



Australian Government

Forest and Wood Products
Research and Development
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Log Presentation: Log damage arising from mechanical harvesting or processing





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Project no: PN02.1309

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**Log Presentation:
log damage arising from mechanical
harvesting or processing**

Prepared for the

**Forest & Wood Products
Research & Development Corporation**

by

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The FWPRDC is jointly funded by the Australian forest and wood products industry and the Australian Government.

EXECUTIVE SUMMARY

Objectives

The major objective of this study was to identify the major sources of damage to hardwood sawlogs arising from mechanical harvesting and to document “Best Practice” techniques in use to minimize this damage.

As part of that objective CSIRO Forestry and Forest Products undertook to:

1. Report on the types of sawlog damage occurring through machine harvesting of hardwood trees and its causes, and
2. Report on ‘best practices’ of components of the industry and detail these ‘best practices’ for harvesting, transport and pre-sawing preparation at sawmills.

Key results

The major results of the study were:

- Hardwood sawlog damage occurs at all processing points in the harvesting and processing system prior to presentation at the saw bench. Damage occurs on butt logs and subsequent logs. Damage includes torn wood fibres both internally and externally, and the splitting of stems.
- Some of this damage occurs because of the application of the extremely high mechanical forces applied by the machine, and, in combination with operator lack of knowledge or inexperience, can create significant but unquantified damage losses from forest to mill.
- Damage if it occurs is attributed mostly to:
 - poor operator skills (up to 90% of damage attributable to poor technique or inexperience); and
 - inappropriate machinery (up to 5-10% of sawlog damage where machine systems are working outside ‘specific design parameters’).
- The larger machines and felling heads are the most effective on the wide range of tree sizes encountered in the natural forest but the economic efficiency of such machines is greatly affected where the proportion of small trees increases.
- Volume and product losses occur when:
 - falling trees are damaged,
 - damage necessitates downgrading of potentially valuable sawlogs, and
 - docking is required to remove damaged and dangerous wood.
- Scarfing techniques can minimize sawlog damage during felling (especially splitting damage) and can therefore reduce volume losses throughout the processing chain.
- Cross-cutting during log making has the potential to create damage, exacerbate existing damage and reduce volume recovery potential. Improved techniques and training will reduce both damage and volume losses.
- Some ‘damage’ is unavoidable due to the physiology (growth stresses) of the tree. Often damage to a log (particularly damage involving splitting) is exacerbated by impacts during handling and processing.

- Sawlog damage and the consequent volume and value losses can be minimized by experienced operators using ‘best practice’ techniques in all parts of the processing chain from forest to mill.
- General ‘best practice techniques’, appropriate to a range of machinery and conditions, which can minimize sawlog damage and losses during harvesting and processing operations are presented in the final sections of the document.

Application of results

The results of the survey demonstrate that there is potential to reduce both the occurrence of damage during machine harvesting of hardwood sawlogs and to minimize the worsening of the extent of that damage in further processing. Operator training either through experienced tutors in the field, or by more formal training in machine simulators, could reduce a considerable amount of the damage, and the value loss caused by the damage, within a short period after suitable training.

Further development of machinery, particularly felling heads, will allow the tree to be controlled more during the falling process without unnecessary stresses. In conjunction with carrier base improvement the aim would be to prevent the operator from applying the damaging forces. Machine technological advances could further decrease damage and therefore volume and value losses. Recommendations of particular machine and felling head combinations for particular forest structures or tree species are outside the scope of this report.

The general ‘model’ of best practice is based on the availability of the specialist machines and quotas large enough to support their purchase for the longer term. Smaller operations where machinery types are limited to the basic falling and loading machines can follow these best practice rules but machine characteristics may play a more important role in the opportunity to reduce damage.

Further work

The production of a “best practice manual” for the machine felling of hardwood sawlogs in Australia would be a significant and complex document that should take account of the wide variety of machinery types and sizes, forest structure, stand condition and inherent differences in tree species as they are affected by the application of felling stresses. Information from this report could provide a basis for a “Best Practices Manual for Mechanized Hardwood Sawlog Harvesting”.

Machine specific studies are required to estimate actual volume losses due to damage (during harvesting and processing and yard presentation). To enable industry to more accurately quantify loss in value and to estimate the ‘value’ of training, these field damage studies should be partnered with sawmill processing studies which follow the progress of logs through sawing and value – adding streams.

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Information for CSIRO abstracting:

Contract number	PNO2.1309
Products investigated	Hardwood sawlogs
Wood species worked on	<i>Eucalyptus sp.</i>
Other materials used	Machine harvesters
Location	NSW, VIC, TAS, WA, QLD

INTRODUCTION

Much of the machine development in the hardwood sawlog industry in Australia is an extension of the development which took place in Canada, America and Europe in the latter part of the 20th century (1980's to now) in the intensively managed softwood industries.

The use of mechanised harvesting systems is increasing in hardwood harvesting operations in Australia. This is due in part to increased efficiency in machinery and capability of these machines to work in a wider range of stand and terrain conditions. However a significant imperative in converting to mechanized harvesting systems is due to occupational health and safety issues. Harvesting contractors are safer in the protected cabin of a mechanical harvester, compared to being on the ground with a chainsaw, and the industry is leaning towards reducing the number of operations using chainsaw felling in order to improve operator safety.

Many of the machines currently used in natural eucalypt forest have been 'transferred' from previous softwood or hardwood operations. The high investment cost for harvesting and processing machinery and the variability of the available sawlog resource has initially inhibited the purchase and development of purpose built machines. Operators must necessarily develop experience in the variety of forest structures and species encountered in this developing segment of the industry.

The increase in use of mechanized harvesting systems has led to problems of log damage, including butt pull, log splitting during handling and cross cutting and crushing of the log. However, it has been reported that some mechanised harvesting operations have greatly reduced the incidence of log damage due to mechanical handling. The project aimed to record these improved practices and to allow other mechanized harvesting operations to improve the quality of the sawlog arriving at the sawmill.

By improving the log quality arriving at the sawmill, a greater value can be achieved from individual sawlogs through increasing the recovery of timber from the log. It is difficult to estimate a value to industry by reduction in the amount of damage caused by mechanised harvesting, as the amount of log damage that is being caused by mechanised harvesting systems is unquantified. However as an example if,

- 40% of the total annual volume harvested from NSW and Tasmania (approximately 410,000 m³ (ABARE, March 2000) is mechanically harvested;
- the best practices described in this project improve log recovery by 1%;
- 35% of the log is recovered as sawn product; and
- sawn product is worth \$500 m³,

then the annual worth, to that segment of the industry, of improved practice in mechanised harvesting is \$287,000.

This project surveyed contractors currently involved in mechanised harvesting to determine current practices. The survey involved site visits in NSW, Victoria and Tasmania and phone surveys to other mechanised harvesting operations in other areas, and other States. In addition a number of sawmills were surveyed to determine sawmill requirements and experiences with machine harvested logs. The survey also involved forest harvesting training providers whose advice was sought on providing the 'best practice' information in the most effective manner to both existing and future, operators.

Any 'best practice' manual which may be produced for the industry will, by necessity, need to accommodate the variety of species harvested and forest structures which contractors encounter.

RECOMMENDATIONS AND CONCLUSIONS

- Hardwood sawlog damage occurs at all processing points in the harvesting and processing system prior to presentation at the saw bench. Damage occurs on butt logs during felling and on subsequent logs cut further up the stem. Damage includes torn wood fibres and the splitting of stems and logs during felling (capping, slabbing, splitting, shake, shatter and fracture), snagging (shatter, fracture), cross cutting (slabbing, spiking) and transport (shatter, spiking, quartering), and includes internal damage to wood structures during falling and processing.
- Some of this damage occurs because of the application of the extremely high mechanical forces applied by the machine, and, in combination with operator lack of knowledge or inexperience, can create high damage losses from forest to mill.
- The two major ‘damage risk’ areas are the felling of the tree and the cross-cutting of the stems into the appropriate sawlog lengths.
- Mechanised harvester (and processor) operator skill is a major factor in reducing damage as observation and survey evidence suggests approximately 90% of the damage caused to sawlogs can be attributed to technique (or inexperience).
- Inappropriate machinery may contribute 5-10% of sawlog damage where machine systems are working outside ‘specific design’ (machine head cannot handle some larger or smaller trees in coupe).
- Some ‘damage’ is unavoidable due to the physiology (growth stresses) of the tree. It is the natural expression of tension and compression forces within the bole caused by the growth characteristics of eucalypts, and is generally more prevalent in fast grown trees. Often damage to a tree (particularly damage involving splitting) is exacerbated by impacts during handling and processing. Some damage is hidden or latent until further processing.
- Sawlog damage can be minimised by experienced operators using ‘best practice’ techniques for particular machines, tree sizes, forest structures and stand condition. Species and site specific techniques are generally achievable with experienced operators of each machinery type in the harvesting system.
- Improvements in machine and/or operator efficiencies, and product recovery, will continue as the industry develops. Improvements will be accelerated by investment in training of operators and the continued development of ‘best practice’ techniques.
- Operations which have already developed their own ‘best practice’ techniques are most successful in reducing damage where the processing line for a hardwood log is understood by all of those in the chain who handle each individual log i.e. faller, snigger, log grader, transporter, sawmilling yardmen and sawyer. These same skills can minimise product losses through appropriate removal of damaged wood without further damage or excessive wastage of potential products.

DEVELOPMENT OF MECHANICAL SYSTEMS FOR HARVESTING AND PROCESSING SAWLOGS IN NATIVE EUCALYPT FOREST

1. Characteristics of Australian eucalypt forest

Eucalypt forests utilized for wood production exhibit a wide variety of stand characteristics, largely determined by climatic factors and previous management history. Within stand variation in density, tree size, form and habit of overstorey and understorey vegetation affect the efficiency of any forest operation. A number of stand characteristics are critical factors in determining machine harvesting and processing options.

1.1. Forest structure

Stand characteristics relevant to harvesting have largely been determined by previous forest management practices. Naturally regenerated eucalypt stands are quite variable in their species composition, stand density and size class distribution of trees. The common occurrence of dead or overmature trees and the presence of older fallen logs (called morganers or downers) and other forest debris all impact on the efficiency of harvesting. In natural forest, understorey and mezzanine vegetation layers can restrict movement and visibility.

Steeper slopes and short sharp gullies and ridges are often a feature of the native forests available for wood production. The occurrence of rocky ground or outcrops in particular is obstructive, as are very steep slopes. In typical eucalypt forest, most machines are limited by slopes of 15-18 ° although machines with self levelling bases can successfully work up to 25° . The amount of debris especially in the form of larger old logs restricts safe movement, particularly on slopes, and in general, tracked machines can only manoeuvre over debris and logs which are less than half the height of the track.

Naturally regenerated stands frequently contain unmerchantable trees and trees of a number of species – some species being more desirable than others. This may involve selective logging or removal of unwanted stems at the same time as harvesting desirable species. Older uneven aged stands have a wide range of stocking and stem sizes and can have great effects on efficiency of harvesting operations. A wide range of stem sizes makes it difficult for one machine to achieve and maintain high efficiency and productivity.

Results from this survey and other studies by the Forest Engineering Research Institute of Canada - FERIC (McMorland and Guimier 1984) found tree size had the greatest effect on the incidence of damage. Tree size is significant especially in combination with other factors which affect the manoeuvrability of the machine. The ability of the operator to get the machine in close (visibility, stable base) is an important factor in reducing impact damage to the base of the tree with head or grabs during manoeuvring. Given the same type of damage and the same causal factors, small trees will often exhibit larger proportional losses.

Studies on machine systems and machine types have found that smaller trees exhibit greater proportional losses from butt damage and stem damage if damage occurs. Shatter is the most severe problem in smaller diameter trees as smaller trees are easier to bend and 'bruise'. Larger trees that extend the capability of the machine usually cause difficulties in falling and therefore create more damage during the falling process (McMorland and Guimier 1984).

It would be difficult to quantify the impact of the combination of all the possible 'adverse' conditions to felling damage; however, stand factors which affect machine productivity are likely to show similar increases in damage levels. Conditions such as steep slopes and rough ground which make manoeuvring and control difficult for the machine are likely to provide similar difficulties in controlling the machine felling head.

Stand density is variable between forest types and can vary greatly within a single stand. The risk of damage to the falling tree and to other adjacent trees as the tree passes through other canopies and layers is greatest in dense stands. Open stands may have fewer trees but if tree architecture is expressed as large and heavy crowns then this may also create a damage risk to potential sawlogs.

1.2. Physiology of eucalypt stems

Many eucalypts are suitable for efficient machine harvesting operations producing long clear boles at even an early age through pole to mature stage growth. However, the physiology of the tree can have considerable effect on sawlog quality and the stringiness and persistence of bark can reduce machine efficiency.

Despite the tendency for clean straight boles, some species will not make good sawlogs until they have reached larger diameters. This is due to the cellular structure and orientation of the fibres within the sapwood and heartwood of the eucalypt and in the tensions created by the development of these fibres during growth (Florence 1996).

The outer layer of any green eucalypt bole is in a state of tension along its longitudinal axis and correspondingly the inner wood is in a state of compression. Stresses caused by the longitudinal strains across any diameter can be considerable. These can have consequences during the release of these tensions either naturally or during falling and processing:

1. The cells of the inner compressed wood may fail over time and develop large numbers of small compression weaknesses in the cell walls, commonly called 'brittleheart'.
2. When trees are harvested for sawlog lengths, the effect of longitudinal forces described above is dependent upon the species. Species with straight fibres are likely to split at the end of the logs particularly where the trees have been grown quickly. Species with interlocked grain usually split less frequently and may be preferable for pole applications.
3. When the eucalypt stem is cut lengthwise, the release of this inner compression may cause curvature in the outer pieces. When tensions are severe, end splitting of sawn pieces (log lengths and pieces) can occur as the growth stresses are released – reducing potential and value. The release of tension in outer wood causes a decrease in length whereas release of compression in inner wood causes an increase in length. This has consequences for volume recovered and market use. Conversion of smaller eucalypt logs is usually more of a problem and may require conversion to shorter lengths.

There are also lateral stresses and strains which occur in a cross section of the boles and such tangential compressions impose radial tension in the inner wood resulting in star shaped 'shakes' which radiate out from the pith to the outer wood. This phenomenon is very common in eucalypt logs.

The bark on eucalypts can be very persistent and may be difficult to remove from the selected sawlogs. Often fibrous it can interfere with and jam felling head components, which can have a dramatic effect on machine efficiency.

1.3. Harvesting systems for sawlogs in eucalypt forest

Generally the lower limit of diameter class which can be harvested by machine heads is determined by the maximum affordable harvesting cost for felling and processing. The upper limits are determined by the capacity of the machine and head, the largest of which has a capability of felling trees of about 1.3m diameter at breast height over bark (DBHOB).

Harvesting involves 5 main processes in the eucalypt forest:

- 1) tree falling,
- 2) extraction from the stump to the landing,
- 3) the debarking of the logs,
- 4) cutting to length, and
- 5) sorting and loading onto trucks for transport to the mill or market.

Harvesting systems may be characterized as either longwood or shortwood on the basis of when and where process 4 occurs.

Shortwood systems

This is where logs are cut to length (chosen market lengths) at the stump or landing and generally produce logs of length between 2.4 to 6 metres. The logs are usually extracted to the landing by a forwarder which generally loads itself using grapples or grabs. Cutting to length can be done by the felling head, manual chainsaw operator or by cut to length grabs on the forwarder.

Longwood systems

Generally longwood systems only involve heading at the stump (removing upper non-merchantable stem and crown) and produces truck length logs (11 – 13 metres) for extraction to the landing which is usually achieved by a ground snigging machine. Typically a longwood system transports the longest possible lengths to the mill.

Combination of systems are common and in most cases longwood lengths are snigged to the landing and cut to desired sawlog length at the landing to suit a variety of markets. Most Australian hardwood sawlog operations are referred to as longwood systems, with some sawlogs and pulpwood logs transported to the mills as shorter lengths.

1.4. Harvesting systems for sawlogs in eucalypt plantations

Sawlogs trees grown in plantations exhibit similar characteristics to many of the trees in native hardwood stands. Fast grown trees in plantations can and most often do show ‘freeness’ which makes them prone to splitting and popping. The lower density and even spacing of trees in plantations has a dramatic positive effect on efficiencies and productivity. Due to the more even size distribution, machine selection may be easier. Machine design can be purpose built to handle the major product. Stand conditions are usually less obstructive (depending on site preparation), however, if the plantation has been relatively undisturbed in the latter part of the longer sawlog rotation then visibility and brushing of understorey and intermediate shrubs and trees may be an issue. Slope factors will also be important. Operational techniques which reduce stresses and damage will be just as important to maximising the sawlog volume.

2. Development of mechanical harvesting machinery

2.1. Productivity gains

Gain in efficiencies and volume production with the use of mechanised equipment is as dramatic as the original gains made by the movement from hand saw falling/axe falling to chainsaws. The development of machinery for specialised wood production and species handling is an ongoing process.

Equipment designed to carry larger loads either from the stump or from the log landing needs to be fed at similar rates by the tree felling component of any operation. Volume per day and the economic imperative in purchasing and fully utilising the capabilities of any machine determine the choice of machine and its required sophistication.

2.2. Safety issues

Inherent in any tree falling operation is the risk presented by falling trees, falling debris and the ever present danger for operators close to large and largely unpredictable trees working with powerful and exposed high speed cutting equipment (Plates 1 & 2). The development of mechanised falling equipment has helped significantly to reduce the occupational health and safety concerns in one of the most dangerous occupations in the natural resource environment.

The protection afforded by well designed equipment (Plate 3) and its consequent reduction of lost time injuries to extremities of workers (hands, arms, feet and legs), reduction of impact injuries from small debris and the extension of the area and time of the 'safe' working environment has given forest owners and harvesting contractors a preference for mechanised systems in forest harvesting. This safety culture has developed to the point where insurance premiums and contract tenders state that preference will be given to operations which offer mechanical harvesting systems as contract components (SFNSW 2001).

2.3. Development of mechanised felling heads reducing risk and volume losses

As machinery has developed the industry has gone from chainsaw felling through to systems where the tree is either snipped off using mechanical shears or cut off using a saw blade (chain or disc) incorporated in the felling head. Chain saw falling is still practised in many operations.

The felling of large trees by either manual falling methods or by specialised machine heads often results in damage to the more valuable butt log of a tree. Through various actions of the tree and operator in the falling process, damage can be caused to subsequent logs and other wood products that may have been available from the same tree. Butt logs may also suffer further damage.

Machine innovations are progressive and have realised great improvement in efficiency, safety and scope of application in the mechanical harvesting and processing environment. Australia has taken up many of the machinery and innovations developed in Canada, America and Europe. Much of the technology in felling and processing practices in Australia has been initially applied to the plantation softwood industries (more recently, these innovations have been applied in the hardwood sawlog industry in Australia, particularly as the industry moves into younger regrowth resource). Both clear felling and thinning practices have benefited from the ongoing work of the overseas forest industries.

A number of organisations such as the Forest Engineering Research Institute of Canada (FERIC), the Logging Industry Research Association in New Zealand and CSIRO have carried out many machine and equipment evaluations. However, in Australia little work has been carried out in the definition of sawlog damage and its occurrence during felling and processing by machine. Much of the work in hardwood species has been directed at developing techniques for efficiently handling and debarking of small to medium size eucalypt logs (*pers comm.* Bob McCormack¹). Machines developed for commercial thinning operations have received greater attention, but most have been directed at productivity, debarking efficiency and avoiding damage to retained trees - not to the damage incurred during the felling and processing. Early work by Barnacle (1969) looked at felling damage to butt logs and subsequent logs during chainsaw felling of eucalypts. Similar forces can also apply in machine felling.

Damage to the butt log has the potential to incur the greatest loss in both volume and value. McMorland and Guimier (1984), in British Columbia, undertook a detailed analysis of butt log damage associated with various felling systems and rated the degree of damage to the type of felling system. These studies provide analysis of stresses in softwood and hardwood species caused during machine felling. In the order of increasing butt log damage to felled trees, a person operating a chainsaw has the least potential damage followed by mechanical harvesters which employ non-shearing heads. The most damage was caused by shearing heads.

No shearing heads are currently used in hardwood sawlog operations in Australia.

The particular designs of machines are often a contributing factor to the damage (particularly butt damage) which may occur by either the way the tree fits or is held in the felling head, or by the stresses which are applied to the tree by the felling head. The stresses can be an artefact of the machine design or they may be being applied by the actions of the operator at the time of felling.

Tree felling heads were first attached directly to the front of robust machinery such as a rubber tyred or tracked tractor or earth mover. Subsequently felling heads were mounted on fixed and then articulated booms for versatility and manoeuvrability.

Shear-felling heads

Shearing knives were first used in felling heads felling small diameter softwood trees. Shearing knives at the base of the head snipped the tree off at the stump and the felling heads either directed, encaptured or accumulated the cut trees. The mast of the felling head gave support and/or directional forces to the tree during felling.

In the early to mid 1970's shear felling heads were gradually replacing manual chainsaw felling in many small sawlog operations. Development of shearing heads with hydraulically operated shears in feller bunching heads continued into the 1980's. However, volume losses in logs destined for sawn timber were a major concern as the action of the shearing forces caused considerable tearing and compression damage and led to serious butt splitting of the valuable sawlogs. Shearing heads were being used for softwood and small hardwood, and in America, Canada and Sweden and damage to butt logs was worse in the extremes of cold in the winter months. By 1984 some sawmills were already refusing to accept sawlogs from shear head felling. In the early to mid 1970's shear felling heads were gradually replacing manual chainsaw felling in many

The softwood industry in Australia trialed shearing heads in the late 1960's to early 1970's. For hardwoods the force required by the shears to sever the bole is

¹ Bob McCormack, CSIRO FFP, Forest to Mill Centre, 2003



Plate 1: **Mature tall eucalypt forest in East Gippsland, Victoria.**



Plate 2 (left): **Manual chainsaw operations in a harvested coupe.**



Plate 3 (right): **Overhead protection afforded by cabins of machine carrying a felling head.**

considerably greater than for softwoods and hence only large and powerful shear heads could work efficiently in small hardwood trees (15-25 cm diameter at the shear). This factor and the potential to damage valuable sawlogs saw the shear heads restricted to wood fibre operations and felling of small trees.

Development of a reliable saw head attachment was seen as a priority, to improve efficiencies and reduce damage to valuable logs. Interchange of heads and carriers was seen as a development advantage to suit different forest conditions. In the mid to late 1970's a few non-shearing (augering and sawing) heads were in use in Sweden but were not independent of the carrier. Development began in earnest in the 1980's overseas and entered the softwood and small hardwood markets quickly. In Australia it is only in the last few years that mechanized felling heads have been in operational use in hardwood forest sawlog operations.

Chainsaw felling heads

Chain saw felling heads were initially less robust than shear heads and operational down time for repairs and maintenance was a serious productivity problem. In particular the complex heads were not suited to brushing smaller non-merchantable trees and scrub aside in natural forest. More robust machinery with enclosed hoses and components has largely negated that deficiency. They were most effective in evenly spaced managed stands of similar size class trees.

The action of the saw causes no wood compression damage. Butt log damage was not eliminated however as the saw blade needs to be kept from binding and this imperative means the trees are often 'bent away' from the cut – creating stresses in the bole and stump. It is not the chainsaw which creates the damage but the stresses applied to the tree. Chainsaw heads which required the least amount of bending of the tree away from the cut caused the least butt damage (splitting).

Tree size is a critical determining factor in felling head design and a range of head sizes have been developed by many manufacturers that can efficiently process trees from a few centimetres to over 1 metre in diameter. In Australian native hardwood forests most operations are required to fall and process a range of size classes. The placement and versatility of grab arms to assist in supporting, and controlling the directional falling of the tree has been a convergent development in felling heads.

Disc saw felling heads

Boom mounted circular saw felling heads were developed in the early 1980's because observation of the continuous felling operations using circular saw carriers caused minimal wood splitting damage and indicated high production potential. Boom mounted heads reduce butt splitting damage to minimal or non existent as there is no need for bending stresses placed on the trees during felling since the trees are not grappled until they are fully severed. As with chainsaw heads the action of the saw caused no wood compression damage. Circular saws can handle hardwoods and the capability to make cuts lower on the stump due to machine geometry is an advantage (Folkema and Mellgren, 1982). Providing adequate and timely power to the spinning disc saw usually limits the size of the head and the size of the tree which can be efficiently cut.

Combination felling and processing heads

Felling heads and feller bunching heads incorporated either shears, chainsaws or disc saws to sever the tree and place it on the carrier or in the path of the extraction equipment for snigging to the landing prior to processing. The new generation of felling heads are often purpose built for particular felling operations but their versatility and efficiency have been improved. With the innovation of Grapple style harvesting and processing heads and similar multipurpose machines the versatility of

chainsaw heads has been taken to a new level – where the felling head can directionally fall, debark, cut to length and load. Although designed for higher productivity in evenly sized small to medium trees in thinnings and plantation clearfelling, these machines have found some application in the native hardwood sawlog industry. In small log hardwood operations these have advantages in efficiency and productivity. Added advantages to chainsaw heads is their versatility in scarf cutting and back cutting to assist directional falling and reduce butt log damage. However, chainsaws generally require more maintenance.

For machine heads that will minimise damage to the butt log especially, the following factors hold the greatest potential for success.

- No shears in the felling head
- Leave the tree free (minimal forces applied by machine head) during the cutting process
- Machine designs need to reduce binding of the saw and be less sensitive to binding
- Any stresses imposed should apply to the stump which will reduce the splitting of the log
- Eliminating any opportunity for the operator to apply uncontrolled stress to the tree during cutting, falling and cross-cutting.

Machine design factors hold a great potential for the systematic reduction of butt log damage and other forms of damage in mechanical harvesting (McMorland, 1985). With respect to the second and subsequent sawlogs in a tree, the losses due to various types of machinery are more dependent on the size of the tree and nature of the final product.

2.4. Necessity for continued chainsaw felling

Manual falling of trees is a dangerous operation and a prevalence of injuries and death to manual operators has been a major impetus towards machine harvesting. However, manual chainsaw operations will still be required to fall particular trees unreachable by machine or to provide initial access and support to a forestry operation. Some cross cutting and most log assessments will continue as a manual operation for some time. Some harvesting operations are still solely carried out by manual fallers.

Manual chainsaw operators can minimise the damage to sawlogs when falling by the skilful and proper use of scarf and back cuts. The general principles for manually falling and processing of hardwood trees and minimising both danger and damage are taught by a number of training centres (such as ELITE, NSW and Hollybank Forestry Centre, Tasmania). Examples and logistics of chainsaw tree felling techniques are given in user manuals (Hollybank Forestry Centre Inc., 2001) and taught by experienced instructors.

Some operations which can minimise splitting at the stump can only be carried out by an experienced chainsaw operator. For trees which have a tendency to split, or are very free in their growth characteristics, a manual chainsaw operator can insert a boring cut to be used as the initiation of the back cut (Hollybank Forestry Centre Inc., 2001). This of course cannot be emulated by a machine felling head.

SURVEY OBSERVATIONS AND DISCUSSION

1. Types of mechanised falling and processing heads used in Australia

Felling and processing heads are currently being used in Australian conditions on either purpose built carrier bases (complete machines built to specification Plate 4) or excavator bases modified to specific heads and purposes (Plate 5). Machine bases vary in size and sophistication and the combination of head type, head capacity (diameter of cut/processing speeds) and bases are many and varied. The range of harvesting machine bases and felling heads now available for specific forest structures and harvesting systems is large (Johnson 2002; Anon. 2002), although relatively few are represented in Australian forest operations.

Table 1 gives examples of machinery viewed in hardwood forest operations during this study. As often the machinery was 'transferred' from previous operations the table is not meant to be a recommendation for any particular head or machine or combination. It was not possible to visit or interview all operators/operations.



Plate 4: Purpose built carrier and fixed falling head.



Plate 5: Excavator based ‘floppy’ or live felling head.

1.1. Felling heads

Felling heads are designated as either Fixed heads or Live (‘floppy’) heads. Both head types have their specific strengths and weaknesses for components of the harvesting system.

Fixed heads (Plate 6) can be used to directionally fall, bunch trees (using specifically designed accumulating or feller-bunching heads), debark, load and shovel logs with a high degree of control available to the operator. The efficiencies of the machinery are determined by the machine architecture (base type, dimensions and weight; head size weight, cut diameter; boom length and travel). Machine architecture can be tailored to suit specific forest types and terrain – in choice of base (tyred or tracked) and head size especially. Heads are most often used as an after-manufacture attachment to an excavator base which has been modified for specific requirements. Fixed head machines can be used for a number of coupe operations outside their purpose built features: re-distributing debris; pushing small trees; loading; scarf cutting larger trees to facilitate directional falling;. In general the machine moves for each operation and is lined up on the direction of falling. Fixed head machines may be fitted with either disc saws (Plate 7) or chain bar saws (Plate 8). Chain saw felling heads require the tree to be grasped by the grab arms of the felling head prior to the cutting to keep the kerf free and avoid pinching of the saw. Some heads require the grabs to be ‘closed’ to allow operation of the saw some do not. The follow plate on most disc saws allows the cut to be completed before the tree is grabbed at the operator’s discretion.

Floppy heads (Plate 9) as the term suggests have generally more available movement and versatility with the cut tree (especially for debarking operations) and in general the machine can maintain a position which encaptures the versatility of the head. The head

Table 1. Examples of harvesting and processing machinery (carriers and felling and processing heads) used in Australian eucalypt forest.

Forest Structure	Falling	Stump to landing	Debarking	Cut to length	Sorting/Loading
Mature Clearfell/Seed Tree	Fixed Head Large diam capacity (Timbco, Tigercat, Unicon, Logmate, Hultdins) (Disc or chain saw heads) Purpose built or mounted on excavator base (Komatsu, Caterpillar, Volvo)	Long length snigging Rubber tyred articulated grapple skidder (Timberjack, John Deere)	Excavator based (Komatsu, Kato, Volvo etc) Grabs or Grapple harvester with floppy head (debarking and some falling) (Large Waratah, Rossen)	Excavator based Grabs with cut-off saw (large range of makes and carriers) manual Chainsaw	Grabs (large range of makes and carriers) With or without cut-off saw
Mature Thinning	Fixed heads (Disc or chain saw) Large diam capacity Sometimes supplemented by larger capacity floppy head processing at stump (Waratah)	Long/short lengths Large capacity Rubber tyred forwarder articulated with grabs (Volvo, Timberjack, Valmet)	Excavator based Grabs or Grapple harvester with floppy head (debarking and some falling) (Large Waratah, Rossen)	Excavator based Floppy head grapple harvester Grabs with cut-off manual Chainsaw	Excavator based Grabs With or without cut-off saw
Regrowth Thinning	Large diam capacity grapple harvester (Waratah) Feller buncher	Short lengths Rubber tyred forwarder articulated with grabs	Excavator based Grapple harvester with floppy head (debarking and some falling) (Med Waratah, Rossen, Logmax)	Generally at stump	Grabs on Forwarder at landing
Mature Sawlog Plantation	Large diam capacity grapple harvester or Fixed Head	Long/short lengths Large capacity Rubber tyred forwarder articulated with grabs	Excavator based Grapple harvester with floppy head (debarking and falling at stump) (Large Waratah, Rossen, Logmax)	Excavator based Grapple harvester with floppy head (debarking and some falling) Chainsaw	Excavator based Grabs With or without cut-off saw Grabs on Forwarder at landing
Mature Pulpwood Plantation	Feller buncher and/or Small capacity grapple harvester Feller buncher	Large capacity Rubber tyred forwarder articulated with grabs	Excavator based Grapple harvester with floppy head (debarking and some falling) (small Waratah, Rossen, Logmax)	At stump	Grabs on Forwarder at landing

Notes. (1) indicative table only (2) Bunching heads not used in eucalypts as trees are too heavy (3) Often only one felling machine does all large and small trees.



Plate 6: Fixed head used for directional falling.



Plate 7: Disc saw utilised in Fixed Head.



Plate 8: Chain saw utilised in rotatable Fixed Head.



Plate 9: **Live ‘floppy’ head showing grabs and feed rollers for debarking.**

is supported at the end of the boom via a rotating joint. Tree control in a felling mode is, however, limited and although manipulation of boom and head can initiate 'directional' falling the operator has much less control than with a fixed head. To a degree directional falling is facilitated by the versatility of the head in being able to round the back of the tree for a scarf cut without shifting the machine. With usually less power (strength/control) and less operator control of the tree, these machines are more suitable for felling on smaller log diameter operations such as younger forests and thinning operations. Floppy heads generally do not have the bunching capacity of a fixed head. These heads are fitted with chain bar saws for versatility.

In addition to the felling functions floppy heads are usually capable of processing the stem using powered feed rollers and delimbing knives which facilitate delimbing, debarking and cross-cutting the tree to required lengths.

1.2. Debarking heads

Mechanical debarking of *Eucalyptus* stems, at the stump, has gone through many developments in the last 20 years (Wingate-Hill and MacArthur 1991). In larger logs debarking using grabs and grab arms to peel bark plates off the logs still occurs (Plate 10). The bark on the largest of logs is sometimes 'bruised' along its length to facilitate its separation from the sapwood and allow the grabs to gain purchase. However, many machine felling heads have very effective debarking capability. Debarking requirements for hardwood logs has seen the development of specialized feed rollers designed to both feed and debark (Plate 11 and Plate 12). Many heads have debarking capability and machinery is becoming more specialized (feed rates, roller pressures, debarking lugs). The combination of felling head and debarking capability can be very efficient in smaller diameter stands such as regrowth thinning coupes which may also involve selection and processing of small sawlogs.

1.3. Cut-off saws

Cut-off saws (variously named 'cross-cut' saws, 'bucking' saws, 'length' saws, and 'docking' saws) are described as the saws used in the processing and log grading operations in the coupe. In the strict sense of the description of cut-off saw the chainsaw contained in the felling head is also a cut-off saw – as it can be used to cut to pre-determined lengths such as in a thinning operation.

The most common usage of the cut-off saw in operations is the machine used at the log landing to cut to length after debarking and log grading – preparing the logs for their journey to their destination market. Often the cut off saw is combined in a floppy head with the debarker at the landing or it can be a separate machine head with grapples and cut-off saw combination (Plate 13).

1.4. Loading grabs

Loading grabs, used as a less sophisticated log loader, may be incorporated into the machines system at a coupe landing. Other operations of debarking and log presentation may be carried out by a separate but dedicated machine. Log grabs (Plate 14) and log grab technology are utilized by skidders and forwarders in bringing logs from the stump to the landing. In this way grapple arms of the felling heads are often used to bunch and move logs at the stump or to load snagging/forwarding machinery in special circumstances.

1.5. Specialised developments for eucalypt felling and processing

Harvesting systems investigated have utilised a wide range of machinery and combinations of machinery for the various felling and processing operations. Often the choice of machinery is limited at the time of the commencement of the operation and may have been as simple as the machine being the only machine available. Other machinery choices are made on the basis of the 'major' proportion of the resource to



Plate 10: Debarking using crab grab attachment.



Plate 11: Debarking head used at landing.



Plate 12: Debarking head with delimbing arms.



Plate 13: Cut-off saw for log presentation at landing.



Plate 14: Crab grabs used for log sorting and loading.

be harvested and the efficiencies and suitability of the machine may suffer when used outside the optimum range of tree sizes and conditions.

Most machine and head development has been carried out in the softwood industry and transferred with some modification to hardwood operations. For the more specialised problems of hardwood eucalypts (green density, bark characteristics) components of the machine felling heads have undergone further development either by innovative operators or by consultation with manufacturers.

Innovations in felling head design have been necessary to allow the more complicated felling heads to work successfully and efficiently in the stand conditions common to eucalypt forests. Protection of components, circuitry and hoses are essential in this environment and various modifications to include components in protective casings or inside booms have been investigated and developed. This has reduced downtime considerably from earlier designs.

Because of the hardness and density of eucalypts, power outputs from motors and hydraulic components have been upgraded to maintain or improve the efficiency of operations. Increases in efficiencies and reductions in the risk of capping and slabbing in both felling and cross-cutting have been achieved by increasing the power and speed of the chainsaws and disc saws in felling heads and cut-off saws.

Feed rollers have been modified to apply sufficient pressure (compression) to break bark/wood bonds and the geometry of combinations of position and pressure of grab arms has been successfully modified to assist that process. Spiralling bars (lugs) have been developed and further modified to suit characteristics of some of the main eucalypt bark groups.

Raised gripping lugs at the back of the felling head were originally designed to prevent the tree from sliding or rotating during felling or end-cutting. This has been found to cause damage to valuable small sawlogs. Some operators have replaced gripping lugs with specialised flat plates to clamp the stem or log and so 'hold' with a larger surface area and reduce compression damage.

Since many operations are required to fall larger trees (up to a metre or so in diameter) and recent modifications in the versatility and movement in the chainsaw components

have improved the ability to scarf and backcut even larger trees to facilitate felling and reduce the risk of damage.

Some small scale operations continue to use the combination of manual chainsaw falling and machine falling where the falling head doubles as a felling machine and a debarker and loader. This compromise between falling and processing for smaller operations requires careful attention to minimising damage. Operations dedicated to smaller diameter thinnings may only use a floppy head machine as a falling head and processor coupled with a forwarder to snig from stump to landing and to load trucks.

Specialist mechanised harvesting operations often utilise a purpose built felling head on an excavator based platform and each subsequent part of the processing operation (post falling) has a machine and head designed to be most efficient for the throughput of the processed log - utilising debarking heads, specialised cut-off saws and grapple loaders. Systems such as these, although much more expensive to set-up and require substantial contract volumes for economic efficiency, can be adapted to changing forest structural conditions where specialist machinery can be added or ignored to maximise the efficiency of the operation. Harvesting contractors with more than one simultaneous operation can 'swap' machinery as needs, damage factors and efficiencies dictate.

2. Damage caused during felling, transport and processing operations

The results of the surveys (telephone and field) showed that logging and harvesting contractors utilized a wide variety of machinery types, sizes and combinations. Contractors were expected to deal with an array of forest structures and tree sizes throughout the life of their contracts and equipment. Across all of these operations the contributing factors to sawlog damage were similar in origin and in relative effect on potential sawlog losses and value. A number of related studies returned similar findings (McMorland 1985; Hill *et al.* 2000). End product considerations, such as availability of markets for different log grades, lengths and quality influence the magnitude of losses through rejected volumes, and hence would affect the economic consequences of harvesting and processing damage during machine operations.

Table 2 reports aspects of log damage and where it might occur in the felling and processing chain. Some indications of machinery type and management practices which could aid in minimising damage are presented for consideration. The log damage occurring during harvesting system operations and its causes are dealt with below in operational order.

2.1. Falling

During falling enormous stresses can be produced as the tree weight and natural stresses (stresses caused by the 'lean' of a tree, disproportionate crown size, wind effect) are transferred to the "hinge" wood during cutting. These stresses can occur during manual falling (particularly if wedging is used to 'force' the direction of fall) and especially during machine falling as most machines have the power and weight (leverage) to force the tree to fall either in an unnatural direction, or before fulcrum points are reached in cutting. Applying pressure to the tree in any way creates the stresses that can break the tree off the stump rather than cutting it completely off the stump. Cutting the tree completely and placing the falling tree is achieved in small diameter trees and appropriate machine combinations (size, weight, diameter capacity). In the majority of situations (medium to large logs) in the hardwood sawlog industry it is essential that scarf and 'hinge wood' techniques be used to control the fall of the tree. Variations of the Humboldt scarf (Hollybank Forestry Centre Inc. Anon, 2001; see also Plate 15) are successfully employed and 'following the tree' with the saw cut whilst controlling the kerf as it opens can reduce pinching of the saw and potential damage to saw or log.

Table 2. Damage scenarios during harvesting and processing in Australian eucalypt forests and machine strategies which minimize that damage.

Operation	Characteristic or unavoidable 'damage' of eucalypt logs	Damage caused or made worse by machine or operator	Machine characteristics which can assist an operator to minimize damage	Strategies to reduce damage
Felling Large Trees	Endsplitting Shake Damage to other selected trees	Slabbing/capping Shake/shatter Fracture Spiking	Head with diam capacity of largest tree sizes Fixed directional felling head Plated (flattened) grab surfaces (not raised) Self levelling cab/boom Chainsaw head to facilitate backcuts Fast chainsaw speeds Disc saws can achieve lower stumps	Use machine in close to tree Use Scarfing techniques Adjust technique for tree size Place falling tree to avoid impacts / bending with high spots or gullies, with other trees, stumps, rocks etc
Felling Small Trees	Endsplitting Shake	Slabbing/capping Shake/shatter Fracture Spiking	Head with diam capacity of largest tree sizes Fixed directional felling head Larger Floppy heads may be suitable Plated (flattened) grab surfaces (not raised) Chainsaw head to facilitate backcuts Fast chainsaw speeds Disc saws can achieve lower stumps	Use machine in close to tree Use Scarfing techniques for larger trees (see above) Adjust technique for tree size Place falling tree to avoid impacts / bending with high spots or gullies, with other trees, stumps, rocks etc
Snigging Long Lengths	Fracture Shake Exacerbation of endsplitting	Shake/shatter Exacerbation of endsplitting Spiking	Articulated snigging machines Grab type bunching snigging	Felling machine adjusts bunch height to facilitate 'clean' efficient loading Herringbone access Minimize stump heights
Debarking	Exacerbation of endsplitting	Dogears, (spiking, chatter) Crushing Exacerbation of endsplitting	Adjustable debarking / roller pressure Head size to suit large and small trees Grapple head with cut to length	Appropriate roller pressure Support damaged stems
Log making (Bucking / Crosscutting to length)	Exacerbation of endsplitting	Slabbing / capping Fracture Exacerbation of endsplitting	Grabs with cut-off saws to suit largest material Flattened profile grabs to minimize pressure points Fast chainsaw speeds	Support log ends Debris mats for landing
Sorting	Quartering	Fracture Quartering	Flattened profile grabs to minimize pressure points	Placement not dropping Minimize impacts
Loading	Quartering	Fracture Quartering	Flattened profile grabs to minimize pressure points	Placement not dropping Minimize impacts



Plate 15: Modified Humboldt scarf cut executed using floppy head.

In felling heads utilizing either chainsaw or disc saw cutting, the overriding variable determining the butt-splitting damage suffered is the amount of bending pressure (stress, force) applied in keeping the kerf open, or in forcing the tree in a particular direction. The saw itself does not cause the damage. Bending stresses can be caused by the large mechanical forces applied by the closed grab arms prior to cutting or pushing. The pressure exerted by the grabs can damage the butt log of small trees without any conscious effort on the part of the operator to force the tree or open the kerf.

The use of a disc saw can, however, complicate the log grading process as the saw marks on the cut face can sometimes make assessment of log grading characteristics difficult.

Capping

Trees which have been ‘forced’ to fall - where pressure is applied to the tree by pushing during cutting and felling causing the wood to tear – often split off the stump. The resultant tearing can extend for some meters up the length of the butt log and may occur some distance into the heartwood depending on the severity of the stresses created either naturally or by the machine and/or operator ‘bending’ the tree. This damage which may not be visible at the cut surfaces and only become evident during processing. Most often referred to as capping (Plate 16) it occurs mostly where the tree is felled using only one cut and forced off the stump. The forces also cause damage referred to as butt pull (Plate 17), end-splitting, and slabbing (Plates 18 and 19) and sometimes the names given to the damage are interposed. Substantial volume losses can be incurred by removing this damaged and sometimes dangerous material before log grading.

Shake / Shatter

End cracks or shakes are frequently observed to occur during and after cross cutting logs, particularly those of hardwood species. It is likely that many of these cracks are caused solely by the release of longitudinal growth stresses at the face; however, shakes can occur as a result of falling the tree.



Plate 16: Capping visible at cut surface caused by forcing tree.



Plate 17: Butt pull caused by forcing tree from the stump.



Plate 18: Slabbing and end-splitting caused by forces during felling.



Plate 19: Slabbing in butt log through forcing the tree.

Shattering of the fibres occurs from tearing stresses within the log diameter as wood fibres are torn and stretched – creating a separation along and within growth rings. Shatter of the butt log most often occurs during the cutting and forcing processes and is usually visually more ragged and concentrated than natural shake. The term shatter is usually applied to damage of the upper butt log and subsequent logs and can occur both if the tree is severely bent during the arc of its falling or more importantly when it comes into contact with fulcrum points as it reaches the ground. The forces are similar in all cases (Plate 20 and 21) and the damage results in considerable volume losses both at the stump and during downstream processing. Also termed ‘felling shake’ (Barnacle 1969) this damage is attributed to concealed fractures which may have occurred during falling, or to the exacerbation of existing natural shake when trees have been stressed.

Any impact on hard objects during felling (stumps, rocks or other trees) can create considerably more felling shake, usually in the upper section of the stem. Felling shakes are usually accompanied by an audible cracking or ‘popping’ of the end face soon after cross cutting commences and splits due to growth stresses which are usually opened up more rapidly when felling shakes are present. Felling shakes are more common in large logs.

Fracture

Fracture is often interposed with shatter and shake, and because this damage type damage was often described by operators, rather than seen, fracture and shatter are regarded as similar damage in this report. In general the stress effect is the tearing or squashing of wood fibres breaking bonds between fibres and growth rings. Fracture seems to be applied to damage which occurs further away from the butt end of the log.

Spiking

Spiking or ‘dog ears’ (sometimes also called ‘slovens’) can also occur during the felling process as the machine head is manoeuvred into position prior to cutting. Inappropriate use of the grabs and rough contact with the chosen tree can injure the bark, sapwood and heartwood and create holes in the log with associated protrusions of woody material (seen also on Plates 21) which can affect log presentation. Generally these dog ears do not cause significant volume loss as they are mostly cushioned by the bark of the tree which is removed before processing. Debarking of valuable logs needs to be carried out carefully so as not to bruise or dog-ear the log (Plate 22).

2.2. Bunching and snigging

Shatter (viz. Shake)

Bunching is most often carried out by the felling machine and during this process of manoeuvring and removal of the crowns it is possible to apply stresses to the upper portions of the stems which may induce shattering. Machinery snigging longer lengths of logs from stump (Plates 23 and 24) to landing must manoeuvre the dragging lengths past trees and stumps and there is the potential of levering logs around obstacles causing bending and shatter particularly in the smaller diameter secondary logs. Sniggers and skidders use either hydraulic grapples or wires on winch drums to bunch and lift butt ends of logs behind the extraction machine. Sometimes a notch is cut into the butt of a log to facilitate the grip of wire shackles. This notched portion may be removed at the landing. Thinning operations and other operations using shorter length logs suffer less from shatter damage during snigging or forwarding but damage can occur if shorter lengths are dropped into carry beds of forwarding equipment.



Plate 20: Shatter/Fracture in a tree forced off the stump during felling – interior capping is evident extending away from the cut face.



Plate 21: Shatter in a fallen log from striking an obstacle (stump?) which has translated into protrusions during debarking.



Plate 22: Machine marks and ‘dog ears’ caused by processing (debarking).



Plate 23: Snigging long lengths along major feed tracks.



Plate 24: Snigging ‘bunched’ long lengths through previously harvested area

Spiking

The risk of external spiking damage to logs during bunching, end-cutting and from grabs during loading and snigging should be reduced because of improved access to the cut trees and logs, but can occur due to operator carelessness.

2.3. Debarking

Debarking is rarely done by hand and most often undertaken by use of grapple arms on processing heads, and loaders, or by purpose built debarking heads with feed rollers designed to compress and loosen bark (Wingate-Hill and MacArthur 1991). Designed to compress the whole outer part of the log, debarkers most often roll the log in a spiral to maximise coverage and to feed the bark away from the stem. Rollers usually have lugs to bite into the bark during compression and create more uniform separation. This often produces small ragged edged pieces of bark and similar shaped bruises or dog ears on the log.

Chatter

Excessive application of compressive forces creates damage which is often called chatter caused by impressions from the lugs. The debarking bruises and separates the bark/wood bond and the pressure required to ‘debark’ without undue bruising varies with species and season of felling and time since felling.

Spikes

Grabs on cross cutting and loading machines can be used to debark logs. The points of the grabs can compress logs in small high impact points during handling and loading, causing raised spikes to occur on the surface. When using grabs for debarking pulpwood logs a log is sometimes dropped from considerable height to loosen the bark – this can have dire consequences as the impact may exacerbate any splits and stresses already present in the log.

Large variation exists in requirements for compressive forces in debarking different species of eucalypts. The desired end products limit the amount of pressure that can be applied during debarking. High value material has very low damage allowances whereas logs destined for pulp can be debarked quickly with little regard to surface damage.

Experienced operators can minimize the compressive force and adjustments can be made to the compressive forces applied by the machine.

2.4. Cross-cutting and log sorting

Slabbing

Slabbing is caused by similar stresses which cause capping/slabbing in the falling tree. Stresses caused by the hanging weight of elevated logs (Plate 25) during cutting to length cause splitting of the suspended portion of the log. Most often associated with grab and cross-cut saw combinations it can also occur during manual crosscutting at the landing and at the stump.

Shake / Shatter

The log grading process and the usual sorting of different log grades and products on the landing provides potential for shatter due to stresses created along the stems in longer lengths and the ever present danger of impact shatter from dropping logs during processing. The required stacking, grading and log presentation of the 'selected' logs means that damage occurring at this time realizes a relatively greater loss in volume and value. Felling shake which was not evident may be exposed during cross cutting.

End-splitting

Many trees have existing growth stresses and these stresses can be released when the tree is cut into log lengths. Described by most in the industry as being 'free' the logs usually exhibit 'end-splitting' or 'popping' (Plate 26) which can vary from star splits at only the extremities of the cut logs to the most serious phenomena of 'quartering' (Plate 27) where the tree can literally explode into radial pieces along its length. Usually a problem most common in younger faster grown sawlogs, it can occur in most size classes and species.

Spiking

Spiking, as described previously, can occur at any time during cross cutting and sorting operations with inappropriate use of the grabs.

2.5. Loading (including road transport)

Shatter

Considering road transport as loading of trucks and travel then there is the possibility of rough treatment (impact and bending stress) creating shatter particularly in longer lengths and smaller log diameters. Once again operator carelessness can have a more significant impact on losses due to damage as the operators are dealing with the value – added product at this point.

End-splitting

End splitting which is due to existing growth stresses ('freeness') within the log can occur at any time from stump to loading but the severity and dimension of the end splitting can be exacerbated by rough handling of these 'free logs' during loading and by rapid moisture loss from the cut ends. Splitting may continue to develop during transport to the mill as air movement over the log may further increase the rate of moisture loss (Wingate-Hill and MacArthur 1989). Even logs which have been end-coated with wax, or have had gang plates attached can develop serious end-splitting if



Plate 25: Slabbing caused by a single cut to unsupported log during bucking (subsequent handling has exacerbated the damage).



Plate 26: End splitting and shake in a small 'free' grown log.



Plate 27: Quartering in a 'free' grown log which occurred during transport.

mishandled. Any splitting damage which occurred during falling (such as that due to slabbing) can be exacerbated by mistreatment also.

Quartering

The final consequence of severe end-splitting and further impacts and stresses during handling may be the complete quartering of the log into separate pieces. This can occur in the time from loading until the mill is reached.

Debarked logs, particularly small diameter logs, lose significantly more moisture than logs transported with the bark remaining, however there was no significant difference in end cracking between logs with bark on and de-barked logs, although it was noted by Wingate-Hill and MacArthur (1989) that covering logs during transport with a non-pervious tarpaulin did reduce end cutting.

2.6. Sawmill yard handling

Handling damage

Damage can occur during movement, unloading, sorting, stockpiling and preparation for the saw bench. Most damage will be caused by impacts during handling which could exacerbate any previous splitting or shatter damage present. The careful handling of any damaged logs will minimize production losses through the necessity to dock ends or 'repair dog ears' caused by 'spiking' prior to feeding into the mill.

Exacerbation of damage during yard storage

Storage techniques which expose 'free' logs to extremes of temperature – particularly hot dry periods – prior to processing will exacerbate end splitting. In hot weather long yard storage times will affect the deterioration of split logs through extensions of the splits and checks in most species. It was the opinion of many yardsmen that storage under water sprays in the log yard reduces the occurrence and/or exacerbation of end splitting.

3. Other factors affecting sawlog damage

3.1. Stand condition

The main factors in the harvested coupe that can affect the amount and severity of log damage are the stand characteristics – which affect the ease and efficiency of harvesting. These include:

- Relative density of harvestable sawlogs
- Tree size
- Tree lean
- Terrain condition (steepness of slope, stability of ground viz, rocky and steep terrain)
- Visibility (understorey and intermediate layers)
- Ground Debris (morganners/slash material)
- Climatic factors (snow, frost, wind)

On slopes - particularly steeper slopes, working uphill is best as uphill felling creates less damage to falling trees, provides more control on the final placement of the fallen stem and provides easier extraction procedures with the butts pointing downhill.

Tree size can be a major factor in machine productivity; however, it is variation in tree size that can greatly affect damage levels. The felling of large trees in the stand can considerably damage (shatter fracture) other smaller potential sawlogs during felling and this lost volume may not even be seen at the landing as the damage is 'cut-off' 'bucked' as non-merchantable in the forest.

Barnacle (1969) found that when the fall line of large trees was impeded by other trees so that they landed more softly, less fracture and shatter attributable to felling occurred. Trees which fell freely onto even ground had felling shakes which were observed either totally or predominantly in the upper half of the cross section of the trunk relative to the ground.

3.2. Operator skill

The skill of the machine operator has a large determining role in the damage which is done to the sawlogs both during falling and at other mechanical parts of processing. Experienced operators can foresee likely damage problems for individual trees and minimise the damage. Machine dexterity, which comes only with practice and experience, has a significant capacity to minimise damage at all times. Familiarization with falling techniques, scarf and back cutting, and the mitigation of falling and processing stresses on logs are essential as there are opportunities in all parts of the processing stream to minimise damage. A knowledge of different species properties could also change techniques.

3.3. Contamination of log ends

Docking may be required for log ends which have been forced into mud, gravel or seriously oil or grease contaminated water puddles during snigging and the subsequent processing. Mills dock these ends to reduce wear and tear on cutting machinery and to ensure the safety of their workers.

3.4. Night falling

Some harvesting operations double shift felling machinery and this necessitates use of the machine either in darkness or poor light conditions. Although most types of machinery are amenable to the fitting of suitable light sources, the risk of damage becomes greater for valuable sawlog harvesting. Visibility around the selected tree is less and approaches, shapes of trees, presence of debris and presence of unstable

ground (holes, rocks) are less definable. Outside the perimeter of light (for both falling and snagging machines) the presence of morganers, cut stumps, and other structures which may contribute a danger to operators or to levels of shatter in the cut logs, are less visible.

3.5. Harvesting near buffers and boundaries

In most forest operations, boundaries are fixed and harvesting plans have specific rules and regulations regarding the falling of trees at the edge of the coupe. Directional falling of trees into the coupe (away from boundaries) becomes essential. Fixed head machines with essential control of the tree during falling can minimise incursions (accidental falling of stems and crowns into buffers and reserve areas) into 'illegal' areas. With trees well within the capability of a larger machine, trees can be cut, lifted and placed within the coupe. However, for larger trees, machines need to get behind the tree to directionally fall the tree into the coupe. This may necessitate crossing the boundary with the tracks of the machine and in some operations this is allowed. Floppy head machines which can use the versatility of the head to cut behind the tree and initiate directional falling over a scarf cut do not need to cross the boundary. Once again tree size and machine capability are the critical factors. The compromise is between a machine which can remain in the harvestable coupe area and depending on tree size - not have proper control of the tree. Operationally if permission is not granted to cross the boundary for manoeuvring then the very real compromises are (a) not harvest the tree at all, (b) to manual fall trees near boundaries as necessary (expensive and higher risk when forcing direction in terms of occupational health and safety) or (c) to risk log damage and to pull and force the tree away from the boundary with the machine head and boom.

The forcing of the direction of fall of trees of any size increases dramatically both the risk and magnitude of damage to valuable sawlogs. Occupational health and safety risk factors are increased in both manual falling and machine falling under these conditions.

3.6. Choice of harvesting system

In species and boles prone to end splitting retaining longer lengths for as long as possible through the processing stages reduces the proportion of the log exposed to drying factors. If end splits remain reasonably inert, this would reduce losses in volume if end splits need to be docked. A longwood harvesting system should reduce these losses if sawlogs were uniform in character and were destined for a similar market. However the necessity to cut to sawlog lengths around damage and size limitations exposes more of the sawlog to stress release and moisture loss, both of which exacerbate splitting damage. Short wood techniques are used mainly for pulplogs where 'damage' and splitting are less important factors.

3.7. Holding and storage time of cut logs

All damage which causes the splitting of the sawlog is affected by the ambient temperature and moisture content. Once logs have been debarked and cut to length the drying process, particularly if accelerated by hot dry conditions and/or air movement during transport, can exacerbate splitting and hence the amount of docking and downgrading of the individual logs.

Reducing the amount of storage time between stump and breakdown (sawn timber) or treatment (poles, veneers) will reduce losses.

It has been suggested that debarking could take place at later stages in the processing chain to assist in minimising the extension of 'splits' from whatever source. In some Spotted Gum (*Corymbia maculata*) operations, for instance, sawmillers leave the bark on until it begins to separate by itself as this reduces checking and splitting by slowing

the drying process, particularly in ‘free’ logs. However, work by Wingate-Hill and MacArthur (1989) found that debarking made little difference to end-splitting during transport.

3.8. Species differences

In native eucalypt stands, there is often more than one tree species which will be harvested. Certainly in most mills, sawlogs will be sourced from more than one species or forest type. The opinions of fallers, processors, yardsmen and sawyers differ as to which are more susceptible to the variety of damage that affects sawlog quality and volume recovered. The survey highlighted some trends which, although informative, only reinforced the notion that knowledge of species differences will be important to any ‘Best Practice’ strategies.

Species such as Cut-tail (*Eucalyptus fastigata*), Silvertop Ash (*E. sieberi*), River Peppermint (*E. elata* and (sometimes) Flooded Gum (*E. grandis*) were regarded as more prone to freeness and splitting and younger regrowth of these species were particularly prone. However, older, slower grown trees (*viz.* tree size) of these species were not always regarded as worse than any other species. Mountain Ash (*E. regnans*) and Spotted Gum (*Corymbia maculata*) were often regarded as intermediate in their proneness to splitting damage. Messmate (*E. obliqua*), Alpine Ash (*E. delegatensis*) and Blackbutt (*E. pilularis*) were most often regarded as ‘safe’ logs which created no specific problems. Blue Gums (*E. globulus*, *E. bicostata*, *E. maidenii*) were variously ‘good’ or ‘bad’ depending on source, age and season. The source and age of the resource was often regarded as a major factor in whether logs split freely or not – ridge tops and dry country were regarded as better (slower grown) than gullies (faster grown-more growth stresses). Trees of most species harvested from ridge tops were attributed with wind stress (tension wood) and often created more problems at the sawbench.

Of the few sawlogs sourced from plantations that were seen or discussed during this project the issues of freeness and its affect on splitting damage was the most serious for harvesting and processing. For downstream conversion and losses in volume, collapse in faster grown plantation sawn timber was a major issue. Opinions were variable on the seriousness of the damage/loss problems. The same issues of source, age and tree size were expressed.

4. Consequences of damage for downstream processing

4.1. Losses in volume and value due to damage

The discussion above details the types of damage occurring during operations of the harvesting system from falling to transport to the mill. The consequences of this damage and loss of merchantable volume are not only felt within the coupe but are extended along the processing stream. The losses in volume are more and more becoming the onus of the contractor as downstream processors are refusing to accept damaged sawlogs at delivery to the mill.

When the potential sawlog arrives at the mill, log grading and presentation is again assessed. Damage to sawlog which has not been adequately addressed in the bush must now be taken into account at the mill. The treatment of damaged sawlogs in the various mill yards differs greatly in the current sawlog operations and varies from a quick docking and discarding of damaged material without penalty to contractors or carters through to rejection of loads with excessive damage necessitating the return of damaged material to the bush (contractor) with its consequent losses (time, non-payment, quota) for everybody in the processing chain.

Acceptance of damaged material may occur, but only be made as a lower value product. It may necessitate the transport of the damaged material to another mill

utilising the lower value products. Particular types of damage may have more serious consequences for selection of sawlogs for high value products. For instance, it is sometimes difficult to see stress fractures in the log (or they may be completely internal) and yet the consequences for veneer quality in such logs are a drastic loss in value of the veneer product and losses in volume.

Damaged sawlog material accepted into the yard may not be regarded as a lower value product, but may require docking and additional processing to make damage points such as spikes, dog ears and slabbing 'safe' on individual logs so that the safety of the sawbench operators is assured. The potential (particularly in only partially automated mills) for flying debris and splinters is far greater when processing damaged material. Capping, slabbing, shatter, fracture and the various forms of grab damage ALL have the potential to create safety hazards at the sawbench.

Determining the extent of the docking is often done with repeated cuts with a chainsaw in the log yard until sound wood is found. Estimates are then made of the volume loss using diameter and length. There are a number of methods for estimating losses where penalties may be involved. However, it is generally expected that damage volume is removed prior to presentation at the mill. If it reaches the mill and any penalties are likely to apply, then it is most often estimated by application to the forest owner for an assessment of losses at the mill door prior to sawing (Plate 28).

Losses occurring during the sawing process (often due to shatter and fracture, and quartering) are most often not assessed although they can sometimes be significant even on logs which had been previously assessed as sound prior to presentation at the sawbench.



Plate 28: Yardsman identified lost volume (about to be docked) due to damage.

4.2. Quantity, quality and issues at the sawmill

Most mills receive a mixture of source material in species composition, log sizes and from different harvesting operations. Generally mills are satisfied with manual chainsaw felled logs and less happy with many machine felled supplies. The level of satisfaction is related to the necessity to dock damaged and dangerous material and the concerns raised that this does not include the material that may have already been docked in the bush. The real cost is not only in lost volume but in the lost time to 'repair' and remove the damaged material. The total loss of potential volume is thought to be high but has not been quantified.

Apart from the very real issues of the security of supply, sawmillers would like security of quality and a knowledge that volume delivered is able to be processed. Damage caused by harvesting and processing in the bush is often brought to the mill in damaged logs. This necessitates an assessment of the damaged volume and adjustments need to be made to processing length and product suitability. In cases of serious damage, volume adjustments are made in the log yard and the contractor has payment for volume delivered adjusted. This is usually facilitated by the mill complaining to the forest agency, with an agency assessor examining the log and damage and adjudicating in the volume loss.

Some sawmillers have noted that logs delivered from operations using floppy heads exhibit more damage in splitting, slabbing and slovens than logs originating from fixed head and directional falling operations.

All sawmillers have noted that logs delivered from operations with experienced fallers exhibit less damage.

Damage types most evident at the mill

Severely damaged trees do not usually make it the mill yard as they are docked, rejected or the log downgraded to pulp or other markets. This constitutes a loss in volume and time for contractors and operators in the bush. Damaged logs that reach the mill require assessment, and perhaps some further grading, or docking.

Slabbing off is a major loss of volume at the mill yard and is caused both during falling and bucking, but by far the largest amount is regarded as coming from cut-off saws. Poor operator technique is thought to be the major contributing factor to this damage and its subsequent volume losses.

Severe end splitting and quartering are common damage types and are mostly related to characteristics of the resource. Experienced and careful harvesting and processing operators can minimize the occurrence in delivered logs. The presence of this type of damage limits the choice of cutting on the carriage, however it is acceptable to some because they regard the quarters as suitable for recovery volume and therefore not rejected. It can, however, downgrade the material and affect value-adding potential.

The handling of logs around the landing and the mill yard is a cause for concern as rough handling can exacerbate splits and existing damage, particularly with smaller and faster grown logs. This popping of the logs along already existing splits can lose 5 to 10% of the volume at the mill. In some species which are very free and exhibit end splitting, then even a minor impact in the mill yard can cause the log to split its entire length.

Cutting to length for maximum recovery of sawn timber product

A number of sawmills have noted that cutting to non-standard lengths can cause considerable losses at the mill. Most log length calculations and tables allow a few centimetres for docking and squaring off of sawn timber at the mill, however oft times logmen in the bush cut at exact specified product lengths. (10.8 m or 12.0 m instead of

the nominal 11.0 m or 12.2 m lengths required to allow cutting to millable lengths of 4.8, 5.4 and 6.0 metres etc.) Currently the priority is for logs 4.8 m and above and that means reduced high value recovery and fewer options for the sawyer. If the mill has the capacity smaller length material can be value added.

Losses in volume occur at the mill when the ends of a log are not squared off in the bush and if this has not been taken into account in determining mill log lengths, then considerable loss in sawn product volume can occur.

Sometimes logs that are cut to length in the bush still have the chainsaw cut in the butt which facilitated the locking of the chain for cable snigging. This creates further volume losses at the mill – although with small notches the loss is minimal

Converting to sawn product

The removal of dangerous protrusions (dog ears, slovens, slabbing spears) can be time consuming but the consequences for sawyers and other workers could be catastrophic.

Some damage, such as shatter and fracture, is not obvious on the truck or in the mill yard. When this material passes over the breakdown saw it can create dangerous wood projectiles which are capable of causing serious injury to operators. The consequent re-sawing of the damaged logs also results in time and volume losses. Such damaged material can even pass through as sawn products and not become obvious until the sawn product is removed from the kiln. At this stage, shatter damage requires docking with subsequent loss in sawn product volume.

Long lengths of free timber are unable to be cut on the breakdown saw, as often the spring and bow released during cutting make it impossible to handle the longer lengths safely. Conversely it has been noted that even in small logs, a small pipe in the centre appears to have less spring than a solid log of the same size.

CONCLUSIONS AND STRATEGIES FOR THE FUTURE

1. Strategies to reduce damage during machine harvesting and processing operations

1.1. Importance of operator training

The point of tree selection (which tree now/which tree first) and the technique for any individual tree is also largely the point where damage and future value is determined. The skill of the operator, his knowledge of his machine's capabilities and his experience with similar forest structures, tree sizes and species are assimilated in making falling decisions. A tree which is severely damaged during falling provides very few options in the processing chain and extremely low value-adding potential. Observing the machine limits not only reduces potential damage but also has implications for occupational health and safety responsibilities.

Much of the 'training' is done in the bush in the quite usual 'learn as you go' principle. Experienced operators are a boon to any harvesting operation as they are most often high productivity and minimal damage operators. Training organisations have provided some expert training and the opportunity to learn from experienced operators. There is great potential in these systems is to increase operator safety through knowledge and experience and also deliver productivity gains through experience and learned techniques.

Understanding the processing and value chain associated with the hardwood sawlog industry is an advantage to all machine operators and consequently to the forest owners in the harvesting system. An appreciation of the determinants of product type and value assists decisions in the cab of each machine - where simple choices can have a dramatic effect on product value.

Skills and experience gained during manual falling operations also provide the knowledge required for decisions with machine falling. Operators showing the most appropriate skills, occupational health and safety management, productivity, and care of machine are often those who came from a manual falling background.

Education and training of all those associated with selecting and processing of the sawlog is seen as a factor in minimizing damage and in minimizing volume losses due to damage. The more people who are qualified log graders (including fallers and snigging operators) then the more likely that felling decisions, and, docking and end-cutting decisions, are made effectively and minimise losses whilst maximising value.

1.2. Machinery choice

Choosing the right machine for the harvesting operation is a critical step in the path to minimizing damage to high value sawlog products. It was not within the scope of this project to recommend any particular machine and felling head / processor combination. However, the following discussion highlights factors which should be considered in choosing any machine/head combination.

Machinery needs to be of a size (capacity) and weight (stability) to handle the size of the trees to be harvested and the forest structure (topography, density, size class distribution) in the harvesting coupe. Operations with the availability of a range of machines (size and configuration) obviously have an advantage.

Machine heads that have follow-plates which can support the weight of the trees and keep the kerf open result in less bending stress (forcing during cutting). This is particularly important in medium to large size trees. Small trees can be easily handled by a large machine head. 'Floppy' felling heads cannot generally provide sufficient control for larger trees and are more suitable for small log systems or clear fell systems where placement of the tree is not so critical.

Disc saws with follow plates can reduce the need to bend the tree away from the kerf, reducing slabbing/capping and their engineering generally allows lower stump cuts which increases volume recovery. Felling heads with chainsaws and lower grab arms which are required to be in contact with the tree, generally cannot cut as low and have closure problems on flared butts resulting in less control and higher stumps.

Machines are often 'assisted' to fall larger trees than design specifications suggest by scarf cutting and directional falling. For valuable saw logs and for medium to large trees, most operators recommend a scarf and back cut for every tree. Chainsaw felling heads of a suitable diameter capacity to control the tree can also perform this safer and damage mitigating technique. The additional rotation now available in the majority of felling heads can assist scarf and back cutting and the versatility of machine and head saves time and manoeuvring.

The use of purpose built machines and purpose built heads for different parts of the operation is obviously an advantage although more expensive. Systems which have the capacity to use fixed head feller bunchers for the majority of falling and which are backed up by more specialised machinery with debarking heads at the landing have the potential to minimise volume losses at each point. Log grading and presentation,

which is assisted by specialist grab/cut-off saw combinations, provide efficient options at the landing.

In most situations a larger capacity machine will be the machine of choice as experienced operators can minimize the damage done to smaller trees - whereas a machine working outside its capacity can do uncontrollable damage.

Manual operations will continue to be a necessary part of the harvesting system and can be performed with minimal damage in all cases. However, occupational health and safety considerations and the capacity for productivity gains suggest that manual components in these harvesting systems will reduce even further with time.

1.3. Reducing volume losses due to damage

Other strategies that are regarded as noteworthy in reducing volume losses from damage, and from sawlog characteristics that exacerbate damage, are mentioned below as they were part of scenario discussions with operators who took part in the study.

For many regrowth stands or patches of regrowth, where many trees exhibit the 'freeness' that results in end-splitting and quartering damage, the time of harvesting could be varied to correspond with more moist and cooler periods to minimize the drying out of cut ends.

For similar reasons wood harvested from these stands should not be stored at the landing for any longer than necessary and when arriving at the mill should be processed as soon as possible or stored under cool moist conditions (water spray).

Some of the more valuable sawlogs are gang plated on the ends or waxed to reduce splitting and moisture loss. If most sawlogs could be treated in this way, provided it was shown to be of value in reducing splitting, and then damage loss due to splitting would be reduced. Some mills and operations already treat most of their valuable sawlogs in this way.

1.4. Developing technology

Further development of machinery and felling head technology is acknowledged as a means of further reducing damage in hardwood sawlog operations. As these machines are continuously adapted for Australian conditions the ability to reduce damage through the essential grabbing and sawing of the tree will improve. Some factors which are continuously under development and have already undergone some testing and proving are:

- Shape and size of lugs that 'hold' the stem during cutting (lugs vs. bands)
- Felling heads that apply holding pressure to the stump not the stem of the tree (slabbing occurs on the stump below the cut)
- Various lugs and grips for debarking rollers
- Butt plates on felling heads which can support the weight of the tree (non binding)
- Positioning and versatility of grab arms.

2. 'Best practice' methodologies

It is obvious that the choice of the right machine for a particular part of the harvesting system and the presence of an experienced and skilled operator is essential for safe and productive mechanical harvesting operations. Each machine and machine operator therefore creates their own 'Best Practice' where machine care, operational safety and volume production can be maximised for a particular coupe (forest structure and stand condition). It will be nigh impossible to eliminate all damage. Best practice ethics then seek to minimize damage and volume loss.

The proposed market of the sawlog/s from the selected tree will also determine the limits of 'acceptable' damage likely to occur during falling and snagging.

A 'best practice' manual could, with more investigation, be produced for particular eucalypt species and machinery types. It would, necessarily, be specific to certain forest types, age classes and product utilization.

The value of the end products and the specific requirements of the sawmill market will determine the relative importance or necessity for some of these 'best practice' techniques. In operations which provide more than one sawlog product, compromises will be struck or separate processing methodologies may be undertaken at the stump or on the landings.

However, there is a wealth of experience which can be assimilated from successful contractors, operators, and forest supervisors which can be applied generally to the falling and processing of hardwood sawlogs.

Consideration of the specific operations involved and the collating of the survey opinions and suggestions from experienced operators has defined some best practice techniques which will assist greatly in minimizing unnecessary damage to valuable sawlogs.

2.1. Recommended 'best practice' strategies'

Falling

The initial value assessment of the tree is carried out by the operator / tree marker. Clear visibility for the machine operator both at the bole and the crown allows proper assessment of the tree and the techniques required. Having the machine close and stable provides a safer working platform and provides the best control over the tree falling operation. Clear spaces to fall into will minimise damage from shatter and fracture and provide more efficient work areas for bunching and snagging. Visibility factors are important as are avoiding impacts with other trees, morganers, rocks and uneven ground, and previously cut stumps to minimise shatter and fracture.

To minimize damage to the butt log during felling the tree should be kept as free as possible during the cutting process with minimal pressure from grab arms and with no uncontrolled stresses being applied to the stem. Forcing the tree to fall in a direction away from the natural lean applies pressure to the stem and often causes binding of the saw. Actions required to keep the kerf open and force the direction of fall create considerable stresses with the stem and contribute most of the forces causing capping and slabbing. For this reason there is good argument for scarf cutting all trees to be felled. Directional falling is facilitated by the scarf cut and less forcing is required during the final cutting phase.

Once the tree is committed to the direction of fall it can be released so that shock forces are not transmitted back to the machinery. Forcing the tree (as often happens with

small trees) through the initial falling from the stump can create enormous forces in the stem which exacerbates shatter and fracture both during falling and on impact with the ground. Avoiding fulcrum points (rocks, stumps, gullies etc) which will cause the stem to bend or flex on contacting the ground will minimise shatter and fracture.

Falling uphill on steeper slopes will minimise impacts and damage and assists to present the butt ends of the logs ready for snigging. Aligning and bunching the headed boles, preferably at a height to suit grab collection, will save time and reduce the risk of damage during grappling.

Snigging

Care should be taken with the use of grabs during bunching and capturing to minimize damage to butt logs especially. An easy access and loading pattern may be facilitated by the feller buncher which leaves butts aligned and at an approachable height. If contamination of log ends (mud, gravel etc) is to be avoided this approach height will assist. Snigging tracks adhering to 'Herringbone' patterns towards the landing will minimize manoeuvring and therefore potential damage during transport to the landing. Clearways need to be established for longer log lengths.

Attention to the details whilst the tree/log is already under the control of the machinery reduces extra effort and increases efficiency of bunching, loading and snigging.

Cross-cutting

Reducing impacts on the log landing during sorting, cutting to length and log presentation will reduce volume losses from serious splits and slabbing, as they may be made worse with rough treatment. Experienced and careful machine operators will be considerate of the value of the products they are sorting and selecting. Some operations provide a bed of slash material (mostly bark) for traction and cleanliness of the site and products. Such a layer of material also cushions impacts during sorting and provides a clean base for supporting one end of a sawlog during cutting. Cut-off actions should be carried out whilst supporting one end of the sawlog and having the other end close to the ground or supporting material. Some operations use low value support logs to provide a working bench for supporting sawlogs off the ground during log-grading and docking and this also allows grabs to close around the log gently without being forced into the grab via the grab points. This reduces spiking and dog-ears during handling.

Manual chainsaw operations can benefit from the same attention to the working area but an awareness of the mobility and possible movement of a fresh sawlog sitting on support logs is needed.

It is believed it is possible to relieve some of the stresses which bring about end-splitting in logs by cutting a groove around the log near the position of the cross cut before making the cross cut itself (Barnacle and Gottstein 1968). Cross-cutting produces a pair of directly matched log ends which differ only in the amount of growth stress released at each face. Concentric saw cuts are usually made 8 to 12 inches behind the face to be cross cut on the upper log. Sometimes two cuts 8 and 12 inches may be made. This type of operation would have considerable negative effect on productivity at the landing if it was attempted for all logs.

Loading

Grabs used in loading of trucks (and in sorting) have the potential to damage the valuable sawlog. Minimising grab pressure and excessive force in pinching with the grab points will minimise this damage and if impacts are reduced through the handling and loading process (particularly onto the truck bed), damage, or the exacerbation of existing damage, will be avoided.

Off- loading at the mill yard

Similar attention to the care of valuable sawlogs in mill yards will prevent or minimise any further losses in volume or value. Large loading grabs often used in mill yards are capable of applying extreme compression to individual logs and the large grab diameters can allow severe impacts with the grab body and other held logs. Releasing the grabs so that logs are placed gently will minimise impacts and damage. Mill yards often provide supporting base logs and sawdust ground cover to facilitate handling and cleanliness.

Training

The skill levels of operators are seen as quite variable. The ‘learn as you go’ approach has been a necessary transition since the introduction of more and varied machinery. But a number of principles appeared regularly in the survey. Operators who had an appreciation of the consequences of volume lost through damage and of the consequent loss in value were generally more careful with each tree. Decisions made in the cab were ‘damage and value’ decisions made before ‘productivity’. But importantly, experienced operators were regarded as more ‘productive’ in achieving volume outputs. Hand in hand with knowledge of the forces and stresses which cause damage came appreciation of the capability of the machinery and the two factors together reduced damage to valuable sawlogs and reduced downtime of expensive machinery with high running costs.

Training has been provided in a number of States and although it appears to be spasmodic there is a general agreement that training is an important means of increasing efficiency and reducing damage to valuable sawlogs. The lead time for the ‘inexperienced’ to become valuable experienced operators is considerably reduced by appropriate training.

2.2. Developing a ‘Best Practice Model’ for a harvesting system

As described combinations of machines and machine heads are numerous. Although machine design and selection has been discussed, it is not in the scope of this project to choose the best machine for each variant of the harvesting systems examined. However, if we assume that the machine chosen is capable of the task, and can be efficient and safe in the terrain and stand conditions, then the survey results clearly indicate that operator skill and technique is the single most important factor in reducing damage.

Therefore a ‘Best Practice Model’ for a generalised harvesting system would contain the following elements:

Training

Provide training (using experienced tutors or formal training) for all machine operators
Encourage operators and associated workers to qualify in log grading.

Falling

Achieve good visibility of the bole
Position machine close and achieve a stable platform
Scarf cut every tree that cannot be held easily
Keep the tree free during the cutting process
Do not apply uncontrolled stress to the tree during cutting or felling
Do not grip the tree tightly until after the cut is completed
Plan the fall into the gaps
Minimise impacts with all other elements in the stand
Release the tree before impact with the ground

Bunching

- Bunch trees and/or logs where snigger has easy access
- Support the weight of the cut ends (heads and butts) to minimise slabbing
- Align sawlog butt ends during heading and bunching
- Minimise impacts of cut logs

Snigging

- Align snigging tracks in herringbone pattern to minimize manoeuvring and prevent log bending
- Adhere to product length allowances if end-cutting to size at stump
- Minimise contamination of cut ends

Cross-cutting

- Support the log during cutting
- Ensure end to be cut is close to ground during cutting
- Provide supports (low value logs) to keep logs above ground - improves grab efficiency
- Provide debris mat to keep logs clean
- Minimize dropping and impacts during cutting, sorting and stacking
- Gangplate or end-coat with wax as necessary

Loading

- Use minimum force to hold and move logs safely
- Minimise use of grab points to prevent spiking
- Minimize impacts in truck bays

Off loading at the mill yard

- Minimize impacts during handling
- Provide clean storage areas (sawdust or other surface)
- Providing supports (low value logs) to keep logs above ground improves grab efficiency

A manual of 'Best Practice' would refine the techniques and requirements for these elements for each harvesting system, taking account of species differences, terrain conditions, machine combinations and products.

MATERIALS AND METHODS

1. Review of machinery development for limiting damage in felled sawlogs

A number of industry organisations researching improvements to the sawlog industries have existed for many years in Europe, Canada and America. Much of the work centres upon softwood species but a number have catered to both softwood and hardwood industries. A review of research carried out in the 1980's and 1990's provided information on the rationale of design of mechanical felling equipment, discussion of the damage problems associated with such equipment, and suggested improvements in creating greater efficiencies in the hardwood industry. This technology was imported to the Australian softwood industry and subsequently to the Australian hardwood sawlog industry.

2. Survey of current practice

In the time frame of this study, a complete and extensive survey of all parts of the industry involved in the mechanical felling of hardwood sawlogs (and their downstream industry processes) was not possible. To gather as much information as possible, surveys were carried out either by telephone link or by field visits to harvesting operations or sawmills (Appendix 1 lists most of those individuals and companies who contributed to the survey results).

Field visits were undertaken to areas and operations large enough to have a range of felling equipment and supply contracts which consisted of a major component of mechanically felled product at the mill door. Operations and sawmills which did not rely on mechanical harvesting were also visited.

Field visits were undertaken to eastern Victoria (Gippsland) in July 2002, southern and northern NSW in August and September 2002 and Tasmania in October 2002. Phone surveys were made in other regions and States.

Phone surveys and field visits have been used opportunistically by project staff as other work and travel permitted.

3. Survey content and analysis

Because of the complexity of the hardwood sawlog industry, which has regions and contractors who deal with a range of different species, both between and within regions, and a range of mechanical equipment, then no one set of survey questions would be appropriate to all. However, to raise and discuss the same issues, a set of topics covering the main issues of felling, felling damage and its mitigation was used to facilitate the survey responses. Appendix 2 provides the list of topics raised with each of the contacts either by phone or by personal contact during field visits.

The advantage of this approach was that it did not inhibit many other concurrent discussions and provided the opportunity for a balanced view of the issues surrounding sawlog quality and supply in the mechanised environment.

A summary of the discussion points is set out below:

1. Current practice in recognised harvesting operations;
2. Improvements implemented in the last year for efficiency or quality improvements;
3. Discussion of effects of improvements;
4. Impact on customers;
5. Customer satisfaction; and
6. Safety issues.

4. Possible generation of a 'best practice' document

Following the survey analysis, links between species, machinery and component operations were investigated with the view to assessing what elements of the wood flow stream would need to be considered for incorporation into a 'Best Practice' document for hardwood mechanical falling and subsequent processing and handling.

Acknowledgements

During the course of this study many native forest hardwood sawlog harvesting operations were visited, and many companies and individuals involved in the hardwood sawlog industry were consulted. Issues of analytical interest to the survey were discussed as well as many other related issues which affect decision making and management strategies in the hardwood sawlog industry.

There were a number of organizations who assisted the process of the study by giving of their time and that of their staff in arranging for field visits and meetings. My thanks go to the following organizations and their staff:

In Victoria

- Department of Natural Resources and Environment
- Hallmark Oaks Pty Ltd
- Austimber Industries Pty Ltd

In New South Wales

- State Forests of NSW
- Davis and Herbert Sawmills Pty Ltd
- Blue Ridge Sawmills Pty Ltd
- Boral Timber Pty Ltd

In Tasmania

- Hollybank Training Centre
- Gunns Pty Ltd
- Forestry Tasmania
- Forest industries Association of Tasmania

It is not possible to list all of those that were consulted (either as part of field visits or the telephone survey) and the list provided in Appendix 1 is by no means a measure of input or importance to the study.

Finally my thanks to the many people who freely gave their time, and to all, a special thanks for their openness and willingness to discuss the issues and the possible solutions in mitigating harvesting and processing damage.

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Glossary

- accumulating head** – mechanical felling head that can hold previously severed trees to accumulate a bunch before placing them on the ground
- back cut (chainsaw)** – final cut for directional falling, opposite the scarf cut
- barrel checking** – longitudinal checks or separation of fibres along the grain of the curved surface of the round log, not extending to the centre
- bend (in log)** – large radius bend in a bole or log
- bending (during felling)** – caused by application of pushing forces to the falling tree in effect accelerating the tree's fall and bending the stem
- binding** – closure of the saw cut caused by the tree leaning back on the saw blade during cutting
- bole** – the trunk or stem of the tree large enough for conversion into sawn timber
- brittle** – a condition that permits breaking or snapping easily across the grain
- brittleheart** – wood characterized by abnormal brittleness caused by compression failures in the fibres. It is usually located in the heart but may occur elsewhere in the stem
- bruising** – small fractures spikes and protrusions evident in the sapwood usually caused during debarking
- bucking** – cutting to length during processing
- bunching** – accumulating trees or logs to facilitate heading or snigging in the stand prior to extraction
- butt log** – the lower (base) log of the selected tree stem
- butt pull** – tearing of the last of the hingewood when the tree is forced from the stump
- butt splitting** – tears or splits in the butt of the severed stem which occurs during felling
- cable skidder** – a skidder usually articulated, rubber tyred, fitted with a winch and wire rope to accumulate trees to form and hold a load during skidding
- capping** – capping is exhibited as an unnatural/unplanned split in solid wood extending along the log. Capping is generally caused by poor falling and cross cutting techniques
- chain saw** – rotating cutting chain either manual or contained in felling head
- chatter marks (logs)** – ridges and lumps in the outer surface of a log (usually sapwood) caused by compression forces during rolling and debarking
- check** – separation of the fibres along the grain forming a fissure, but not extending through the piece or log from face to face
- clear** – free from all visible defects and imperfections
- compression failure (induced)** – a deformation or fracture of the fibres across the grain resulting from excessive compression parallel to the grain either by direct end compression or bending. It appears as a minute fracture running across the grain, the fibres being crinkled by compression or broken transversely, and is often difficult to detect until the timber is machined
- compression failure (natural)** – natural compression failures may develop in standing trees due to internal stresses set up by rain, snow, unequal growth, etc. They are commonly associated with brittleheart and may occur as a result of felling
- compression wood** – inner sections of most eucalypt boles have wood fibres under compression. Also describes other areas of abnormal wood which is more dense, more brittle and prone to greater longitudinal shrinkage than normal wood

cross cutting – cutting of tree stems into pre-determined log sizes by cutting across the grain

cull – a tree, log or piece of timber of merchantable size rendered unmerchantable by defects

cut off saw – a chainsaw incorporated into a grapple head for cutting to lengths

damage – that proportion of the volume of a log which cannot be used to produce desirable products in the wood flow stream

DBH (DBHOB) – diameter of a tree at breast height (1.3m) usually over bark (OB)

debarking – removing the bark from logs

debris – loose bark removed from the logs which accumulates on the landing and is often used as a mat on landings and snig tracks to minimize soil disturbance and can be used as a cushion during log handling. Also other non merchantable wood, branches, bark and leaf material left in the stand

defect – any irregularity in timber that lowers its strength, durability or utility. That proportion of a volume of a log which cannot be used to produce sawn timber due to knots, keno, unfavourable grains, fungal decay or insect attack

degrade – a perceived lowering of the value of a log as a result of natural or imposed defects and damage

directional falling – techniques used in either manual or machine falling to dictate the placement of the fallen tree to reduce damage or facilitate further handling

disk saw – cutting saw with a spinning head with teeth on the outer rim

docking – cutting to length. Cross cutting timber to a specified length or to free it from defects

dog ears – protrusions and ‘spikes’ occurring on the outer surface of the log usually caused by the points of grabs or debarking machinery

downer – a log which has been on the ground for some years (as a result of felling or wind) – see also morganer

downgrade – decision to devalue the log to a less valuable sawlog product

end coating – application of wax or other sealant to prevent/reduce evaporation losses from the cut ends of logs. Retards drying and consequent checking and splitting

end splitting – end splits are checks caused by air drying and are created as stress cracks during rapid surface evaporation of the log. They usually occur after processing and holding in storage at either the landing or the mill yard

extraction – removal of logs from the stand

extraction track – the tracks used by skidding or forwarding machines during extraction

felling – falling the selected tree

fixed head – a felling head which has limited rotation and movement and requires the base machine to be aligned in the direction of cut or fall. Often capable of feller bunching

flitch – a large piece of sawn log intended for further cutting. A flitch is sawn on 2 surfaces at least

floppy head – a felling head or processing head which has considerable rotational movement in more than one direction. The base machine can maintain position and utilize the rotations of the head to carry out felling operations. Often used for processing and debarking

follow plate – a plate of steel which follows the opened kerf and prevents the cut tree from closing onto the cutting edge of an auger, chainsaw or disc saw. Also called a base plate

forcing – the act of accelerating the fall of the tree or forcing the tree to fall in an unnatural direction. Also used to describe the forces applied when bending the tree away from the kerf

forwarder – extraction machine which carries rather than drags its load of logs to the landing (usually fitted with a crane grab for loading)

fracture – fracture occurs as hairline separations across the grain although - usually a natural defect caused by wind movement in the growing tree, however it can also occur when logs have suffered severe impact during falling

free – during felling making sure the tree is not forced

freeness – characteristic of the cut log to release growth stresses by splitting

gallery (termite) – a passage or burrow, bored or excavated by termites in the wood or bark. Also attributable to borers

gang plates – metal plates nailed to the cut ends of logs after processing to minimize end splitting

grabs – pincer type arms or claws to grasp stems or logs during falling or processing

grade – to sort timber into different established classes according to quality, market or use

grain – the general direction of the fibres or wood elements relative to the main axis of the stem, bole, log or timber

grapple skidder – a skidder usually articulated and most often rubber tyred fitted with a hanging grapple used to pick up and secure logs during extraction

grapples – see grabs

growth stresses – tensile stresses developed in the cambial layer which can induce splitting and distortion in logs during processing and sawing

gum (or kino) – a natural exudation produced in trees as a result of fire or mechanical damage

gum vein – a ribbon of gum or kino between growth rings

harvester – the machine dedicated to tree falling

heading – removing the crown and unwanted upper portion of the stem (usually done in the stand)

head saw – the initial saw used to break down the log into suitable pieces (flitches) for further sawing

hinge wood – the last portion of the holding wood used to facilitate directional falling

honeycomb – a group of internal checks

impact – the physical force created by collision of stems or logs with other solid objects (other trees, logs, stumps, rocks, ground or machinery)

joist (or joist log) – an undervalued log used as support on landings and in mill yards to keep more valuable logs above the ground surface to facilitate loading, sorting and cross cutting

kerf (saw) – the space created in the timber being sawn by the cutting ‘blades’ (chainsaw, disc saw, blade saws)

kink – an abrupt offset occurring in the length of a log

kino – sap or gum exuded or internally compartmentalized in many eucalypt species

knot – a section of a branch which is imbedded in the wood of the trunk of a tree or larger branch

landing – the holding and sorting area where logs are received and loaded for transport

loading – the final process of loading onto road transport for delivery to the mill

log-making – cutting to selected market length after determining log grade and/or product

log (peeler) – a length of log prepared for conversion into veneer products

log (pulp) – a length of log for conversion into wood chips or wood fibre

log (saw) – the length cut from the stem of a tree from which sawn timber is to be produced

lugs – raised portions of grabs and rollers to facilitate gripping the logs

mast – the upright frame of the felling head which encaptures the tree when the head and/or grabs are applied to the trunk

marks – small to large indentations and compressions in the outer surface of a log (usually sapwood) caused by processing machines during docking, rolling, grabbing, debarking, sorting and loading (see chatter marks)

morganer – a log which has been on the ground for some years (as a result of felling or wind) – see also downer

pipe – a longitudinal cavity along the centre of a log

pith – central core of a stem consisting mainly of soft tissue

popping – forming excessive end splits (see end splitting)

processor – usually applied to the debarking head which may also cut to length

quartering – the result of large and active shakes in the log. Sometimes the stresses are so great that the whole log separates into a number of sections

reaction wood – abnormal wood formed typically in leaning and crooked boles. Also occurs in large branches. Wood laid down is tending to restore the tree or branch to the original shape or position (see also tension wood)

ring shake – ring shake is a natural weakness in the growth rings and the timber separates along the growth rings

round timber – generally all unprocessed and processed logs for conversion into other products

rupture – defamination or fracture of wood fibres across the grain due to excessive compression parallel to the grain caused by direct end compression or bending

scarf – the undercut applied to the tree to initiate directional falling

secondary log – the second or third log cut from the stem of a taller tree

shake – a partial or complete longitudinal separation between adjoining layers of wood fibre. Often showing as a split in the end of the tree or log. One shake is dominant and a second shake will often appear at right angles to the first shake

shake (felling) – a shake caused by felling operations when fibres are torn or compressed

shatter – shatter is an unplanned break in the wood fibres generally caused by an impact of the falling tree over another tree, rock, stump or gully. Shatter can also be caused by rough handling during extraction and processing – often described as a concentration of long splits or shakes (sometimes also described as fracture)

shearing head – mechanical shears which use a pincer or scissor movement to cut the tree

skidder – an extraction machine which drags (skids) its load to the landing

skidding – extraction technique where logs are dragged to the landing usually with one end of the load suspended behind the machine

slabbing – longitudinal splits caused by the release of the hanging weight of elevated logs during cutting to length

slash – green leaf, branch and crown components of the tree which remain in the stand after heading

slovens – a general descriptor of protrusions from logs after processing

snigging – extracting cut logs from the stand and transporting to the landing for processing

spikes – usually small protrusions from sapwood caused during debarking and handling

sweep – a large radius bend in a log or tree

support log – a log placed on the ground to keep logs above the ground and to facilitate handling and sorting

tail-swing – rotation of the rear section of machines during slewing of the cab or crane base of a machine (usually excavator based)

tension wood – outer sections of boles of eucalypts are under tension longitudinally with a tendency to decrease in length when released (see also reaction wood)

under-cut – belly cut or scarf cut used to facilitate directional falling

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APPENDIX 1: LIST OF ORGANISATIONS AND CONTACTS MADE DURING THE SURVEY.

Organisation/contact	Region
A & R Howard Timber Pty Ltd	Cessnock, NSW
AHF Pty Ltd	Cann River, Vic
Apperdean Forest Products	
Auswest Timbers	Orbost, Vic
Bartlett Haulage	Wauchope, NSW
Beveridge Logging	Orbost, Vic
Big River Timber Co Pty Ltd	Grafton, NSW
Blue Ridge Hardwoods	Eden, NSW, Vic
Blue Tier Logging	Tas
Boral Timber Pty Ltd	Regional reps, NSW,QLD, SA
Britton Timbers	Smithton, Tas
Strategic Research - Forestry	Wynyard, Tas
Burgundy Heights Pty Ltd	Coffs Harbour, NSW
Canberra Pine	Hume, ACT
Davis & Herbert	Narooma NSW
Department of Conservation and Land Management	Regional reps, WA
Dryforce Logging Pty Ltd	Tas
Eastern Syndicated Logging	Gippsland, Vic
Forest Industries Association of Tasmania	Tas
Forest Products Commission	Manjimup, WA
Forestry Tasmania	Tas
Forest Technology Program	Canberra, ACT
Grant Timbers	Woodford, QLD
Greensill Bros	South Grafton, NSW
Gunns Ltd	Regional reps, Tas
Gunns contractor network	Regions, Tas
Hallmark Oaks Pty Ltd	Cann River, Vic
Hans Sumberg Pty Ltd	East Gippsland
Hardwood Harvest Pty Ltd	Wauchope, NSW
Harris-Daishowa (Aust) Pty Ltd	Eden, NSW
Henrys timber Co Pty Ltd	Newmeralla, Vic
Hoffman Haulers and Fallers	Wauchope, NSW
Hollybank Forestry Centre	Launceston, Tas
K.W Murrell Pty Ltd	Karuah, NSW
LT Doland Pty Ltd	Cann River, Vic
McKays Sawmills	Glenorchy, Tas
MDL Logging	Tas
Morgans Logging Pty Ltd	Tas
Notarus Bros Sawmills	Grafton, NSW
Newells Creek Sawmilling Co.	Buladelah, NSW
Northern NSW Forestry Services	Casino, NSW
Pambula Sawmills	Pambula Sth, NSW
Parkside Timbers	Theodore, QLD
Partek forest Pty Ltd	Smithfield, NSW
Pope Logging	Bega, NSW
Private Forests Tasmania	Tas
Robertson Bros Pty Ltd	Gympie, QLD
Rockbridge Milling	Manjimup, WA

Organisation/contact	Region
Ryan Logging	Geeveston, Tas
Spring Bay Logging	Hobart, Tas
State Forests NSW	Regional reps, NSW
Sumberg Pty Ltd	Cann River, Vic
Syndicated Central Gippsland Logging	Gippsland, Vic
Tasmanian Logging Association	Launceston, Tas
Tasmanian Timber Industry Training Board	Northern region Tas
Tunsester Sawmills	Lismore , NSW
Partek Forest Pty Ltd	Smithfield, NSW
Winston's Timbers Pty Ltd	Yandina, QLD

APPENDIX 2: SURVEY “QUESTIONS AND ISSUES” RAISED WITH CONTACTS.

Machinery: Operational infrastructure (Nos X Types of machines)
 No of operations sharing machinery
 Operator skill levels
 Operator training

Damage Types and Causes
 Chainsaws versus machine heads

Damage avoidance and ‘best practice’
 Species differences
 Tree size differences
 Forest structure differences
 Age classes

Size class distribution

Product base

Sawmill and Market requirements

Transport distance

Seasonality

Losses Log grading
 Bucking
 Docking
 Rejected logs
 Administrative adjustments

Product selection

Processing capability

OHS&E Felling head operators
 Associated machinery operators
 Log yard workers
 Sawbench operators

Efficiency & costs of “best practice”

NB. Many other concurrent discussions have provided a balanced view of the issues surrounding sawlog quality and supply in the mechanized environment.