project. The majority of the Heartwood managed plantations have been established specifically for the Radial Timber Australia Sawmill. Since 2002, Heartwood has established 1,700 hectares of plantations across Gippsland specifically for this market. The most dominant species have been blue gum, spotted gum and yellow stringybark (Figure 44). Approximately 62% of this resource remains less than 10 years old. The average plantation size is 42 hectares, which suggests that they are medium-scale resources.

While there is no doubt that Gippsland hosts additional private plantations to these resource lists, it is unlikely many of them will be of commercial standard or viable for mid rotation management. Most *Eucalyptus* species do not respond favourably to thinning beyond approximately 15 years under conventional establishment stockings of

800-1200 trees per hectare[m]. Research undertaken in thinning *Eucalyptus* plantations in Brazil found that thinning results were best before canopy closure and trees coming under excessive competition[32]. Furthermore, delayed thinning can increase the incidence of wind throw and epicormic shoot development in addition to having potential negative impacts on wood stability[1]. Radiata pine is more tolerant of competition. However, plantations left unthinned beyond 20 years, are unlikely to provide a favourable outcome from thinning either from a silvicultural or financial perspective.

The collated data suggests Gippsland's private forestry estate suited to mid rotation thinning is approximately 2,400 hectares of small and medium-scale plantations (Table 15). This resource is predominantly hardwood, with just 170 hectares (7%) being softwood. More than half of this resource is located in the Wellington Shire (Figure 45), with a further 20% located in the Latrobe Shire. The average plantation area of the pooled resources is 30 hectares.

Table 15. Gippsland Small and Medium Scale Private Plantation Resource

Resource	Total Area (Ha)	Ave. Plantation Size (Ha)	Number of Sites	% 10 Years +
Private Plantations	700	15	40	99%
Heartwood Plantations	1,700	42	41	38%
Total	**2,400**		**81**	

A simple slope rating was given to each of the plantations. A rating of Steep, Moderate or Flat was attributed according to the slope on each site.

- Steep slope rating was given to those plantations with a significant area over 18 degrees.
- Moderate slope rating was given to those plantations falling between 5 and 18 degrees.
- Flat slope rating was given to those plantations falling between 0 and 5 degrees.

A slope assessment indicates that 20% (~480 hectares) of these plantations are rated 'Steep' (Figure 46), meaning that a tracked harvester would be required to successfully undertake a mid rotation thinning operation. A rating of 'Moderate' suggests a rubber-tyre harvester could undertake the thinning with appropriate access to each compartment, although productivity will be restricted on these sites. A 'Flat' rating indicates that it is suitable for either tracked or rubber-tyred forest harvesting equipment.

[m] This is a general rule of thumb which is species and site quality dependent.

Figure 43. Viable Private Plantation Reconnaissance Gippsland – By Species

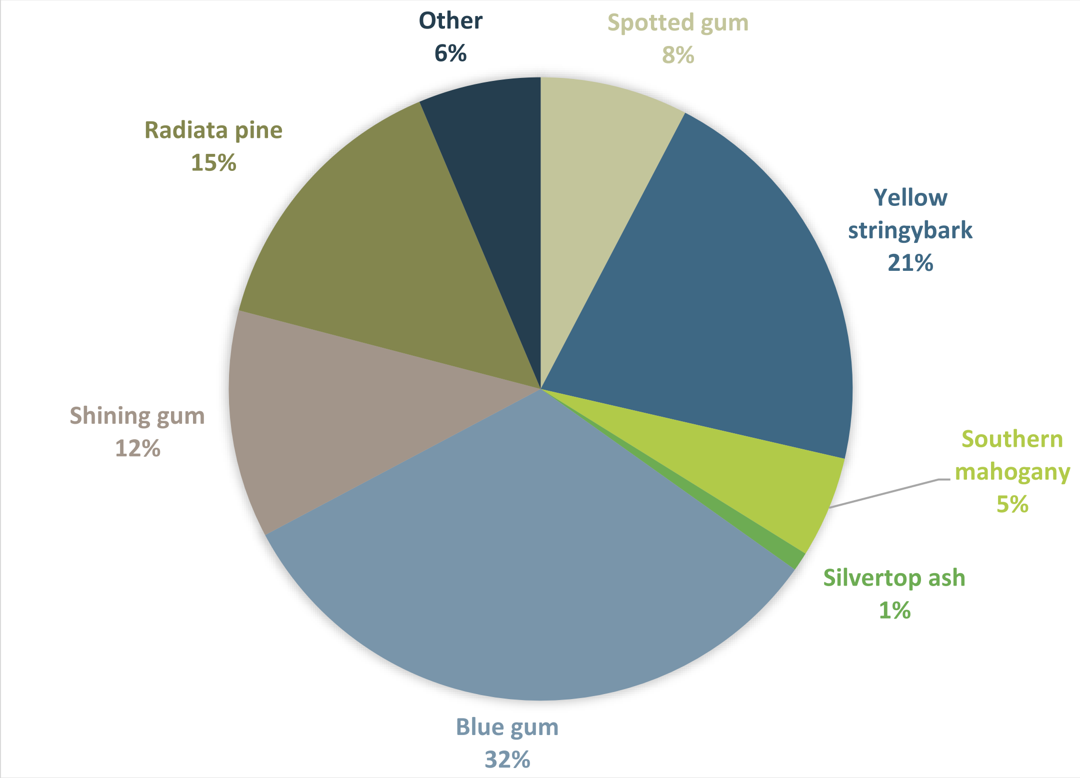


Figure 44. Commercial Plantation Resource Heartwood – By Species

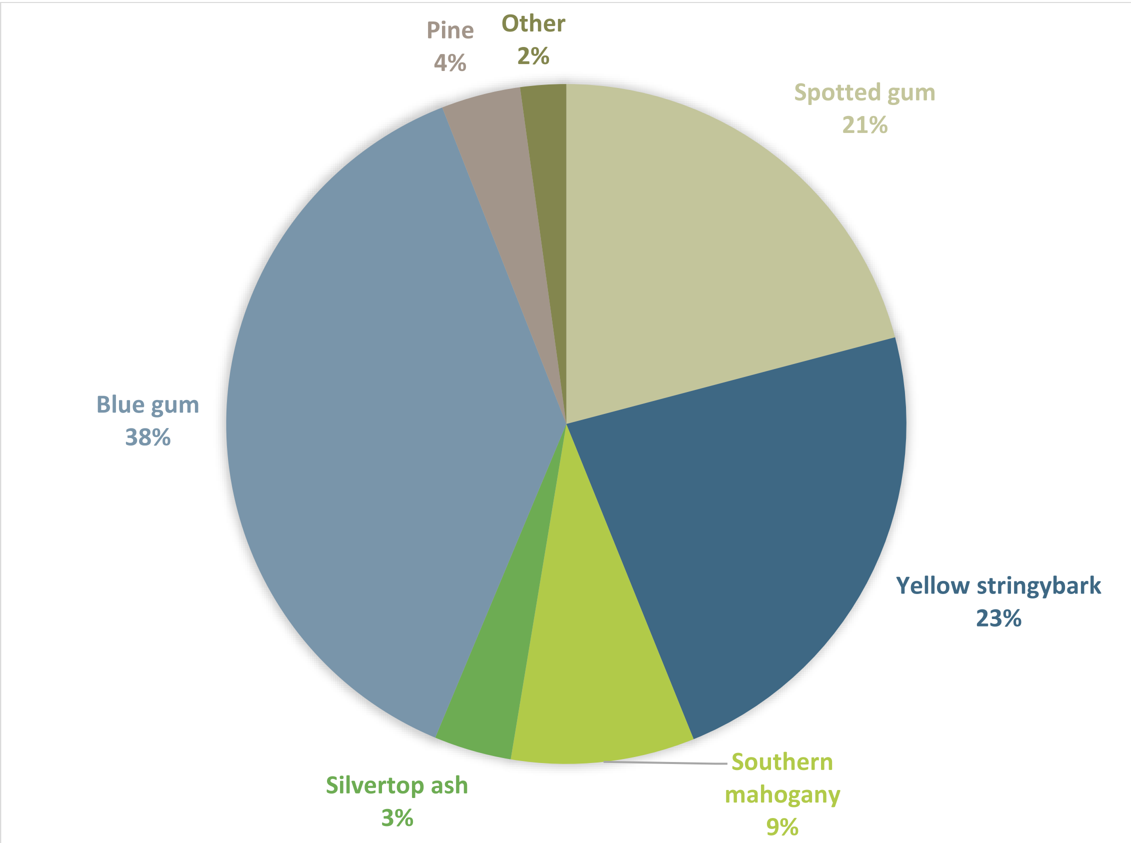


Figure 45. Gippsland Private Forestry Resource Suited to Mid Rotation – by Shire

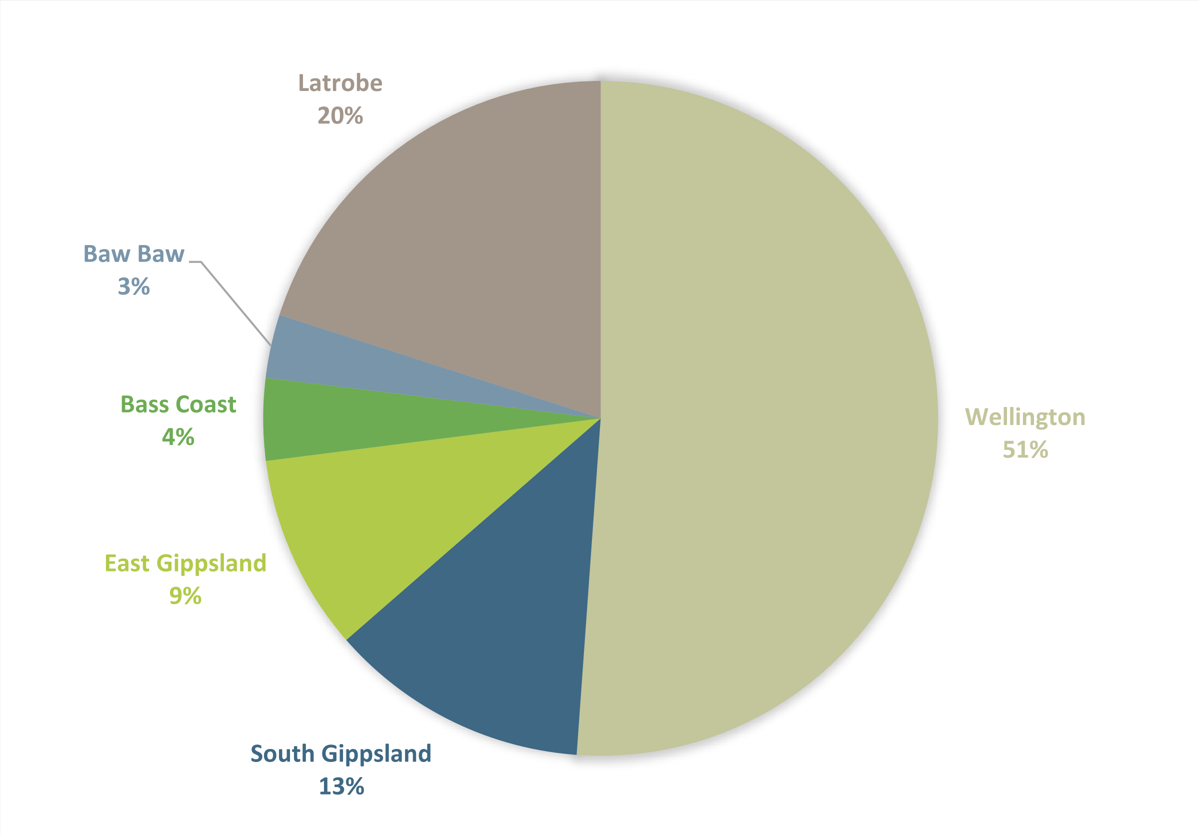
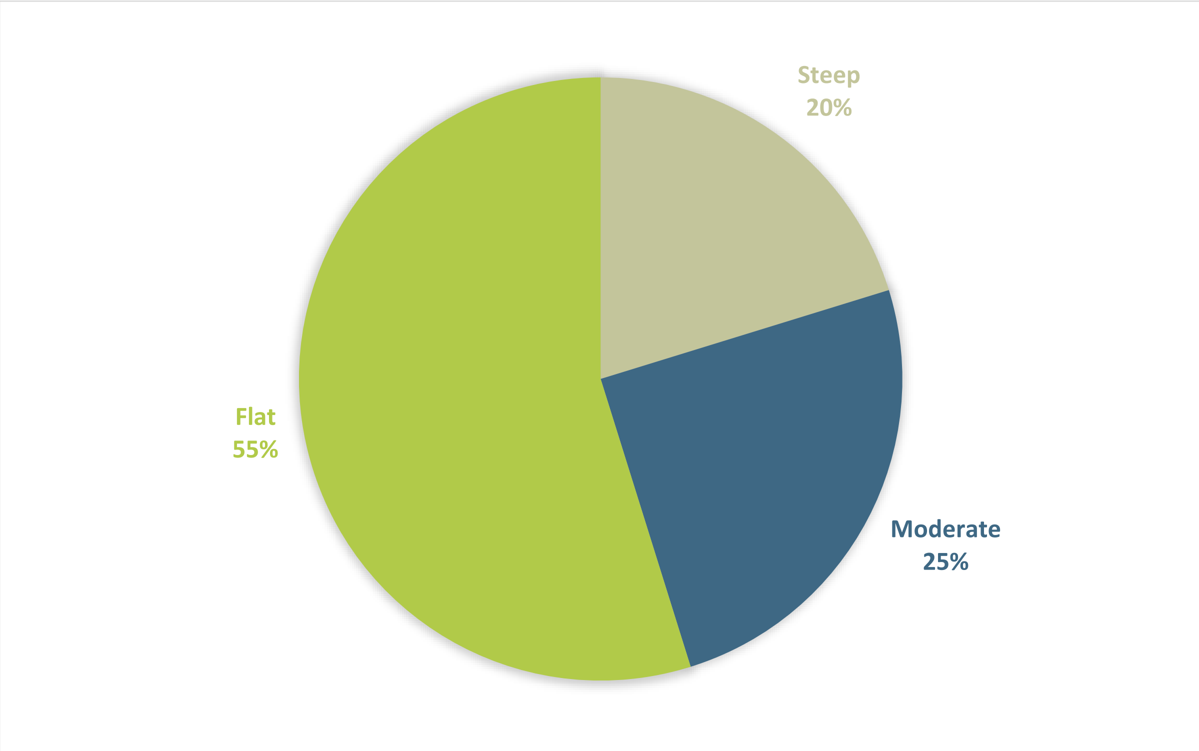


Figure 46. Gippsland Private Forestry Resource Suited to Mid Rotation – By Slope



MARKET OPTIONS FOR THINNING RESOURCES

CURRENT MARKETS

Gippsland has a long history of supplying its forest thinning resources to the Australian Paper Mill (now Opal). Since the closure of the white paper line in 2023, the nearest markets for hardwood chip logs are via export at the Port of Geelong or the Port of Eden in Southeast NSW. While Opal continues to utilise pine for brown paper production, this market is often difficult to access for small private growers given contractual arrangements with HVP Plantations.

While export markets provide opportunities for large quantities of multiple length small diameter logs, these markets can be fickle with fluctuating commodity demand and price. Furthermore, these markets require B-double transport to ensure the long haulage is viable. Larger trucks require good access roads, which are not always achievable for small private growers.

Firewood markets have improved remarkably in recent years with the closure of the public forests. As a result, firewood prices have increased, and plantation logs have become more acceptable to the market (Figure 47). Nevertheless, events such as the windstorms of 2022 and 2023 have led to an oversupply in some of these markets and diminished demand. Furthermore, most local firewood markets are small in capacity, amounting to less than 1000 tonnes per annum in sales, and therefore easily flooded by forestry thinning operations. Cashflow is also a problem for many smaller firewood markets, with the need to pay for logs and labour to process into cut and split wood, followed by 10-12 months of storage and drying before sales can be realised.

Poles and posts can be sold from thinning operations, particularly from radiata pine plantations. Various markets exist for treated round wood. However, appropriate harvesting equipment is required to process round wood including light gauge feed rollers on the harvesting head to reduce damage to stems, and log trucks with shorter log bunks to handle post lengths down to 2.4 metres. Logs suited to preservation treatment must meet strict sweep specifications and contain low levels of branching.

Markets for hardwood poles and posts are less common. Few species in Victoria are suitable for roundwood due to end splitting. Heartwood and Radial Timber Australia have successfully used round wood poles from spotted gum (*Corymbia maculata*), yellow stringybark (*Eucalyptus muelleriana*), red ironbark (*Eucalyptus tricarpa*) and sugar gum (*Eucalyptus cladocaylx*) for fence and vineyard posts (Figure 48). However, inconsistent results in heartwood decay have led to the conclusion that they are only reliable for above ground use without preservation treatment. Nevertheless, poles are also being supplied in small quantities by several hardwood plantation growers for the garden and playground market. These logs are used for nature-play areas and as natural decorative features as a replacement for plastic and treated pine materials (Figures 49 & 50). As for fence and vineyard poles, species with low tendency for end splitting are acceptable for these markets.

Small sawlog markets are viable options for both radiata pine and various hardwood species in Gippsland. AKD in Yarram accept radiata pine sawlogs down to 15 cm small end diameter. Various hardwood sawlog markets including Pentarch and some smaller sawmills, accept hardwood logs of specific species for pallet and stake markets down to 25 cm small end diameter.

Figure 47. Yellow stringybark and southern mahogany plantation firewood, Radial Timber Australia.

Figure 48. Yellow stringybark from plantation thinning used as vineyard posts, Dromana Vic.

Figure 49. Decorative hardwood round wood in use supplied by Outlast Timber Mordialloc, Vic.

Figure 50. Nature play hardwood round wood in use supplied by Outlast Timber Mordialloc, Vic.

Table 16 outlines the current market options for small diameter logs in Gippsland and more broadly for export wood chips. Prices are a guide only and subject to quarterly variations.

Table 16. Current Market Options for Small Diameter Logs

Product	Species	Location	Log Spec.	Haulage (distance from Traralgon)	Estimated Mill Door Price (per tonne)	Estimated Current Capacity (tonnes/yr)
Chip	Blue gum and shining gum	Geelong	Multi-length & SED >5cm	235 km	$85-100	Large scale when available
Chip	Most hardwoods	Eden	Multi-length & SED >5cm	390 km	$80-100	Large scale when available
Chip	Pine	Maryvale	Multi-length & SED >10cm	10 km	$70-80	Limited access
Firewood	Durable hardwoods	Yarram	Multi-length & SED >10cm	65 km	$70-80	5,000
Firewood	Gippsland	Various garden supply businesses	Pre-processed firewood (green or dry)	10-100 km	$100-$300*	5,000
Firewood	Any hardwood	Melbourne	5.2 m min length & SED >20cm	200 km	$100	10,000
E-grade	Various hardwoods	Swifts Creek	3.7-4m, (^5.2m), 7.4-7.6m lengths & SED >25cm	200 & 140 km	$120-140	Large scale when available
Small Sawlog	Various hardwoods	Various small sawmills in West Gippsland	Various lengths, SED>25cm	30-100 km	$120-$250	Small volumes as available – variable species, sizes & capacities
Low grade stakes, posts, pallet material	Various hardwoods	Various small sawmills in West Gippsland	Various lengths, SED>15cm	30-100km	$30-$100	Small volumes – rarely available
Playground & Garden Poles	Sugar gum Red ironbark Yellow stringybark Spotted gum	Melbourne	100-150mm 150-200mm 200-250mm (2.4-6.0m)	200km	$8.50 to $14.50 per lineal metre	1,000

**estimate - due to different forms of product eg, green shorts versus dry split firewood.*

^Least preferred and not always accepted.

Future Markets

Various future markets are emerging in the Gippsland region for small diameter logs. This includes a new pyrolysis plant (Figure 51) and veneer facility (Figure 52) being built in Yarram at Radial Timber Australia. Other potential opportunities are being explored for bioenergy in the Latrobe Valley as outlined in a recent report by the Gippsland Climate Change Network[n]. The products from these bioenergy markets could potentially include electricity, heat, biochar and wood vinegar. While the majority of these markets are in their infancy, there is a potential for small diameter logs from mid rotation thinning operations to form part of the future feedstock. This has been common practice in Scandinavia for the last two-to-three decades.

In the short term, there is potential for a more consistent domestic firewood market if sales could be centrally coordinated, and purchasers registered to access upcoming volumes of log or processed firewood. Spot sales could be arranged with registered purchasers who bid on upcoming resources. This could operate in a similar way to the sawlog bidding system previously used by VicForests.

There is also a possible container backload export market for firewood logs from Melbourne. However, this would be restricted to straight logs of set lengths (3.9 or 5.9 m) to fill containers, with additional costs relating to biosecurity and pathogen treatments for access to places like China. This option would only be viable if there were demand for certain hardwood products that outweighed local options.

[n] Gippsland Biomass Audit and Project Opportunity Analysis, Frontier Impact Group, May 2021

Figure 51. Biochar production, Radial Timber Australia, Yarram Vic.

Figure 52. Veneer production, Radial Timber Australia, Yarram Vic.

GOVERNMENT SUBSIDY OPTIONS

BACKGROUND

Most of the world's industrial forest plantations have been established with a subsidy of one sort or another at some time, either directly or indirectly[33]. In some countries, plantation programs have paid more than 75% of the total plantation costs[34].

Subsidies are delivered for three key reasons being social, environmental, and economic. The forest industry competes with most other major industries for government subsidies. The largest receivers internationally are Energy followed by Agriculture (Table 17)[35].

Table 17. Estimate of Total World Subsidies 1994-98

Industry	Estimated % of World Total Subsidies ($US billions between 1994-1998)
Agriculture	37%
Water	6%
Forestry	3%
Fisheries	2%
Mining	3%
Energy & Industry	49%
Total	**100%**

From an analytical perspective, the effectiveness and consequences of subsidies can be very complicated. Subsidies can simultaneously have both positive and negative impacts on economic development and the environment[36]. For example, a subsidy to establish new forests might stimulate employment and restoration of depleted landscapes initially, however without management and a target market, the plantations may die and become a liability and fire risk in the longer term.

Australia has had a long history of providing grants or subsidies for forestry both directly and indirectly through measures such as tax incentives and Managed Investment Schemes. While many of these incentives succeeded in establishing forest resources, major problems emerged in the aftermath. These have included: (i) creating forests with poor value due to a lack of market development or revenue for ongoing management; (ii) uncovering underlying policy issues; (iii) creation of new risks such as corruption; and (iv) adverse impacts on product and land prices.

A study undertaken by the Asia-Pacific Forestry Commission (APFC) assessed the impact of incentives on forest plantation development. Although it was recognized that people grow trees for many reasons, income generation and financial returns were the overriding motivating factor and indicator of success for tree planting on larger areas (more than one hectare)[37]. Therefore, the study recommended incentives should focus on policy instruments directed at achieving financial goals.

An investigation into the role of plantation incentives in the Asia-Pacific region suggests that plantation development can be divided into three stages, namely **initiation**, **acceleration**, and **maturation** stages[37]. In Australia, interest in the plantation sector has had a long history and by the 2000s the maturation stage had been reached. However, with the closure of many public forests and a growing population, Australia finds itself back in the initiation or early acceleration stage.

While direct incentives are most likely to be important in the initiation stage to raise awareness and scale up plantation establishment, these should be replaced by variable incentives and social services such as research and extension during the acceleration stage. A good measure of an incentive's success is if it becomes obsolete in the maturation stage. At maturation stage, it has been recognized that key measures to maintain private sector interest and investment in plantation development are related to reduction of barriers and removal of structural impediments and operational constraints[5]. Mid rotation management of small-scale plantations in Gippsland clearly falls into this area.

SUBSIDIES FOR MID ROTATION MANAGEMENT

Subsidies for mid rotation forest management in Australia have been scant compared to establishment subsidies. However, the Victoria Government had one such initiative for thinning and pruning hardwood plantations in 2004-05. While the subsidy's goal was to incentivise more plantations being managed for quality sawlog production, it was also an attempt to remove operational constraints by increasing skilled labour in silviculture. Grants of up to $400 per hectare were paid to growers as a 50% contribution for silviculture operations with Government farm forestry advisers responsible for providing silviculture advice and approval of each grant.

While these grants provided improvements in a range of local hardwood plantations and an increase in contractors to deliver silvicultural works, they did not persist. Much like the Victorian Government's Farm Forestry Program in the 2000s! The only negative consequence of this program was the emergence of a range of silviculture contractors providing misleading advice to growers in a bid to secure silviculture work and take advantage of the grant. Nevertheless, the improvement in these plantations has provided a potential future for the logs and an aesthetic improvement to the properties they are hosted on. It could be argued that without the subsidy, these plantations would have remained unmanaged and eventually become liabilities and yet another example of failed farm forestry ventures.

Subsidies for mid rotation forest management have also been offered by the New South Wales Government as part of the Native Vegetation Assistance Package in 2009. These grants targeted landowners with private native forests that had been adversely affected by the introduction of the Private Native Forest Code of Practice. Assistance of up to $120,000 per property was available to eligible landowners for management such as thinning, with at least 50% contribution in cash or kind. There has been no published information on the positive or negative outcomes of these subsidies.

Internationally, several countries have offered subsidies for mid rotation management of forests. Some case studies are listed below.

CASE STUDY IRELAND

European Union statistics indicate that Ireland has one of the lowest forest covers of any Member States consisting of just 11%. Nevertheless, forest cover is currently at its highest level in 350 years. Nearly three quarters of the forests are less than 30 years old. Approximately 50% of the forests are privately owned.

To encourage management of these new forests, a current government initiative offers private forest growers grants for up to €1200 (AUD$2,000) per treatment for the following mid rotation management works in both broadleaf and conifer species:

1. **Thinning and Tending** with the aim of improving forest health and quality, mobilising timber supply, and providing ecosystem improvements.
2. **Agroforestry Maintenance** with the aim of improving the quality of forests under previous grants.
3. **Continuous Cover Forestry** (CCF) with the aim of assisting landowners to convert existing forests to CCF (uneven aged forest) to improve forest health, biodiversity, and timber supply.
4. **Coppice Management** with the aim of improving forest quality.

5. **Seed Stand Management** with the aim of supporting the sustainable use and conservation of Ireland's forest genetic resource.

To be eligible for the grants in some cases a Management Plan must be approved and in the case of CCF, training must be completed. A key plank of the grants is that they are available in two instalments 6 years apart in the case of Thinning and Tending and three instalments (€1200) of over 12 years in the case of Continuous Cover Forestry. Ireland's private forest grower grants are targeted at landowners with 3-5 hectares of forest.

Case Study Finland

Despite its small size (less than half the size of NSW), Finland is the sixth largest exporter of timber in the world and the third largest in Europe. Even with these figures, Finland continues to grow more wood than it harvests.

A significant reason for this is its forest ownership. A staggering 62% of forested land in Finland is privately owned. There are some 600,000 forest owners in Finland and 50% of these have less than 5 hectares. Private forests contribute 80% of the forest industries raw wood material. Harvest areas are on average 1.5 hectares[19].

One of the forest industries key areas of focus is increasing timber production through better forest management. Consequently, the Finnish Government has made a commitment to making renewable energy economically competitive on the open market. Therefore, biofuel and firewood have become a viable market for small diameter and low-value wood. This has been achieved through a number of key subsidies:

1. A carbon-based energy tax was placed on heating fuels. Wood as a result is free of the tax because it is carbon neutral.
2. A carbon-based levy was placed on consumers of electricity. If the energy source is wind or forest chips, the tax is refunded.
3. Thinning subsidies were paid to forest owners. Realising the reduced growth and value of unthinned stands, and the need for additional biofuel resources, the Government pays landowners €5.5 per MWh of electricity produced from the forest chips extracted from their forests. The stands must meet specific silvicultural guidelines to qualify.
4. Financial aid for investments. Funds have been granted to promote the introduction of new technology in the production of forest chips for biofuel.
5. Financial support for the development and commercialisation of biofuel technology.

More recently, the European Commission has approved a €350 million (AUD$570 million) Finnish scheme to support sustainable forest management. The aim of the scheme is to help private forest owners implement economically, ecologically and socially sustainable forest management and use techniques to (i) promote the growth of forests, (ii) adapt forests to climate change, (iii) protect biodiversity, (iv) promote water protection in forestry, and (v) maintain the forestry road network.

Under the new scheme, which will run until 31 December 2029, the aid will take the form of direct grants to private forest owners. In particular, the direct grants will support: (i) remedial fertilisation, (ii) peatland forest management plans, (iii) forest nature management plans, (iv) water protection measures, including road embankment construction, (v) forest road construction, (vi) prescribed burning, as well as (vii) the compensation for income losses of private forest owners resulting from the implementation of measures to preserve biodiversity in forests. The maximum amount of aid per beneficiary is €100,000 (AUD$163,500) per project. For road embankment construction and compensation for income losses specifically, the maximum aid amount is €300,000 (AUD$490,600) per beneficiary.

DISCUSSION

The use of subsidies to assist forestry is clearly a common practice around the world. Nevertheless, the best form of motivation in any industry is its financial viability. Products with a strong economic credentials create a 'pull' rather than relying on a 'push' from government subsidies. However, creating the 'pull' can be difficult without a viable market and support services to the industry.

If Gippsland hosted a strong hardwood market for sawlogs, which also had the capacity to handle small diameter logs for minor products, it is likely that there would be very few issues achieving mid rotation management for growers. The market 'pull' would result in private forest resources being 'sought out' for wood supply agreements and thinning would take place as part of the process of securing future resource. This would be much like the system in Scandinavia, where grower cooperatives work with large timber companies to seek out forest owners to secure future wood supply, offering mid rotation management as part of the deal. While this system has resulted in a very successful and organised forest industry in countries like Sweden and Finland, it has also been achieved with a range of subsidies along the way. Subsidies have targeted forest 'maturation' stage barriers, impediments and constraints in the system. These have included thinning costs, equipment shortages, forest access and technology.

If Gippsland is to develop a successful private forestry sector, then it may need to do so in two waves. This report has identified approximately 2,400 hectares of private forests that are currently less than 20 years old and requiring mid rotation management. While a new 'initiation' phase is being entered, the 'maturation' stage from the last wave requires support to remove barriers, impediments, and constraints.

The current barriers are local markets particularly for small logs. The current impediments are related to accessing the right harvesting equipment during dry months (particularly on steep terrain). The constraints are the haulage costs to access viable markets. Subsidies could be used in several ways to target each of these issues.

It should be noted that one of the other clear constraints for small-scale growers is the cost of non-commercial thinning. While not a specific focus for this report (and more relevant to the next 'initiation' phase), non-commercial thinning does have a significant impact on mid rotation management costs. Research in softwood management in North America[38] confirmed that an investment of USD$500 (AUD$760) per hectare in non-commercial thinning was enough to create a profit of between USD$360 (AUD$550) and USD$4,410 (AUD$6,695) per hectare return during mid rotation thinning. Those forests that were without non-commercial thinning, faced a loss at mid rotation thinning due to small piece size and having just one market option being biomass chips.

RECOMMENDATIONS

SHORT TERM

Haulage – While it is difficult to develop new markets for small hardwood logs in the short term, a subsidy could be used effectively to enable growers to access markets further afield. Pulpwood logs are currently being sold into export markets in Eden, Geelong and Portland. More sizeable (greater intake) firewood markets exist in Melbourne with capacity to buy green logs. A subsidy could offset some of these costs and enable mid rotation thinning operations to be financially viable in the short term.

Harvesting – Similarly, it is difficult to expect harvest and haulage contractors to invest in new equipment suited to mid rotation small-scale plantation management. A subsidy could be used to offset some of the higher harvest and forwarder costs with more mainstream equipment. In due course, as more small-scale plantations emerge on the back of successful outcomes, contractors are likely to purchase more suitable equipment to provide services to this sector of the industry.

To reduce complication or separation, a simple harvest and haulage subsidy could be provided for owners of small-scale plantations for undertaking mid rotation management. The delivery of this subsidy is perhaps one of the most important components. Offering funds directly to growers is unlikely to resolve the issue, given that seeking a contractor and suitable market remains out of reach for most growers. The subsidy would be better off offered to a suitable forestry company to deliver the commercial thinning on behalf of the growers while providing a larger project for a contractor by operating on multiple plantations consecutively.

Firewood Markets – Another alternative might include exploring incentives to assist the firewood industry to transition to plantation resources more rapidly. This could be approached by seeking more accountability for non-plantation material (and increasing regulation and penalties for theft of remnant trees) or by providing subsidies for suppliers to sell plantation resources.

Non-Commercial Thinning – Both the market opportunities and harvest costs would benefit from higher levels of early non-commercial thinning in small-scale plantations. Having invested significantly in establishment, maintenance and (often) pruning, a further cost for non-commercial thinning is often a constraint for many growers. Providing a non-commercial thinning subsidy, or linking it to establishment subsidies, is likely to lead to better mid rotation management outcomes and less dependence on thinning and haulage subsidies in the long term.

Long Term

Ongoing support needs to be given to developing local markets seeking to utilise small logs. Working with existing businesses in the region to support new technologies and techniques will ensure that haulage subsidies are only a short-term measure. The value of a local market for multi-length, small diameter hardwood logs cannot be understated. However, the danger of small grower exclusion remains when industrial plantation companies dominate a region. Biofuel and firewood markets, which reward higher density species, may provide an advantage for small-scale plantation growers who favour hardwood sawlog regimes.

In the same way, support for contractors seeking to invest in equipment that is suited to small-scale plantations cannot be understated. The challenge with most small and medium-scale equipment is that it is an investment decision with significant risk given the small size of Australia’s farm forestry and private forestry sector. Increasing research into viable harvesting equipment for mid rotation management operations in small-scale plantations would assist contractors to make informed decisions prior to purchase.

OVERCOMING MID ROTATION MANAGEMENT CHALLENGES

SECURE A VIABLE RESOURCE

Approximately 700 hectares of small-scale plantations have been identified in Gippsland that require mid rotation management. With an estimated 50 tonne per hectare average log extraction from these proposed thinning operations, a total thinned resource of 35,000 tonnes could be available (Table 18).

A small harvest crew consisting of one single-grip harvester and forwarder ideally requires 500 tonnes per week of wood to be viable in Gippsland with current markets. With the projected level of thinning in Table 18, this would amount to 70 weeks of work for a small crew[o]. While this is enough resource to engage a harvesting contractor on an 18-month contract, it is not of sufficient size to justify investing in equipment specific for thinning small-scale plantations. Furthermore, subsequent thinning or clear fall operations would still be approximately 10 years away for follow up work.

Table 18. Projected Mid Rotation Thinning for Small and Medium Scale Plantations in Gippsland

	Total Area of Small-scale Plantations (Ha)	Ave. Property Area (Ha)	No. of Sites	Approx. Thinning Volume (tonnes/Ha)	Total Thinning Volume (tonnes)
Small-scale	700	15	40	50	35,000
Medium-scale	1,700	42	41	50	85,000
Total	**2,400**				**120,000**

If this resource were to be combined with the Heartwood-managed medium-scale estate of 1,700 hectares it would amount to a projected 120,000 tonnes of wood. While this would theoretically provide work for 5-years and be sufficient to enable a contractor to invest in specific equipment suited to the resource, 62% of these plantations are less than 10 years old and will not be ready for mid rotation thinning immediately.

Nevertheless, with further establishment of small and medium-scale plantations, Gippsland is not far off being able to support a dedicated harvest and haulage crew for mid rotation thinning operations. In the interim, a contractor could be engaged across more than one region to secure long-term work and justify suitable equipment.

SELECT THE RIGHT SYSTEM

This report has highlighted the efficiencies and value of mid-sized purpose-built harvesters and forwarders for mid rotation thinning operations. With approximately 20% of the Gippsland resource on steep slopes, a tracked harvester with a telescopic boom will provide the best combination of access and efficiency. Combining this with a 15-tonne capacity forwarder will provide a capable and efficient system on most of the small and medium-sized resources identified in this report.

Medium-sized purpose-built tracked harvesters are not common in Australia. However, Neuson are an Austrian company building tracked harvesters for the steep European terrain (Figure 53). These harvesters have up to a 13-metre telescopic boom and a self-levelling cab up to 25 degrees forward and 15 degrees on side slope, enabling them to work comfortably on steep terrain. With a width of just 2.7 metres, the Neuson can comfortably work in thinning operations without removing an out-row. They also contain a small front blade, to assist with grip on steep slopes, while also providing the versatility to undertake minor road works. Neuson are powered by a John Deer motor. Importantly, several Neuson machines are now in use in Australia.

[o] Based on operating 48 weeks in a year

Figure 53. Neuson 243 Harvester (20 tonne)

The most appropriate harvesting head for the Neuson would most likely be a mid-size Waratah with eucalypt rollers to handle the variety of bark on the proposed plantations. Fitted with a stump spray system, this harvester would be able to undertake all the thinning operations identified in this report.

While there are several forwarders that could be used in combination with the Neuson, an EcoLog 574F or Komatsu 855 (Figure 54) would be ideal options. With a 14-tonne load capacity and importantly also having a 2.7 m width, these forwarders could follow the path of the harvester effectively without causing retained stem damage. The exception would be slopes above 18 degrees, which would require shovel logging or side cuts to extract the wood.

With a suitable harvester and forwarder, efficient and cost-effective thinning can be completed on all the sites identified. The final consideration is trucks to provide transport to markets. Assuming long distance haulage, the ideal trucks would be B-doubles (where access permits) with a piggyback system and central tyre inflation to minimise roading costs and maximise the operational window.

Figure 54. Komatsu 855 Forwarder (14 tonne)

Implement The Plantation Management Recipe For Success

To build a viable and successful private hardwood sawlog resource in Gippsland there are some important management considerations that must be adhered to. The seven steps outlined below provide the most likely recipe for small-scale growers to succeed in Gippsland using current markets.

1. Establish species with durability class 2 and above plus excellent sawlog qualities. Where possible those that are not susceptible to lyctus borer. Best non-lyctus species include yellow stringybark (*Eucalyptus muelleriana*) and silvertop ash (*Eucalyptus sieberi*). Excellent performing species that are lyctus susceptible include spotted gum (*Corymbia maculata*), sugar gum (*Eucalyptus cladocaylx*) and blue gum (*Eucalyptus globulus*).
2. Select sites with less than 18-degree slopes and lay out trees at 800-1000 trees per hectare in rows 5 metres apart to enable access for thinning.
3. Each plantation should invest in non-commercial thinning (NCT) and form pruning to prepare for mid rotation thinning:
    a. NCT to a stocking of 400 – 500 trees per hectare age 3-5 years to allow space for equipment to move without removing an out-row.
    b. Target an average piece size of 0.2 m^3, equivalent to a diameter (DBH) of approximately 22-25 cm, to maintain a low harvest rate and open up additional market options such as poles, veneer and small sawlog.
    c. Form prune all retained trees to remove multi-leaders and large branches to ensure that a minimum 4.0 metre log length can be processed (i.e. every tree has commercial value). This is the minimum size for standard log truck bunks.
4. Lift prune the best 200-300 trees per hectare to a height of 6.5 m to ensure quality sawlogs are being produced.
5. Undertake commercial thinning between ages 10-14 years (depending on site quality and growth rate) to remove 40% of the stocking and approximately 30% of the volume. This will leave a stocking of 250 – 350 trees per hectare.
6. Repeat commercial thinning between ages 16-20 years to reduce stocking to 150 to 200 trees per hectare.
7. Clear fall between ages 25-30 years.

Figure 55. Non-commercial Thinning Using a Skid-Steer

Provide An Appropriate Subsidy

By pooling the collective resource of private small and medium-scale hardwood plantations in Gippsland a program of mid rotation thinning could be successfully coordinated. This would improve the likelihood of attracting a suitable harvest and haulage contractor and securing markets for the wood. Furthermore, it would enable a program of planning and supervision for a qualified forestry company, which would have efficiency and cost benefits compared to each plantation being handled individually.

There would be several costs that would be incurred for a coordinated mid rotation thinning program. Assuming 40 sites signed up to the initiative and 35,000 tonnes of wood was to be thinned (as per Table 18), an outline and breakdown of the likely costs have been provided in Table 19.

Table 19. Estimated cost breakdown to coordinate a mid rotation thinning program.

Item	Cost per Tonne	Total Cost	Total per Site
Plantation yield assessments	$2.86	$100,000	$2,500
Site inspection with harvest & haulage contractor	$1.14	$40,000	$1,000
Draw up proposal for growers including maps & proposed returns	$2.86	$100,000	$2,500
Sign up growers to Plantation Thinning Agreement	$0.57	$20,000	$500
Complete Timber Harvest Plan including Cultural Heritage and Biodiversity checks	$2.00	$70,000	$1,750
Establish Harvest & Haulage Agreement	$0.57	$20,000	$500
Roading Upgrades (Est. average)	$5.71	$200,000	$5,000
Float equipment (Est. average)	$2.29	$80,000	$2,000
Undertake thinning operations incl. stump spray (Est. average)	$40.00	$1,400,000	$35,000
Undertake haulage operations (Est. average)	$50.00	$1,750,000	$43,750
Undertake Harvest Job Induction	$1.14	$40,000	$1,000
Provide Plantation Harvest Report, payment and Recipient Created Tax Invoice to grower	$2.86	$100,000	$2,500
Total	**$112.00**	**$3,920,000**	**$98,000**

Markets for the thinning resources will be predominantly hardwood woodchip markets. The two current options are (i) Geelong for blue gum and shining gum resources at an average distance of 235 km from Gippsland; and (ii) Eden, for all hardwood species at an average distance of 390 km from Gippsland. Some of the wood could also be sold as firewood into Yarram and Melbourne and as small sawlogs into local markets. Nevertheless, at best, a return of approximately $80-$100 per tonne is achievable in current markets. This would lead to a loss of $32 per tonne at worst case and a loss of $12 per tonne at best. Neither of these options include a return for the grower.

To safeguard this initiative, a $40 per tonne subsidy would be recommended for eligible growers. This would allow a return of between $8 and $28 per tonne to for each site. This would provide some funds for contingencies and a return for each grower as an incentive for participation. This would amount to $1.4 million in subsidies to achieve a favourable outcome. The project would take approximately 2.5 years to complete from planning to completion of harvesting depending on weather and site conditions. This project could create up to 70,000 tonnes of future hardwood sawlog resource in small and medium-scale private plantations across Gippsland.

Report Recommendations

1. *Introduce a Thinning Subsidy*

While the Victorian Government is pushing hard to see new private plantations established in Gippsland, there remains a backlog of unthinned resource from the establishment initiatives rolled out 10-20 years ago. This report has estimated that this could amount to 700 hectares (not including those already beyond thinning). It is paramount that these existing plantations be thinned to create quality resources for the industry to build on. It is recommended that support be placed behind Radial Timber Australia, who has recently applied for a thinning subsidy to complete this work and provide a local market for the future sawlog resources.

2. *Evaluate Suitable Harvesting Equipment For Thinning*

There is a strong desire to see contractors in Gippsland using purpose-built mid-sized harvesting equipment to undertake cost-effective thinning in small and medium-scale plantation resources. If the current resource of 2,400 hectares could be expanded and well managed, a simple thinning subsidy is likely to be enough to encourage a contractor to invest in appropriate equipment. However, there is little information for the equipment proposed in this report. It is recommended that a project be undertaken to assess the suitability, productivity, and cost of this equipment with an existing contractor in Australia. Hurford Forestry in NSW has recently purchased similar equipment to that recommended in this report and would be a suitable partner for the recommended studies.

3. *Support The Development of Small Log Markets*

There are serious concerns about suitable markets for small diameter logs extracted from hardwood thinning operations. While there are some opportunities for firewood and poles, the reality is these markets are very small. Presently only the Eden export market has the capacity to take large quantities of small diameter logs of the species being grown in Gippsland by small and medium-scale private growers. The Geelong export market is another option for blue gum and shining gum. However, both markets are well outside the Gippsland region and have been subjected to recent down turns due to a drop in demand for Australian woodchips. It is recommended that a project be undertaken to explore all the current and emerging market options for small diameter hardwood logs from Gippsland. This project should outline specific support that could be provided to assist the growth of new market alternatives.

4. *Assess Non-Commercial Thinning Options*

This report has highlighted the need for larger tree sizes and lower stockings to reduce harvesting rates and diversify market options. While non-commercial thinning benefits are understood, there has been no effort to assess the various methods with respect to safety, cost and effectiveness. It is recommended that a project be undertaken to assess methods such as chemical (stem injection or bark spray), hand fall, mechanical pushing (up-rooting, Figure 55) and harvest (with stump spray) to better understand the most appropriate and cost-effective options. Beyond this project, it is recommended that all new hardwood plantation grants for Gippsland insist on the inclusion of non-commercial thinning to ensure a minimum level of plantation quality.

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