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# PHYSICAL DAMAGE TO LOGS

Tony Evanson



Sala Street
Private Bag 3020
Rotorua
New Zealand
Phone
07 348 7168
Fax
07 346 2886

Leading Edge Forestry Solutions

For information, please contact: Liro - Forestry Solutions, Private Bag 3020, Rotorua, New Zealand

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# EXECUTIVE SUMMARY

Damage to log products can occur as a result of the felling process, or through subsequent processing and handling. This report represents a first step in reducing the effects of physical damage to logs by investigating the nature and extent of log damage, estimating the effect of damage on sawn outturn (using Forest Research's Treemaps™ program), and recommending remedial action.

Butt damage on stems is responsible for reducing marketable individual butt log volumes (and hence value) and also affects the mix of logs that can be cut from that stem. Damage to log ends, and surfaces affects the volume and value of sawn products that can be cut from a log.

Damage assessed included: Butt damage - draw wood, scarf and buttsplit; Log damage - large and small end splits, grapple gouges, branch draw, branch tear, feed roller marking, and bark loss (with the latter increasing susceptibility to sapstain).

## Results

The incidence of such damage (at least one occurrence per log) varied from 1% for branch draw, to 47% for draw wood, in manual operations; and from 3% for branch draw, to 12% for grapple gouge, in mechanised operations.

In terms of estimated lost value at conversion (value loss*incidence) to the industry, the most important damage effects, measured at the skid, on either pruned or unpruned logs, were those of:

- Grapple/Fork (manual and mechanised source) 1.6% pruned, 1.7% unpruned
- Buttsplit (mechanised source) 1.0% pruned
- Scarf (manual source) 1.0%

Grapple or fork damage subsequently increased, logs assessed in mill yards showed a 20% incidence of some form of loader damage. This translated into an estimated value loss of 2.7%.

Another form of damage, one that affects both the incidence and severity of sapstain, as well as the efficacy of antisapstain treatment, is bark loss. Mechanised delimbing and processing operations were found to remove 83% of bark, compared to 23% for manual operations.

To put the effects of log damage into perspective: approximately 11.5 million $m^3$ of quality logs (sawlog, peeler and export) were produced in 1997 (NZ FOA, 1997). A 2.7% value loss (due to loader damage) equates to an estimated processing loss of \$3 million (at an average log value of \$100/$m^3$).

The value loss results of this study are conservative in the sense that analysis of sawn lumber outturn involved only one type of damage, at one location, per log. Obviously, in the "real world", multiple types of damage, at a number of locations could exist on a single log. These damage points would also present potential problems for successful anti-sapstain treatment.

## Recommendations

1. This report could be said to comprise an indicative assessment of physical damage to logs. Industry-based quality control, and intensive modelling combined with sawmill studies are needed to confirm these initial results.

2. A certain amount of log damage is inevitable. However, emphasis should be placed firstly on attempting to reduce grapple/fork - and buttsplit damage. This could be achieved by:

   (a) Encouraging care in loading or sorting operations, by:

   - introducing damage-based quality control measures
   - educating operators in more benign techniques
   - investigating the effects of different types of grapples

   (b) Ensuring that appropriate equipment and techniques are used in mechanised felling operations, by:

   - introducing damage-based quality control measures
   - educating operators in more benign techniques.

# INTRODUCTION

A tentative definition of physical damage to a log is: "any harmful change to the raw product resulting from the activity of man, machine or environment". Although, for instance, it is assumed that damage is unintentional, an exception may be made for cutting of a felling scarf, which necessitates the later cutting of a sloven so as to give the butt log large-end a smooth face.

Defining "deleterious change" is the real issue, as this is a user-defined concept. The users are various, as are their requirements. In general, the higher the value the raw product has, then the more focused is the buyer (or user) on aspects of log quality.

"Damage" commonly includes:

*Damage to the Butt, Small end, or Barrel of the log:*

- Butt Draw-wood
- Scarf face
- Butt slabbing or splitting
- Small end splitting and slabbing
- Grapple/fork spearing or gouging
- Branch pull
- Branch tear
- Feed roller marking.

*Other damage:*

- Bark loss, leading to subsequent sapstain fungal attack and a difference in log appearance (leading to subsequent buyer resistance)
- Sapstaining via surface damage pre- or post- anti-sapstain treatment
- Outer fibre damage, leading subsequently to lower chip quality.

*To standing stems, and subsequently to log products:*

- Thinning-related damage
- Growth loss through compaction or root damage
- Early introduction of sapstain eg. at pruning

Defining, and attempting to measure the downstream effects of log damage in NZ, is the first step towards finding solutions. Alternatively, the effects of harvesting damage (JAS scaling excepted) may be found to be minimal and perhaps justify a relaxing of standards enabling stem waste volumes to be minimised, so making more efficient use of the resource.

## A log damage project

Accordingly, a project was designed to:

1. Define the types and severity of damage to the butts and surfaces of logs. This would include a review of previous research.
2. Sample the incidence of such damage, including bark loss, in NZ logging activities.
3. Calculate the effect of sampled log damage on mill recovery.

Some factors to be considered are:

1. That following harvesting, or in some cases the first phase of transport, most saw and peeler logs will be passed through debarking apparatus. The debarker, depending on type, will both crush and lacerate the surface of the log to some degree as bark is removed.
2. Every loading and unloading operation before reaching the buyer provides an opportunity for further physical damage.
3. The method of log breakdown influences the economic effect of any damage. For instance, taper sawing will cut boards closer to the log's surface. Larger, eg. 200 * 40 boards are less likely to show damage effects than 100 * 40 boards, because a wider cut-face is, of necessity, further from the log's surface.

## Previous Research

A number of papers and reports were examined for information relating to methodology, and the effects of damage to logs.

The earliest references are from Scandinavia and concern the effect of spiked feed rollers on logs. Wiklund and Gronlund (1973a, 1973b) reported volume losses of 2 - 5% after trialling three different processors. The spikes providing the deepest penetration (11mm) were 25mm long. A later, theoretical calculation produced losses of 1 - 4%. The authors note that actual losses may be lower as sawmillers do not always cut to theoretical limits. Some researchers (Makela and Pennanen, 1980) reported lost value due to spiked feed rollers ie. 0.1 - 0.3%. Today, many Scandinavian harvesters use rubber-tyred rollers, often with chains for extra grip. Consequently, there are no recent reports concerning the effect of feed rollers on either volume or value recovery.

In the US and Canada, manual felling was succeeded by the use of felling shears. Shears are now well known for their effects on butt timber quality. Researchers initially developed methodology to measure butt damage from both disk, saw and shear heads, and estimate the effect on volume and value recovery. Gumier and McMorland (1981) developed the "Bicycle wheel" method of analysing butt splitting, which involved the laying of a grid over "biscuits" cut from the butt. The authors went on to evaluate both shear and non shear heads in British Columbia, reporting volume losses from non-shear heads ranging from 0.12 to 1.86% with a 2*6 inch saw pattern. Magnitude of loss was related to stand conditions, such as tree size and lean, and to operator technique (McMorland and Gumier, 1984). A further survey of felling heads confirmed these results, the least damaging system showed losses of 0.25% volume loss per tree. Lower damage levels were correlated with minimal stress being applied to the tree being cut (McMorland, 1985).

In New Zealand, Murphy (1984) analysed manual felling breakage and stump heights in Tairua Forest. He recorded butt damage if it exceeded 20cm in length ie. longer than the sloven to be cut. Draw-wood was the most common form of butt damage. Butt damage was evident on 20% of the trees measured. Effective stump height for undamaged trees was 16.7cm; for damaged trees, 40cm.

The use of wing-cuts to reduce slabbing of butts was also investigated (Murphy and Buse, 1984; Vaughan and Biddle, 1987). Murphy and Buse found that wing cuts reduced the incidence and extent of slabbing greater than 20cm, higher back cuts reduced the extent but not the frequency of butt draw, and a follow-through was judged to be a dangerous practice. Value loss for damaged trees was estimated at 2.5%. Vaughan and Biddle examined faller technique in more detail, and tested hinge strength under different conditions. They determined that draw-wood frequency was related to hinge-thickness, 5 cm hinges caused less draw wood, but unlike Murphy and Buse, they found that low back-cuts resulted in less draw-wood. Heavy leaning trees were also more likely to produce draw wood. Of 115 trees felled without wing-cuts, 37% slabbed (mean length 55cm). Incidence for side-cut trees was only 3%.

In Sweden, in 1986, the use of grapple harvesters was identified as a source of value loss for the industry. Development of alternative feed roller designs have the potential to reduce damage (Leithe-Eriksen, 1986). Modifications include: changes in spike shape, roll diameter, and pinch pressure. Concern over feed roller damage continued, Helgesson and Hagglund (1987) developed a model providing a computer simulation of value loss (Swedish grading rules) through mechanical damage to sawlogs. In a summary document for IUFRO, and the first paper to consider other sources of damage, Helgesson (1990) looked at 6 effects of mechanised harvesting on timber quality, quantified the effects on recovered value, and suggested remedies (table 1). The cost of damage in Sweden, estimated from three common machines, was from 0.3 to 1.8% of the value of all timber produced.

*Table 1. Value loss in mechanised harvesting*

| Cause | Value loss | Remedy |
|---|---|---|
| Feed roller spikes | 2 - 12% | rubber rollers |
| Cross- cutting splits | 1% | stem alignment and saw maintenance |
| Feed roller slippage | <1% | |
| Bark damage | 2% | |
| Butt splitting | <2% | training |
| Grapple and knife damage | | training |

Concern over damage continued to focus on the butt log and associated butt damage. A study of a Bell Model T Feller-buncher (equipped with a bar saw felling head) by Green and McNeel (1987), showed that for larger trees, machine felling could still produce butt damage. The authors maintained that damage became more pronounced when the "design limit" of the machine was reached. In manual felling, volume and value loss was examined in some Auckland forests (Wybourne, 1990). In terms of frequency of occurrence, the causes of damage were: Draw wood, then splits, and slabs. Results varied by forest, for instance, Maramarua showed more evidence of splitting than Tairua. To what extent the results were biased by individual faller performance is not known.

A review of literature covering wood damage was carried out by Stokes and McNeel (1991). Again, the focus was on butt damage. They revisited shear felling processes, and extended the enquiry to disk and bar-saw heads. Larger, and leaning trees were identified as problems for mechanical felling. The authors examined damage measurement, noting "biscuit" methods, and mill studies. Mill studies were deemed the most reliable, because of the recognition of degrade once timber is dried. Mill studies have the disadvantage of being Mill, operator, and cutting pattern-specific as well as being time and labour intensive, and expensive. The accepted method of quantifying the effects of damage is $/ unit volume of mill or log product.

With the expanding development of a log export market, some researchers investigated the effects of small-end defects on JAS scale diameter, and subsequent volume and value loss (Twaddle and Ellis, 1991). The authors found that out of a sample of 17880 logs, 2 - 9% of logs within a grade had a diameter reducing defect, and 76% of these defects were man-made (rather than say, bark encased knots). This work was further developed when K grade logs were selected for a similar study (Hall and Twaddle, 1992). Between 2 and 6% of logs had scale reducing defects, and 92% were man-made, caused by splitting during cross-cutting. The JAS scaling system involves only the small-end of the log for any log length. No examination was made of other defects.

The issue of sapstain attack was revisited when the British Forestry Commission (TDB, 1992) carried out a large-scale trial looking at sapstain in mechanically processed timber. It was found that mechanically processed logs were more susceptible than manually processed wood, and that a strong correlation existed between bark removal and sapstain fungal attack.

Moshenko, (1993) has probably carried out the most comprehensive recent research in the area of physical damage to logs. The author examined both harvesting and transportation phases, considered mill recovery, and sought to identify causes of damage at source. Sampled loads of logs were initially examined at logyards, damage measured (length, breadth and depth) and described on a log diagram sheet. Defect cause was based on local experience. Estimates of impact were made at the same time. Only the most serious damage per log was noted. Twenty-eight percent of logs had some form of damage, 49% of this was due to machine damage. Total lumber volume loss was 0.5%. Harvesting damage was responsible for 52% and logyard damage 27% of volume loss.

An alternative method for assessing volume loss was used by Yeoman (1994). AVIS software was used to compare value recovery from a mechanised and a manual felling operation. Losses due to breakage, slovens, slabbing and stump height were lower for mechanised than for the motor-manual felling. Volume recovery was 2.5% higher for mechanised felling. Draw wood was not assessed.

The most recent review of the effects of harvesting and transport operations on timber quality was carried out by Warkotsch (1994). A thorough listing of causes and nature of damage is made. The author contends that no damage is caused by motor-manual felling itself, only through poor felling practice. With machines, he feels that damage can be largely avoided by operator selection and training, and by regular maintenance and use of the appropriate machine.

In a study specifically aimed at mechanised processors, Evanson (1995) found that some processors, notably logs produced by stroke delimbers were prone to splitting at the small end. Two Denis DM 3000 stroke delimbers produced end splits (>1cm diameter reduction) in at least 25% of their total output. However, a more modern machine produced only 6%. This report was the first to note other defects such as branch tear and branch draw.

Effective stump height is an indicator of levels of butt damage during felling. A comprehensive manual felling breakage study of 1000 clearfell-size trees (Fraser et al, 1997) found that mean stump height (to the back-cut ) was 10.13cm but effective stump height (including sloven) was 23.41cm. Variation was best explained by tree lean and butt diameter. Average draw wood length was found to be 9.3cm (41% of trees), scarf height 10.9cm, and split/slab length 71cm (4% of trees). As these trees were felled by a competent faller, under non-production conditions, it could be assumed that there may be a minimum felling defect frequency threshold for manual felling. Certainly this will be the case with draw wood, which tends to be hinge-width and back-cut height dependent.

### In summary

Most previous research in New Zealand has focused on butt damage as a result of motor-manual felling. It may be that with the advent of mechanised felling and processing, that a more holistic view of log damage is required. Some aspects, such as bark loss, and feed roller spikes have been partly addressed in Scandinavia, resulting in the adoption of rubber feed rollers for grapple harvesters. In Sweden, there is continuing concern over small-end splitting. In North America, attempts have been made to define damage levels from harvesting, and from transport.

## ACKNOWLEDGMENTS

The assistance, and co-operation of the contractors and crews that enabled the sampling to take place, is gratefully acknowledged. Also contributing was the assistance of staff from several sawmills or processing plants, and staff from Forestry companies. Other assistance with data collection, and analysis was provided by Regan Smith, and Alex van Zyl of Forest Research.

## METHODOLOGY

### Sample size

To obtain a physical description of damage, ten logging crews and four wood processing plants were visited. Approximately 50 logs and 30 stem butts were assessed at each logging site, and 50 logs at each processing plant.

The ten logging crews comprised five motor-manual operations and five mechanised (ie. mechanised felling and processing).

### Definitions

Eight representative types of damage were selected for measurement (to the nearest centimetre):

*Stems:*

- T1: Draw wood
- T2: Scarf
- T3: Split or slab of the stem butt

*Logs:*

- T4: Split or slab of the large, and small ends
- T5: Grapple or fork gouge
- T6: Branch draw
- T7: Branch tear
- T8: Feed roller marking
- T9: Bark loss

### *Stem butt measurements*

Thirty stems per operation were measured for butt damage due to felling (Figure 1).

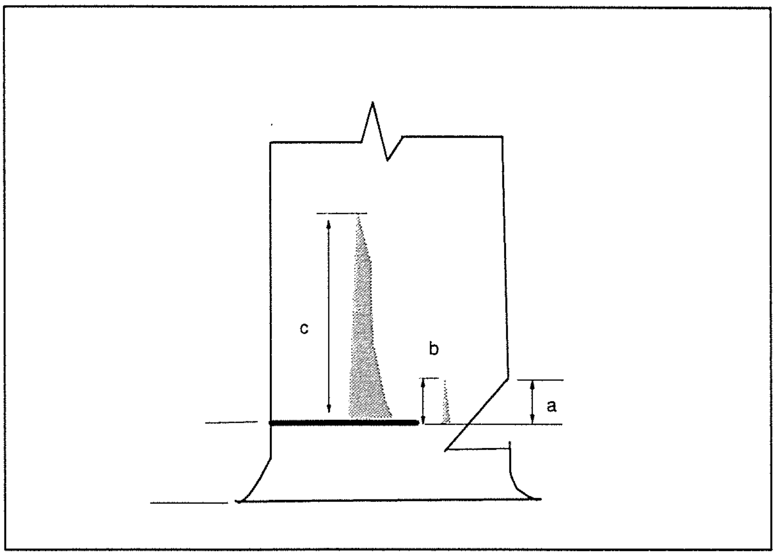


*Figure 1. Stem butt measurements – scarf length (a), draw wood (b), and split or slab length (c)*

T1: Draw wood

- The longest spike was measured, from the stump to the top of any draw wood pulled from the butt log. Measured on stumps.

- The location of the draw wood, relative to the centre of the butt, was measured.

  DBH: DBH of the trees was measured.
  BD: Butt diameter (under bark, average of 2 perpendicular measurements).

T2: Scarf

- Scarf length was measured from the backcut to the top of the scarf.

T3: Split or slab of the stem butt

- Split (visible on log surface) or slab length was measured from the back cut. Width and thickness was also measured.

### *Log measurements*

- Fifty logs per operation were assessed and checked for any occurrence of different types of processing or extraction damage. Significant damage closest to the small end was noted and measured. On all logs, length, large and small end diameters were measured. Length from the small end to the damage site was also noted.

T4: Split or slab of the large and small ends

- The effect on log ends of adjacent logs parting before having been completely severed by saw.

- Measurement was made of width, and depth of splits in the large and small ends of logs found in stacks. *This measurement occurred after routine quality control had been carried out by skid workers, and so reflected the quality of logs delivered to a mill.*

T5: Grapple or Fork gouge

- Marking or scoring of the log surface by grapple or fork tines, as the log is picked out from a stack, or a bunch of logs is lifted.
- Width, length and depth of the affected portion was measured, together with the distance from the small-end of the log.

T6: Branch draw

- Some portion of the branch fibre is pulled, rather than cut from the log.

- Measured were: Branch diameter (2 * perpendicular measurements), depth of draw - from branch face, whorl diameter at the stub, diameters (OB) 20 cm above and below the whorl, position ie. length from SED.

T7: Branch tear

- Measurements were as for branch draw, but included length of tear, width and depth, and diameter at a point 20cm towards the SED from the branch stub.

T8: Feed roller marking

- Feed roller marking occurs mainly as a result of wheel spin, or repeated travel over an affected area.

- Measured were: depth in cm (if greater than 1 cm), length and width of affected area.

T9: Bark loss

- For each log, the cumulative length of log lacking bark (but sometimes retaining cambium) along a single line was measured. The sample point was the uppermost accessible portion.

# SURVEY RESULTS

Tables 2 and 3 comprise a summary of results (all other table references are found in the appendix).

*Table 2. Stem measurements - incidence and mean values*

| Damage Type | Manual Crews 150 stems | | | | Mechanised Crews 150 stems | | | |
|---|---|---|---|---|---|---|---|---|
| | % | Depth cm | Width cm | Length cm | % | Depth cm | Width cm | Length cm |
| Draw wood | 47 | 10 | 2 | 3 | 0 | | | |
| Scarf | 100 | | | 6 | 16 | | | 7 |
| Buttsplit or slab | 6 | 7 | 18 | 44 | 10 | 6 | 21 | 51 |

*Table 3. Log measurements - incidence and mean values*

| Damage Type | Manual crews 349 logs | | | | Mechanised crews 100 logs | | | |
|---|---|---|---|---|---|---|---|---|
| | % | Depth cm | Width cm | Length cm | % | Depth cm | Width cm | Length cm |
| Large end split | 3 | 4 | 14 | 24 | 8 | 2 | 13 | 24 |
| Small-end split | 3 | 4 | 26 | 29 | 5 | 4 | 16 | 21 |
| | 249 logs | | | | 200 logs | | | |
| Grapple gouge | 2 | 2 | 9 | 22 | 12 | 2 | 8 | 8 |
| Branch draw | 1 | 8 | 7 | | 3 | 4 | 5 | |
| Branch tear | 0 | | | | 4 | 2 | 7 | 10 |
| Feed roller | 0 | | | | 5 | 2 | 6 | 13 |
| Bark loss | 23 | | | | 83 | | | |
| | 194 logs | | | | | | | |
| Loader damage | 20 | 2 | 8 | 7 | | | | |

## Stem damage

### *Draw wood*

Forty-seven percent of the manually felled stems measured had draw wood. Average depth of draw was 10cm, and ranged from 2 to 50cm (Table 13). Trees less than 30cm DBH had less draw wood than other DBH classes (Table 14). About 17% of the 150 trees had secondary draw-wood present, and 7% had tertiary draw-wood (ie. three distinctly separate indentations or pull sites).

### *Scarf*

(a) Manually felled trees

As expected, all manually felled trees were scarfed. Average scarf length was 6cm (Table 15). Predictably, scarf length also increased with DBH class (Table 16).

(b) Mechanically-felled trees

Only 16% of mechanically felled trees were scarfed (double-cut). Average scarf length was 7 cm (Table 2), ranging from 3 to 23 cm (Table 17). This average value is similar to the 6 cm average scarf length obtained from manually felled trees. The single cut made to small diameter trees was sometimes not-square, which would necessitate a squaring-off cut or sloven. Generally speaking, only larger trees, 45 cm DBH and over, were double-cut by the felling machines used; scarf length also increased with tree size (Table 18). A comparison is made between tree sizes scarfed manually and by mechanical means (Figure 2).

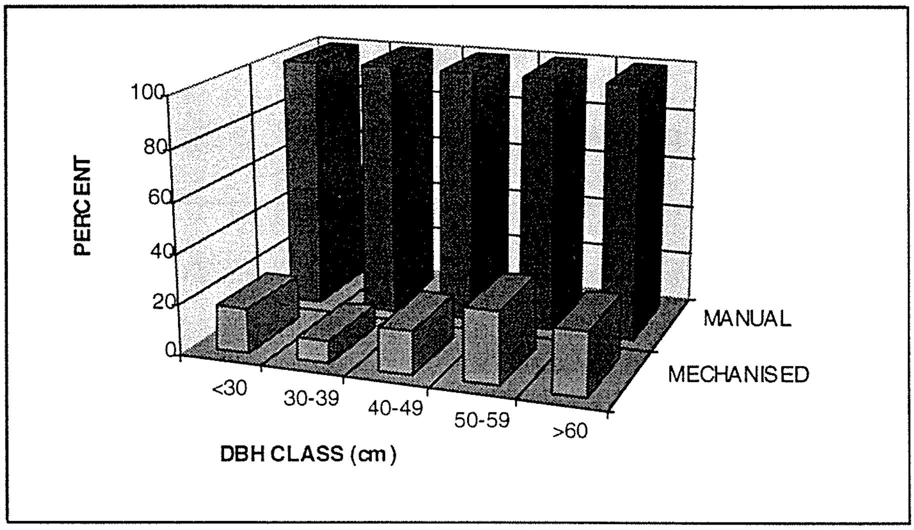


*Figure 2. Comparison of manually and mechanically-felled trees - tree sizes scarfed*

*Split or slab of the stem butt*

(a) Manually felled trees

Only 6% of manually felled trees showed signs of splitting or slabbing (Table 2). This damage appeared evenly distributed across the DBH range (Table 20).

(b) Mechanically felled trees

About 10% of mechanically felled trees showed signs of splitting or slabbing. Damage tended to increase with tree size (Table 22). A comparison between damage caused by manual and mechanical felling methods is shown in Figure 3.

## Log damage

A sample of 349 manually processed logs was measured on stacks, usually following the crew's QC phase. Table 23 shows how those logs were distributed in terms of LED, SED and length.

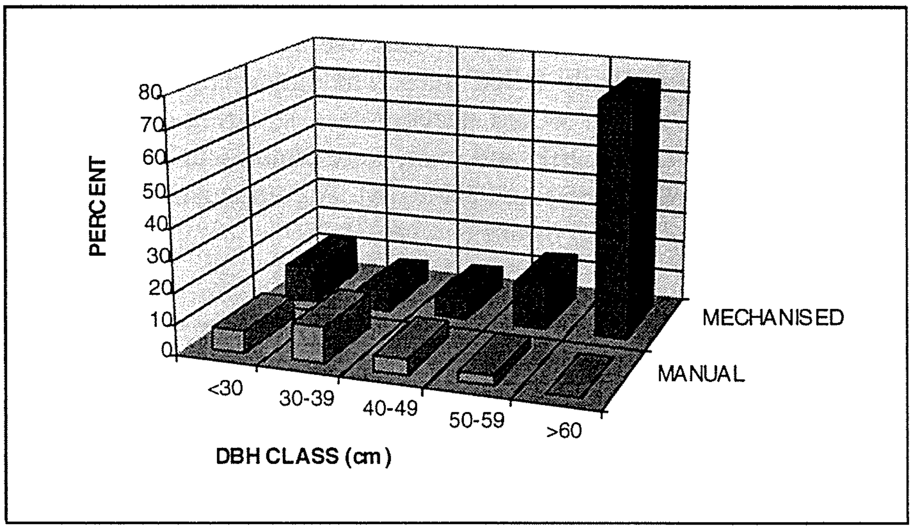


*Figure 3. Comparison between manually and mechanically felled trees - split/slab dimension*

A sample of 100 mechanically processed logs was measured, and Table 26 shows how those logs were distributed in terms of LED, SED and length.

***Large end splitting***

(a) Manual processing

Of the 349 measured logs, 3% were found to have splits to the large end (Table 3). These were evenly distributed among the sampled logs (Table 25).

(b) Mechanically processed logs

Of the 100 measured logs, 8% were found to have splits to the large end. These were distributed among medium-sized sampled logs (Table 28). A comparison between damage caused by manual and mechanical processing methods is shown in Figure 4.

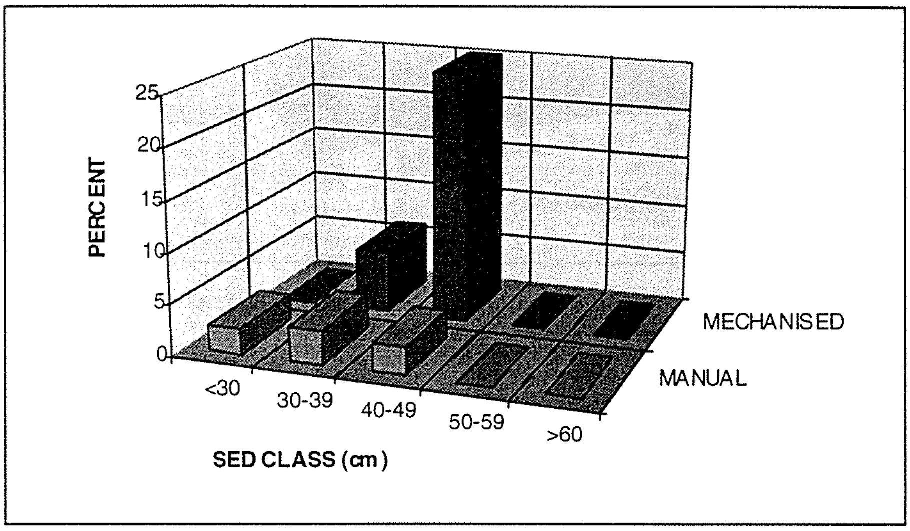


*Figure 4. Comparison between manually and mechanically felled trees – large-end split*

### *Small end splitting*

(a) Manually processed logs

Of the 349 measured logs, 3% were found to have splits to the small end (Table 3). Table 30 would seem to indicate that there was a relatively high occurrence of splits in large logs from manual processing. This is possibly an artefact of the small sample size (one out of nine logs). If this observation is discounted, there is an apparent trend to increasing incidence with mechanised processing.

(b) Mechanically processed logs

Of the 100 measured logs, 5% were found to have splits to the small end. These were distributed evenly among the sampled logs (Table 32). A comparison between damage caused by manual and mechanical processing methods is shown in Figure 5.

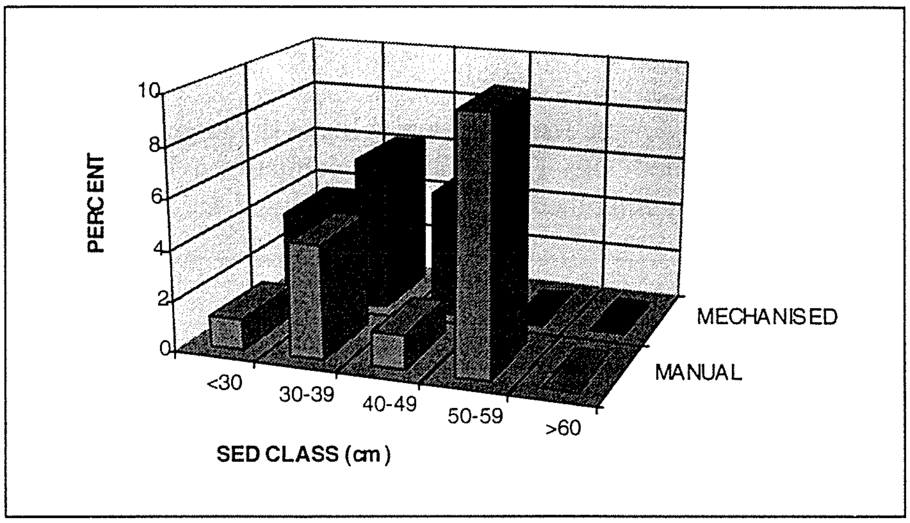


*Figure 5. Comparison between manually and mechanically processed trees – small-end split*

### *Grapple gouge (skidder or loader)*

(a) Manual processing crews

Of the 249 measured logs (Table 33), 2% were found to have gouges that may have been caused by either skidders or loaders. Table 35 shows the distribution of affected logs by SED.

(b) Mechanised processing crews

Of the 200 measured logs (Table 36), 12% were found to have gouges that may have been caused by skidders or loaders. Table 38 shows the distribution of affected logs by SED. Incidence of damage seemed to increase with SED class (Figure 6). A comparison between logs from manual and mechanised crews reflects the increased numbers of grapple-equipped machines in the mechanised operations, and possibly increased handling in the sorting phase (Figure 10).

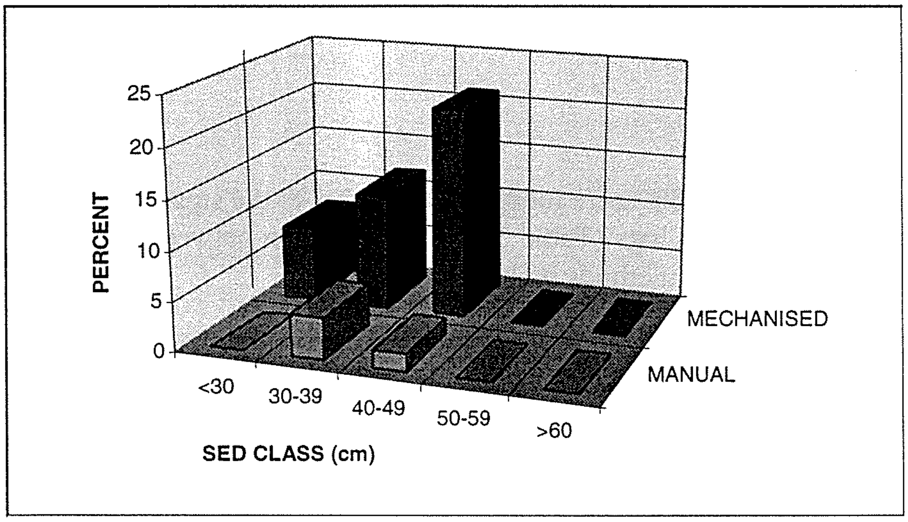


*Figure 6. Comparison between logs from manual and mechanised crews - grapple gouge*

***Branch draw***

(a) Manual delimbing

Of the 249 measured logs, 1% were found to have an incidence of branch draw. Too few were observed to draw any conclusions from their distribution (Table 40). Branch draw in these logs was probably due to either extraction or felling.

(b) Mechanised delimbing

Of the 200 measured logs, 3% were found to have branch draw. The draw depths are distributed by SED class in Table 42. Figure 7 shows a comparison between branch draw in manual and mechanised operations.

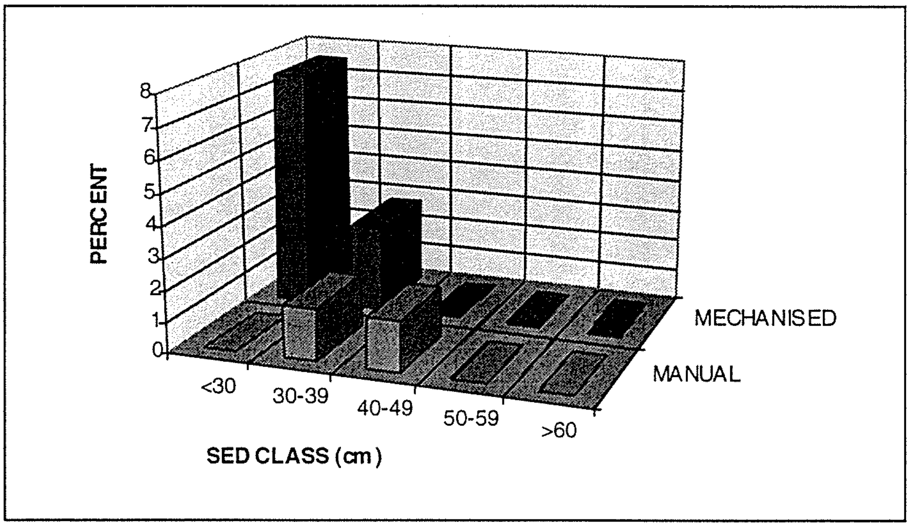


*Figure 7. Comparison between manually and mechanically felled trees - branch draw*

***Branch tear***

Of the 200 measured logs, 4% were found to have branch tear. The tear depths are distributed by SED class in Table 44.

*Feed roller marking*

Of the 150 measured logs (Table 45), 5% were found to have feed roller marks of at least 2cm depth. The marking depths are distributed by SED class in Table 47.

***Bark loss***

(a) Manual felling and delimbing

Of the 249 logs assessed, the average bark loss was 23%. Average bark loss was evenly distributed across SED classes (Table 49).

(b) Mechanised felling and delimbing

Of the 200 logs assessed, the average bark loss was 83%. Average bark loss was fairly evenly distributed across SED classes (Table 51). Of the four mechanised operations sampled, one without feed-roller delimbing, had a significantly lower ($p<0.05$) average bark loss compared to the operation with both feed-roller delimbing and processing (50 logs per sample). Two operations without drive-roller processing had significantly lower bark loss than the operation with both feed-roller delimbing and processing. Figure 8 shows a comparison of bark loss between mechanised and manual operations.

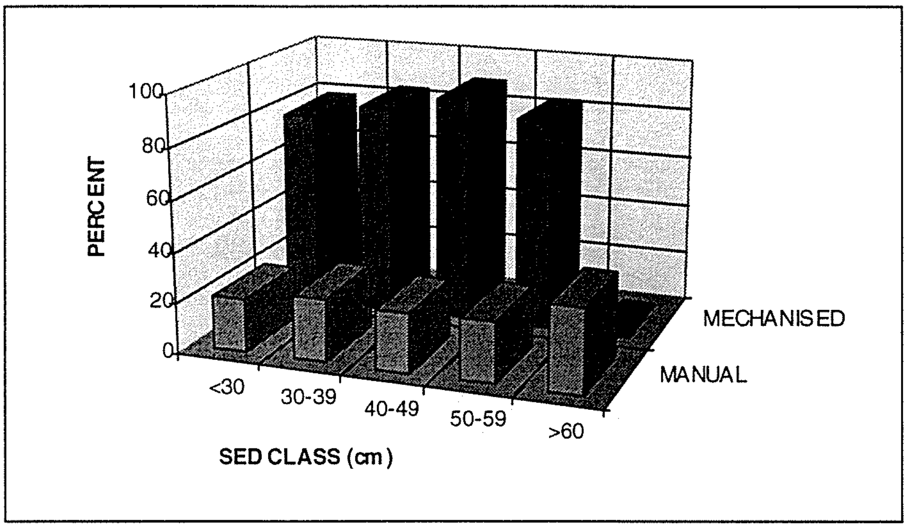


*Figure 8. Comparison of bark loss between mechanised and manual operations*

### *Loader damage*

Of the 194 logs assessed at sawmill yards (Table 52), the incidence of loader damage was 20%. Incidence across SED classes showed a higher percentage of damaged logs in the 30-39cm SED class (Table 54).

### *Comparison between different damage types*

The relative difference in incidence of different damage types between mechanically and manually delimbed and processed logs is shown in Figure 9.

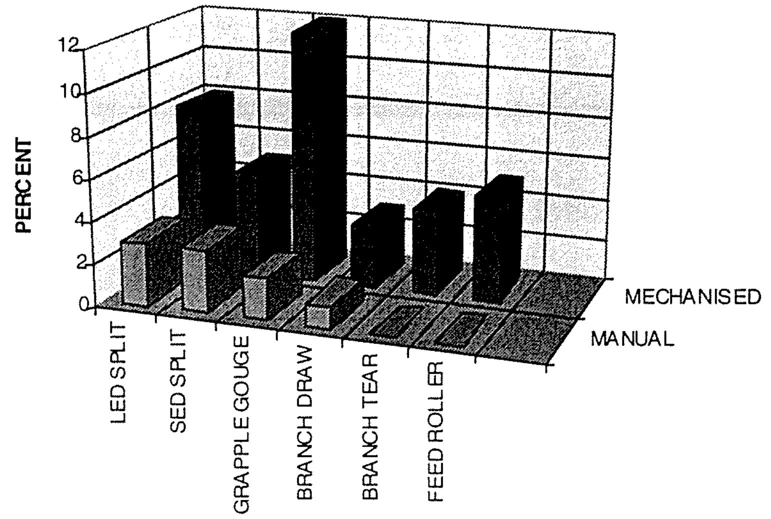


*Figure 9. Comparison of different damage types (except bark loss)*

***Machines used in mechanised operations***

Mechanised crews in the sample used a greater proportion of excavators, and loaders generally, relative to the total number of pieces of equipment used, than manual crews. Besides felling and processing equipment, they also used grapple skidders; no manual crews used this kind of skidder. However, the increased use of grapple-type machinery (and associated handling) also increases the risks of grapple-related surface damage. A comparison of machinery used by manual and mechanised crews is shown in Figure 10.

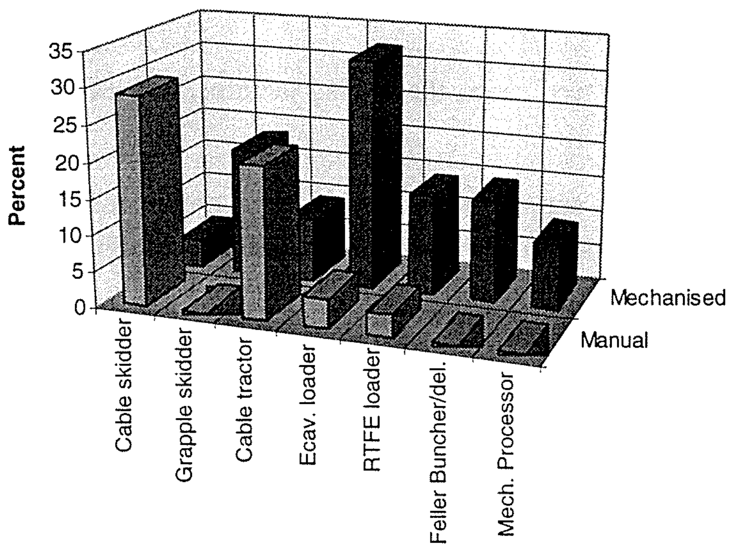


*Figure 10. Distribution of equipment used - by type*

# THE EFFECT OF MACHINE DAMAGE ON SAWN LUMBER OUTTURN

## Use of the Treemaps™ model

In order to ascertain the effect of machine damage on sawn outturn, a simulation model, developed by ***Forest Research*** (Treemaps™) was used with six 5.3m "seed" or sample logs:

- medium (SED 34cm)
- small (SED 26cm)
- pruned
- unpruned

These were cut to a cant-type saw-pattern. Damage was then superimposed on the pattern, and the effect on total log lumber value noted.

Total lumber values (docked) for the three logs are shown in Table 4.

*Table 4. Log values used in Treemaps™*

| Log (5.3m) | SED (cm) | Pruned Value | Unpruned Value |
|---|---|---|---|
| Large | 41.3 | $216.88 | $130.46 |
| Medium | 33.6 | $109.69 | $94.44 |
| Small | 25.6 | $47.39 | $41.19 |

A detailed description of the "seed" logs, the cutting patterns, and the damage imposed is supplied in Appendices 2, 3 and 4.

This analysis was intended to supply an indicative result only. This is because the value of any modelled sawn lumber outturn depends on a dynamic set of inter-related settings, including: log size and characteristics, saw pattern, board sizes, kerfs, minimum lengths, and docking rules.

All affected boards were docked in 0.3m intervals to remove damage. Chip values of damaged boards are not included in the analysis. With pruned logs, the minimum board length cut by the model was 2.4m; and for unpruned logs, 1.8m (likewise, docking to remove damage used these minimum lengths). Total log or lumber value was taken as the cumulative value of all boards, "normally" docked to a 0.3 multiple. If any damage could be removed by "normal" docking, then it was not included in the assessment of loss to the sawn lumber value.

Damage to logs was divided into two generic types:

a) Type 1. Log-end damage, including: draw, scarf, buttsplit and end-split (or SED split).
b) Type 2. Surface damage, including: fork or grapple, branch draw, branch tear, and feed roller damage.

Each log example (large, medium and small, pruned and unpruned) was analysed with only one type of damage present, and one of several degrees of severity:

- at one of four different radial positions - for log end damage (Type 1 damage)
- on two sides - at three equidistant length-wise positions for log surface damage (Type 2 damage).

  eg. For draw-wood damage of two different depths, the number of "virtual" damaged logs would be:

  3 seed logs * pruned and unpruned examples (2) * 4 quadrants * 2 depths = 48 logs

For log-end damage (Type 1), a total of 96 virtual logs; and for log surface damage (Type 2), a total of 126 logs were analysed.

The damage levels (depth, width, and length) imposed were chosen to reflect the earlier findings.

# RESULTS

## Pruned logs - Type 1 damage

In pruned logs, no damage exceeded 6% of lumber value. Maximum value loss for Type 1 damage is shown in table 5.

*Table 5. Maximum value loss for Type 1 damage in pruned log.*

| | Maximum Value Loss ($) | | |
|---|---|---|---|
| **Damage type** | **Small log** | **Medium log** | **Large log** |
| Draw | 0 | 0 | 0.37 |
| Scarf | 0.76 | 0.91 | 1.11 |
| Buttsplit | 5.93 | 3.25 | 2.83 |
| SEDsplit | 2.95 | 3.83 | 0.98 |

For Buttsplit and SEDsplit, average losses per log showed an increasing trend with smaller log sizes (Figure 11).

Buttsplit was the worst form of damage, followed by Draw and SED split. Draw and Scarf damage caused less than half the loss of value compared to Buttsplit.

## Unpruned logs - Type 1 damage

In unpruned logs, no damage exceeded 3% of lumber value. Maximum value loss for Type 1 damage is shown in Table 6.

Average lumber value losses show an increasing trend with smaller log sizes, but still at values less than 2%. The trend is stronger for Buttsplit and SEDsplit.

*Table 6. Maximum value loss for Type 1 damage in unpruned logs*

| | Maximum Value Loss ($) | | |
|---|---|---|---|
| **Damage type** | **Small log** | **Medium log** | **Large log** |
| Draw | 0 | 0 | 0.7 |
| Scarf | 0 | 0.52 | 0.61 |
| Buttsplit | 2.89 | 1.52 | 1.49 |
| SEDsplit | 2.89 | 2.27 | 0.84 |

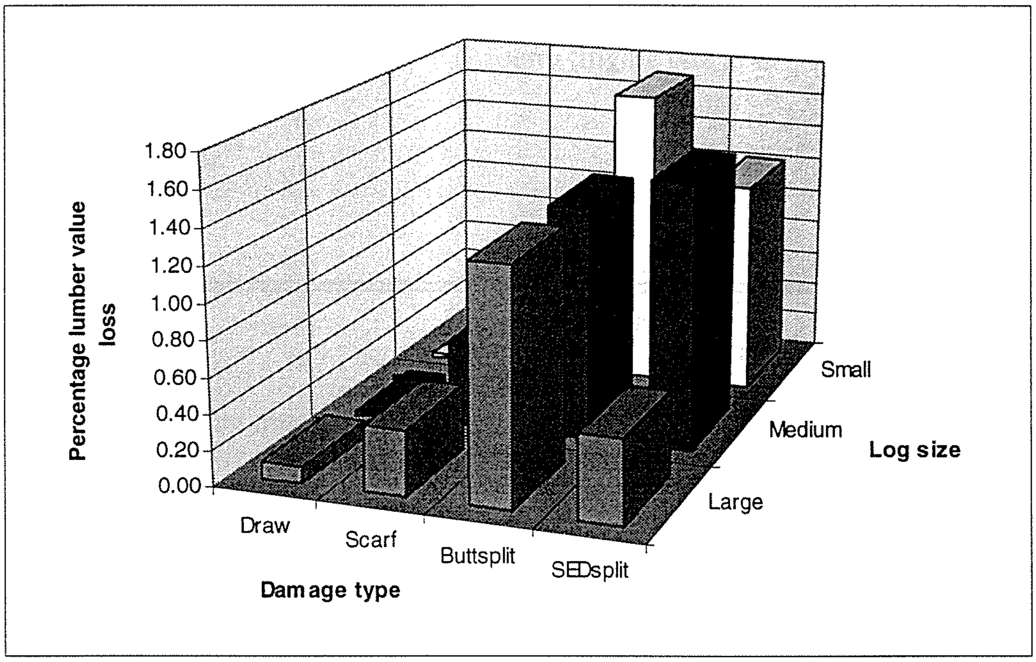


*Figure 11. Pruned logs - average value loss per log*

SEDsplit was the largest form of damage, followed by Buttsplit. Draw and Scarf caused very little value loss (Figure 12).

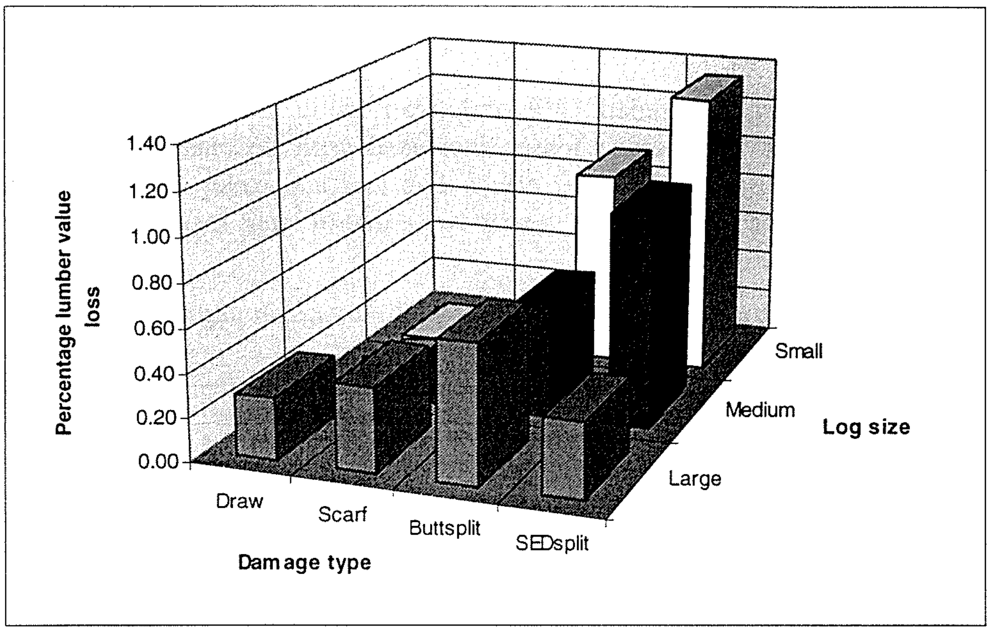


*Figure 12. Unpruned logs - average value loss per log*

## Pruned logs - Type 2 damage

In pruned logs, no damage exceeded 8% of the lumber value. Maximum value loss for type 2 damage is shown in Table 7. Average losses per log tended to increase with decreasing log size (Figure 13).

*Table 7. Maximum value loss for Type 2 damage in pruned logs.*

| | Maximum Value Loss ($) | | |
|---|---|---|---|
| **Damage type** | **Small log** | **Medium log** | **Large log** |
| Grapple/fork | 7.52 | 2.94 | 2.94 |
| Roller | 4.25 | 1.76 | 2.94 |

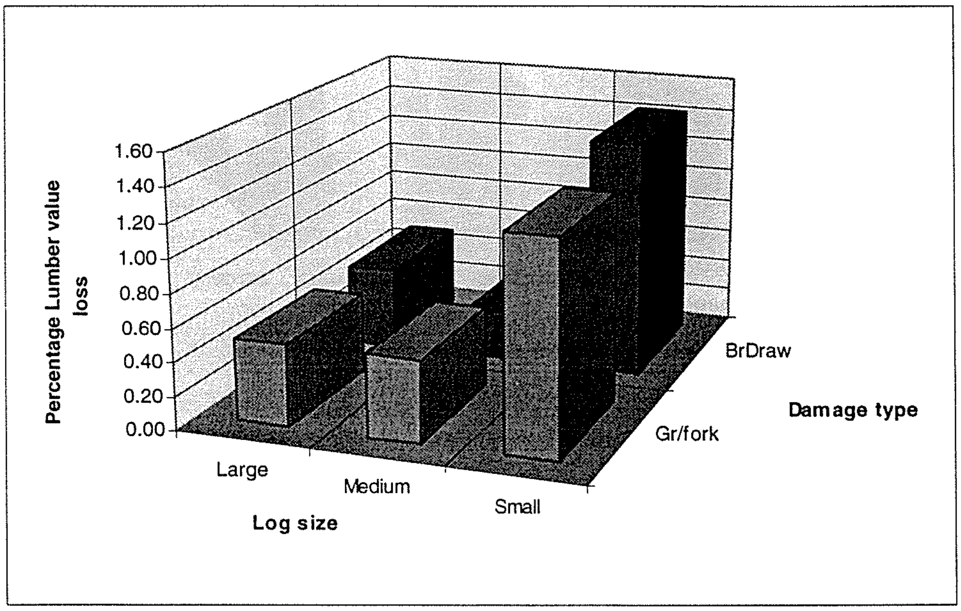


*Figure 13. Pruned logs – effect of log size on average value of Type 2 damage*

## Unpruned logs - Type 2 damage

In unpruned logs, no damage exceeded 14% of lumber value. Maximum value loss for type 2 damage is shown in Table 8. Average losses increased with decreasing log size (Figure 14). Grapple/Fork and Branch Draw had greater effect than tear and roller damage. In small logs, all forms of damage had nearly equal effect (ie. nearly twice that of large logs, in percentage terms).

*Table 8. Maximum value loss for Type 2 damage in unpruned logs*

| | Maximum Value Loss ($) | | |
|---|---|---|---|
| **Damage type** | **Small log** | **Medium log** | **Large log** |
| Grapple/Fork | 4.46 | 2.93 | 13.46 |
| Branch Draw | 10.59 | 3.97 | 4.89 |
| Branch Tear | 9.34 | 7.60 | 4.89 |
| Roller | 9.52 | 3.77 | 4.89 |

Note: The effect of nodal swelling was not modelled. In the survey of log damage, it was found that in only two out of a total of seven instances (in mechanised processing or delimbing) did draw depth exceed the boundary of the adjacent inter-nodal diameter. The thirty percent that did, penetrated to 1, and 2cm depth. However, the minimum modelled depth for branch draw was 3cm. This indicates that for branch draw, the Treemaps™ result may be a worst-case scenario, and that branch draw of <3cm below the inter-nodal boundary may have less effect on outturn.

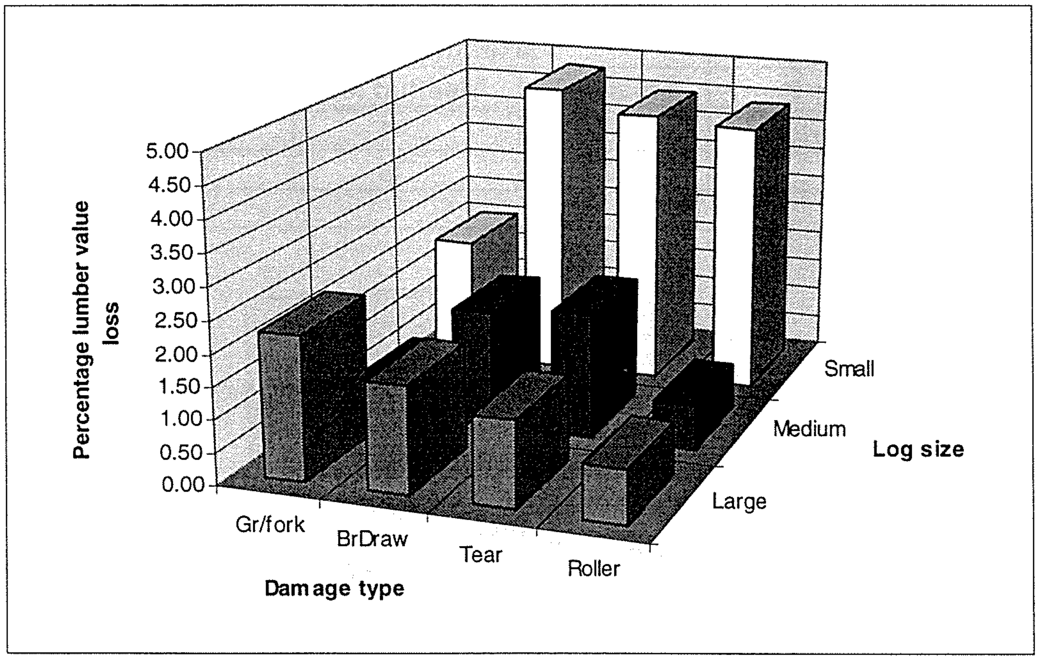


*Figure 14. Unpruned logs - effect of log size on average value of Type 1 damage*

It should be reiterated that the damage recorded in the survey, and subsequently tested in a Treemaps™ analysis, represents only one occurrence of each type of damage/log. Actual damage will obviously involve multiple occurrences of one and/or many types.

To illustrate the overall financial effect of log damage to the industry, the results of the survey, and of the Treemaps™ analysis were combined (Table 9). The percentage incidence of each type of damage was multiplied by the percentage loss in lumber value (maximum value). This provided a measure (index) of damage significance, and might identify which types of damage were most deserving of remedial attention.

*Table 9. A damage-significance analysis*

| Operation type | Damage type | Pruned | Unpruned | All |
|---|---|---|---|---|
| Manual and mechanised | Stump draw | | | 0.5 |
| | Scarf | | | 1.0 |
| Manual processing | Buttsplit | 0.4 | 0.2 | |
| | Small end split | 0.1 | 0.1 | |
| | Grapple/fork | 0.2 | 0.3 | |
| | Branch draw | 0 | 0.1 | |
| Mechanical processing | Buttsplit | 0.1 | 0.3 | |
| | Small end split | 0.2 | 0.1 | |
| | Grapple/fork | 1.0 | 1.7 | |
| | Branch draw | 0 | 0.4 | |
| | Branch tear | 0 | 0.4 | |
| | Feed roller | 0.2 | 0.5 | |

For example, the percentage incidence of stump draw was 47%, and the worst case value loss was 1% $(0.47*0.1*100 = 0.47\%)$.

Pruned log lumber values were then corrected by the pruned to unpruned lumber value ratio (1.667) so that a single list could be ranked.

## The most significant types of damage

When the damage effects were ranked, four damage types out of the 19 combinations accounted for nearly 50% of the summed values (Table 10).

*Table 10. Most significant types of damage*

| Damage type | Log type | Source | Index |
|---|---|---|---|
| Grapple/Fork | Pruned (*Unpruned*) | mechanised | 1.6% (*1.68%*) |
| Buttsplit | Pruned | mechanised | 1.0% |
| Scarf | | manual | 1.0% |

The yard survey showed a damage effect for Loader-related surface damage (Type 2) (which may have included an element of grapple-skidder damage) of 2.7% and 2.8% for pruned, and unpruned logs respectively. This effect exceeded damage from any other source. This result might confirm the theory that increased handling increases the incidence of damage.

Added to this is the finding that for both pruned and unpruned logs, total board value loss with grapple/fork damage was 77% higher for damage located in the top third (closer to the small end) of log length, than the lower third. Damage in this area tended to result in the loss of a complete board as in some cases, the two "halves" would not meet minimum length requirements.

## What was the cause of the most value-significant damage?

Analysis suggested that reductions should be sought firstly in:

- Loader (or grapple)-sourced surface damage (particularly to the upper third section of log surface)
- Buttsplit damage in mechanised felling operations

## What could be done?

1. Encourage care in loading or sorting operations, by:

- introducing damage-based quality control measures
- educating operators in more benign techniques
- investigate the effects of different types of grapples

2. Ensure that appropriate equipment and techniques are used in mechanised felling operations, by:

- introducing damage-based quality control measures
- educating operators in more benign techniques eg. double cuts, well sharpened chain (or disk teeth), not lifting or pushing until more of the tree is cut

## Less significant forms of damage

Damage of less than 1.00% could be construed as less important or deserving of attention. For instance, Butt draw caused only 0.47% loss in lumber value. This finding should not be taken as either a licence to cause this kind of damage or to ignore it. Minor forms of damage should still be minimised wherever possible.

Butt draw is an interesting type of damage because it is a common reason for cutting a waste section (ie. longer than the basic sloven) from the valuable butt section of a log. Cutting a section from the butt of a stem also affects the log assortments that can be cut from that stem, and may reduce its total log value.

## Bark loss

A higher level of bark loss, which has been found to increase the susceptibility of wood to sapstain attack (TDB, 1992) was found in logs from mechanised processing operations. There were indications that feed-roller delimbing and processing removed more bark than just delimbing alone. There are also indications that increased surface roughness (such as can be caused by feed roller teeth or debarkers) can reduce the effectiveness of anti-sapstain treatments, which rely on complete coverage of all exposed wood.

## Mechanised vs Manual operations

The summed indices for mechanised-sourced damage was 6.65 compared to 3.21 for manual operations (pruned and unpruned logs). This is largely due to the effect of increased numbers of grapple handling equipment (grapple skidders, excavator-loaders) present in the mechanised operations sampled. Also, the handling frequency with respect to individual logs will have been higher in these operations.

## Further research

- If it is determined that surface damage caused by grapple and fork loaders is as serious a problem as this report suggests, an investigation of alternative operating techniques should be undertaken in order to reduce the scale of damage caused.

- The sample size (50 logs/operation) probably limits the reliability of damage-type frequency data collected. A long-term damage-specific quality control programme, implemented by a large company, would quickly amass sufficient data to indicate the scale of damage occurrence.

- The extent of the Treemaps™-based analysis was limited to a single cutting pattern, and associated board dimensions and kerf settings, as well as simple docking rules. Additional research is needed to test the effects on lumber outturn value given either different sawing/sorting criteria and/or multiple occurrences of damage of different types. Other forms of damage that might be investigated include shatter, and inadvertent chainsaw cuts.

- The effect of mechanical damage, as indicated by modelling, needs confirmation through intensive sawmill studies.

- The value loss associated with butt draw was found to be relatively low. A more thorough economic analysis of the advantages of not removing draw-affected timber should be undertaken.

- If the "true" cost (or range of costs) of physical damage can be identified, then the scale of resources that might be allocated to reduce damage can be determined.

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# APPENDIX 1 - Survey Results

## Sample description: stems

*Table 11. Description of 150 manually felled trees*

| | LED | DBH |
|---|---|---|
| AVERAGE | 44 | 44 |
| SD | 12.8 | 13.4 |
| MAX | 73 | 71 |
| MIN | 19 | 19 |

*Table 12. Description of 150 mechanically felled trees*

| | LED | DBH |
|---|---|---|
| AVERAGE | 44 | 40 |
| SD | 9.5 | 9.2 |
| MAX | 76 | 67 |
| MIN | 20 | 20 |

***Draw wood***

*Table 13. Main draw wood dimensions and location (n=70)*

| | DEPTH | WIDTH | LENGTH | POS |
|---|---|---|---|---|
| AVERAGE | 10 | 2 | 3 | 12 |
| SD | 7.9 | 1.1 | 3 | 5.3 |
| MAX | 50 | 6 | 19 | 27 |
| MIN | 2 | 1 | 1 | 0 |

*Table 14. Distribution of draw wood by DBH class*

| DBH CODE | n | OTHERS | DEPTH | WIDTH | LENGTH | POS | % |
|---|---|---|---|---|---|---|---|
| <30 | 7 | 19 | 9 | 2 | 2 | 8 | 27 |
| 30-39 | 14 | 17 | 9 | 2 | 2 | 9 | 45 |
| 40-49 | 22 | 16 | 10 | 2 | 2 | 12 | 58 |
| 50-59 | 15 | 16 | 11 | 2 | 3 | 14 | 48 |
| >60 | 12 | 12 | 10 | 2 | 4 | 14 | 50 |

*Scarf*

Manually felled trees

*Table 15. Scarf length (n=150)*

| | LENGTH |
|---|---|
| AVERAGE | 6 |
| SD | 3.2 |
| MAX | 0 |
| MIN | 15 |

*Table 16. Distribution of scarf lengths by DBH class*

| DBH CODE | n | OTHERS | LENGTH | % |
|---|---|---|---|---|
| <30 | 26 | 26 | 4 | 100 |
| 30-39 | 31 | 31 | 5 | 100 |
| 40-49 | 38 | 38 | 6 | 100 |
| 50-59 | 31 | 31 | 7 | 100 |
| >60 | 24 | 24 | 8 | 100 |

Mechanically-felled trees

*Table 17. Scarf length: mechanically felled trees (n=24)*

| | LENGTH |
|---|---|
| AVERAGE | 7 |
| SD | 4.5 |
| MAX | 23 |
| MIN | 3 |

*Table 18. Distribution of scarf lengths by DBH class - mechanically felled trees*

| DBH CODE | n | OTHERS | LENGTH | % |
|---|---|---|---|---|
| <30 | 3 | 14 | 6 | 18 |
| 30-39 | 4 | 41 | 7 | 9 |
| 40-49 | 12 | 58 | 6 | 17 |
| 50-59 | 4 | 10 | 11 | 29 |
| >60 | 1 | 3 | 10 | 25 |

***Split or slab of the stem butt***

Manually felled trees

*Table 19. Split/slab dimensions - manually felled trees (n=9)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 7 | 18 | 44 |
| SD | 6.1 | 10 | 25.7 |
| MAX | 21 | 35 | 15 |
| MIN | 1 | 5 | 100 |

*Table 20. Distribution of Split/slab lengths by DBH class - manually felled trees*

| DBH CLASS | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 2 | 26 | 5 | 12 | 17 | 7 |
| 30-39 | 4 | 31 | 8 | 18 | 52 | 11 |
| 40-49 | 2 | 38 | 10 | 24 | 50 | 5 |
| 50-59 | 1 | 31 | 6 | 15 | 50 | 3 |
| >60 | 0 | 24 | 0 | 0 | 0 | 0 |

Mechanically felled trees

*Table 21. Split/slab dimensions - mechanically felled trees (n=15)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 6 | 21 | 51 |
| SD | 5.5 | 10 | 55 |
| MAX | 20 | 36 | 230 |
| MIN | 1 | 5 | 12 |

*Table 22. Distribution of Split/slab lengths by DBH class - mechanically felled trees*

| DBH CODE | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 2 | 15 | 4 | 19 | 40 | 12 |
| 30-39 | 3 | 42 | 6 | 28 | 53 | 7 |
| 40-49 | 5 | 65 | 3 | 18 | 69 | 7 |
| 50-59 | 2 | 12 | 9 | 11 | 40 | 14 |
| >60 | 3 | 1 | 11 | 28 | 35 | 75 |

## Sample description: Logs

Manually processed logs

*Table 23. Distribution of manually processed logs*

| SED CLASS | n | LED | SED | LENGTH |
|---|---|---|---|---|
| <30 | 83 | 32 | 27 | 5.7 |
| 30-39 | 179 | 39 | 34 | 5.2 |
| 40-49 | 75 | 49 | 44 | 5.3 |
| 50-59 | 10 | 56 | 52 | 5.6 |
| >60 | 2 | 61 | 60 | 4.6 |

### *Split or slab of the large, and small ends*

Manually processed logs

*Table 24. Large end split - manual processing (n=10)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 4 | 14 | 24 |
| SD | 3.3 | 10.6 | 18.7 |
| MAX | 10 | 30 | 70 |
| MIN | 2 | 1 | 5 |

*Table 25. Large end split - manual processing, distribution by SED class*

| SED CLASS | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 2 | 81 | 6 | 17 | 18 | 2 |
| 30-39 | 6 | 173 | 3 | 11 | 25 | 3 |
| 40-49 | 2 | 73 | 5 | 21 | 25 | 3 |
| 50-59 | 0 | 10 | 0 | 0 | 0 | 0 |
| >60 | 0 | 2 | 0 | 0 | 0 | 0 |

Mechanically processed logs

Table 26. Distribution of mechanically processed logs

| SED CLASS | n | LED | SED | LENGTH |
|---|---|---|---|---|
| <30 | 28 | 33 | 27 | 5.5 |
| 30-39 | 49 | 41 | 35 | 5.6 |
| 40-49 | 20 | 50 | 44 | 5.1 |
| 50-59 | 3 | 59 | 53 | 4.5 |
| >60 | 0 | 0 | 0 | 0 |

*Table 27. Large end split - mechanised processing (n=8)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 2 | 13 | 24 |
| SD | 0.5 | 5.2 | 16 |
| MAX | 3 | 20 | 60 |
| MIN | 2 | 5 | 10 |

*Table 28. Large end split - mechanised processing, distribution by SED class*

| SED CLASS | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 0 | 28 | | | | 0 |
| 30-39 | 3 | 46 | 2 | 9 | 19 | 6 |
| 40-49 | 5 | 15 | 3 | 16 | 27 | 25 |
| 50-59 | 0 | 3 | | | | 0 |
| >60 | 0 | 0 | | | | 0 |

***Small end splitting***

Manually processed logs

*Table 29. Small end split - manual processing (n=11)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 4 | 26 | 29 |
| SD | 2 | 12.6 | 6 |
| MAX | 7 | 25 | 88 |
| MIN | 2 | 6 | 6 |

*Table 30. Small end split - manual processing, distribution by SED class*

| SED CLASS | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 1 | 81 | 2 | 10 | 15 | 1 |
| 30-39 | 8 | 171 | 4 | 16 | 25 | 4 |
| 40-49 | 1 | 74 | 5 | 16 | 88 | 1 |
| 50-59 | 1 | 9 | 4 | 25 | 12 | 10 |
| >60 | 0 | 2 | 0 | 0 | 0 | 0 |

Mechanically processed logs

*Table 31. Small end split - mechanised processing (n=5)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 4 | 16 | 21 |
| SD | 3.3 | 9 | 12 |
| MAX | 7 | 29 | 40 |
| MIN | 2 | 5 | 10 |

*Table 32. Small end split - mechanised processing, distribution by SED class*

| SED CODE | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 1 | 27 | 2 | 12 | 15 | 4 |
| 30-39 | 3 | 46 | 4 | 17 | 22 | 6 |
| 40-49 | 1 | 19 | 5 | 20 | 25 | 5 |
| 50-59 | 0 | 3 | 0 | 0 | 0 | 0 |
| >60 | 0 | 0 | 0 | 0 | 0 | 0 |

***Grapple gouge (skidder or loader)***

Manual processing crews

*Table 33. Distribution of logs - manual crews*

| SED CLASS | n | LED | SED | LENGTH |
|---|---|---|---|---|
| <30 | 58 | 32 | 27 | 5.7 |
| 30-39 | 118 | 39 | 34 | 5.2 |
| 40-49 | 62 | 49 | 44 | 5.3 |
| 50-59 | 9 | 57 | 52 | 5.7 |
| >60 | 2 | 61 | 60 | 4.6 |

*Table 34. Grapple gouge - manual crews (n=6)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 2 | 9 | 22 |
| SD | 0.5 | 4.5 | 12.3 |
| MAX | 3 | 15 | 30 |
| MIN | 2 | 5 | 3 |

*Table 35. Grapple gouge - manual crews, distribution by SED class*

| SED CODE | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 0 | 58 | | | | |
| 30-39 | 5 | 113 | 2 | 9 | 21 | 4 |
| 40-49 | 1 | 61 | 3 | 10 | 30 | 2 |
| 50-59 | 0 | 9 | | | | |
| >60 | 0 | 2 | | | | |

Mechanised processing crews

*Table 36. Distribution of logs from mechanically felled stems*

| SED CODE | n | LED | SED | LENGTH |
|---|---|---|---|---|
| <30 | 53 | 32 | 26 | 5.6 |
| 30-39 | 110 | 40 | 34 | 5.3 |
| 40-49 | 33 | 49 | 43 | 5.1 |
| 50-59 | 4 | 55 | 53 | 4.8 |
| >60 | | | | |

*Table 37. Grapple gouge - mechanised felling (n=24)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 2 | 8 | 8 |
| SD | 0.5 | 4.6 | 7 |
| MAX | 4 | 20 | 30 |
| MIN | 2 | 2 | 1 |

*Table 38. Grapple gouge - mechanised felling, distribution by SED class*

| SED CODE | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 4 | 49 | 2 | 11 | 8 | 8 |
| 30-39 | 13 | 97 | 2 | 7 | 7 | 12 |
| 40-49 | 7 | 26 | 2 | 9 | 8 | 21 |
| 50-59 | 0 | 4 | | | | |
| >60 | 0 | 0 | | | | |

***Branch draw***

Manual delimbing

*Table 39. Branch draw - manual delimbing (n=3)*

| | DEPTH | WIDTH | WHORL | WH U | WH D |
|---|---|---|---|---|---|
| AVERAGE | 8 | 7 | 48 | 45 | 45 |
| SD | 3 | 1.5 | 7.2 | 9.6 | 9.1 |
| MAX | 11 | 8 | 56 | 55 | 55 |
| MIN | 5 | 5 | 43 | 36 | 35 |

*Table 40. Branch draw - manual delimbing, distribution by SED class*

| SED CODE | n | OTHERS | DEPTH | WIDTH | WHORL | WH U | WH D | % |
|---|---|---|---|---|---|---|---|---|
| <30 | 0 | 58 | | | | | | |
| 30-39 | 2 | 118 | 8 | 6 | 43 | 39 | 40 | 2 |
| 40-49 | 1 | 62 | 7 | 7 | 56 | 55 | 55 | 2 |
| 50-59 | 0 | 9 | | | | | | |
| >60 | 0 | 2 | | | | | | |

Mechanised delimbing

*Table 41. Branch draw - mechanised delimbing (n=7)*

| | DEPTH | WIDTH | WHORL | WH U | WH D |
|---|---|---|---|---|---|
| AVERAGE | 4 | 5 | 34 | 31 | 30 |
| SD | 1.2 | 2.9 | 5 | 4.7 | 4.2 |
| MAX | 6 | 9 | 40 | 37 | 33 |
| MIN | 3 | 1 | 28 | 25 | 23 |

*Table 42. Branch draw - mechanised delimbing, distribution by SED class*

| SED CODE | n | OTHERS | DEPTH | WIDTH | WHORL | WH U | WH D | % |
|---|---|---|---|---|---|---|---|---|
| <30 | 4 | 49 | 4 | 5 | 31 | 28 | 27 | 8 |
| 30-39 | 3 | 107 | 3 | 6 | 38 | 34 | 33 | 3 |
| 40-49 | 0 | 33 | | | | | | |
| 50-59 | 0 | 4 | | | | | | |
| >60 | 0 | 0 | | | | | | |

***Branch tear***

*Table 43. Branch tear - mechanised delimbing (n=8)*

| | DEPTH | WIDTH | LENGTH | WHORL | WH U | WH D |
|---|---|---|---|---|---|---|
| AVERAGE | 2 | 7 | 10 | 37 | 34 | 33 |
| SD | 0.5 | 3.9 | 5.8 | 8.8 | 8.6 | 7.8 |
| MAX | 3 | 13 | 20 | 28 | 27 | 26 |
| MIN | 2 | 3 | 5 | 52 | 49 | 44 |

*Table 44. Branch tear - mechanised delimbing, distribution by SED class*

| SED CODE | n | OTHER | DEPTH | WIDTH | LENGTH | WHORL | WH U | WH D | % |
|---|---|---|---|---|---|---|---|---|---|
| <30 | 4 | 49 | 2 | 3 | 5 | 31 | 28 | 27 | 8 |
| 30-39 | 2 | 108 | 2 | 10 | 13 | 39 | 36 | 36 | 2 |
| 40-49 | 2 | 31 | 2 | 10 | 17 | 48 | 45 | 43 | 6 |
| 50-59 | 0 | 4 | | | | | | | |
| >60 | 0 | 0 | | | | | | | |

***Feed roller marking***

*Table 45. Distribution of logs handled by feed roller*

| SED CODE | n | LED | SED | LENGTH |
|---|---|---|---|---|
| <30 | 30 | 31 | 25 | 5.8 |
| 30-39 | 97 | 40 | 34 | 5.2 |
| 40-49 | 23 | 50 | 43 | 5.3 |
| 50-59 | 0 | | | |
| >60 | 0 | | | |

*Table 46. Feed roller damage by depth and area (n=7)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 2 | 6 | 13 |
| SD | 0 | 3.2 | 9.5 |
| MAX | 2 | 10 | 30 |
| MIN | 2 | 2 | 2 |

*Table 47. Feed roller damage- distribution by SED class*

| SED CODE | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 1 | 29 | 2 | 5 | 30 | 3 |
| 30-39 | 5 | 92 | 2 | 10 | 19 | 5 |
| 40-49 | 1 | 22 | 2 | 9 | 10 | 4 |
| 50-59 | 0 | 3 | | | | 0 |
| >60 | 0 | 0 | | | | 0 |

***Bark loss***

Manual felling and delimbing

*Table 48. Bark loss values - manual felling*

| | LED | SED | LENGTH | % |
|---|---|---|---|---|
| AVERAGE | 41 | 36 | 5.4 | 23 |
| SD | 8 | 7.4 | 0.9 | 23.5 |
| MAX | 64 | 61 | 7.8 | 100 |
| MIN | 24 | 20 | 3.15 | 0 |

*Table 49. Bark loss by SED class - manual felling*

| SED CODE | n | % | SD |
|---|---|---|---|
| <30 | 58 | 21 | 22 |
| 30-39 | 118 | 25 | 25 |
| 40-49 | 62 | 23 | 22 |
| 50-59 | 9 | 24 | 17 |
| >60 | 2 | 33 | 40 |

Mechanised felling and delimbing

*Table 50. Bark loss values - mechanised felling and delimbing*

| | LED | SED | LENGTH | % |
|---|---|---|---|---|
| AVERAGE | 40 | 34 | 5.3 | 83 |
| SD | 7.5 | 6.8 | 1 | 21 |
| MAX | 67 | 55 | 8.1 | 20 |
| MIN | 24 | 20 | 3.1 | 100 |

*Table 51. Bark loss by SED class - mechanised felling and delimbing*

| SED CODE | n | % | SD |
|---|---|---|---|
| <30 | 53 | 78 | 22 |
| 30-39 | 110 | 83 | 21 |
| 40-49 | 33 | 89 | 16 |
| 50-59 | 4 | 83 | 28 |
| >60 | 0 | 0 | 0 |

### *Loader damage*

*Table 52. Distribution of measured logs*

| SED CODE | n | LED | SED | LENGTH |
|---|---|---|---|---|
| <30 | 17 | 32 | 26 | 5.3 |
| 30-39 | 70 | 43 | 35 | 5.3 |
| 40-49 | 69 | 50 | 44 | 4.6 |
| 50-59 | 27 | 62 | 54 | 4.5 |
| >60 | 11 | 72 | 64 | 5.1 |

*Table 53. Loader damage values (n=39)*

| | DEPTH | WIDTH | LENGTH |
|---|---|---|---|
| AVERAGE | 2 | 8 | 7 |
| SD | 0.5 | 4.2 | 6.7 |
| MAX | 4 | 20 | 40 |
| MIN | 2 | 2 | 3 |

*Table 54. Distribution of loader damage by log SED*

| SED CODE | n | OTHERS | DEPTH | WIDTH | LENGTH | % |
|---|---|---|---|---|---|---|
| <30 | 3 | 14 | 2 | 7 | 4 | 18 |
| 30-39 | 22 | 48 | 2 | 8 | 6 | 31 |
| 40-49 | 10 | 59 | 2 | 7 | 5 | 14 |
| 50-59 | 4 | 23 | 2 | 4 | 18 | 15 |
| >60 | 0 | 11 | | | | 0 |

# APPENDIX 2 - Damage values used in the Treemaps™ analysis

## Type 1 damage

### *Draw wood*

- Depths 5, 10, 15 cm
- Area : <40cm butt dia - 2*2cm, >40cm butt dia - 3*5cm
- Distance from centre: <40cm butt dia - 9cm, >40cm butt dia - 14cm.

### *Scarf*

- Lengths 6, 8, 10 cm
- Angle 45 degrees

### *Buttsplit*

- Depth 0.1 * Dia, 0.2 * Dia
- Length 50cm

### *SED split*

- Depth 2cm, 20 long
- Depth 4 cm, 30 long

## Type 2 damage

### *Grapple/Fork*

| **Section** | **1** | **2** | **3** |
|---|---|---|---|
| Depth | 2 | 2 | 2 |
| Width | 7 | 12 | 7 |
| Length | 5 | 10 | 5 |

### *Branch draw*

| **Section** | **1** | **2** | **3** |
|---|---|---|---|
| Depth | 3 | 3 | 3 |
| Width | | | |
| Length | | | |

| **Section** | **1** | **2** | **3** |
|---|---|---|---|
| Depth | 7 | 7 | 7 |
| Width | | | |
| Length | | | |

***Branch tear***

| Section | 1 | 2 | 3 |
|---|---|---|---|
| Depth | 3 | 3 | 3 |
| Width | 13 | 13 | 13 |
| Length | 15 | 15 | 15 |

***Feed Roller***

| Section | 1 | 2 | 3 |
|---|---|---|---|
| Depth | 2 | 2 | 2 |
| Width | 8 | 8 | 8 |
| Length | 13 | 13 | 13 |

# APPENDIX 3 – Results from Treemaps

## Pruned logs - Type 1 damage

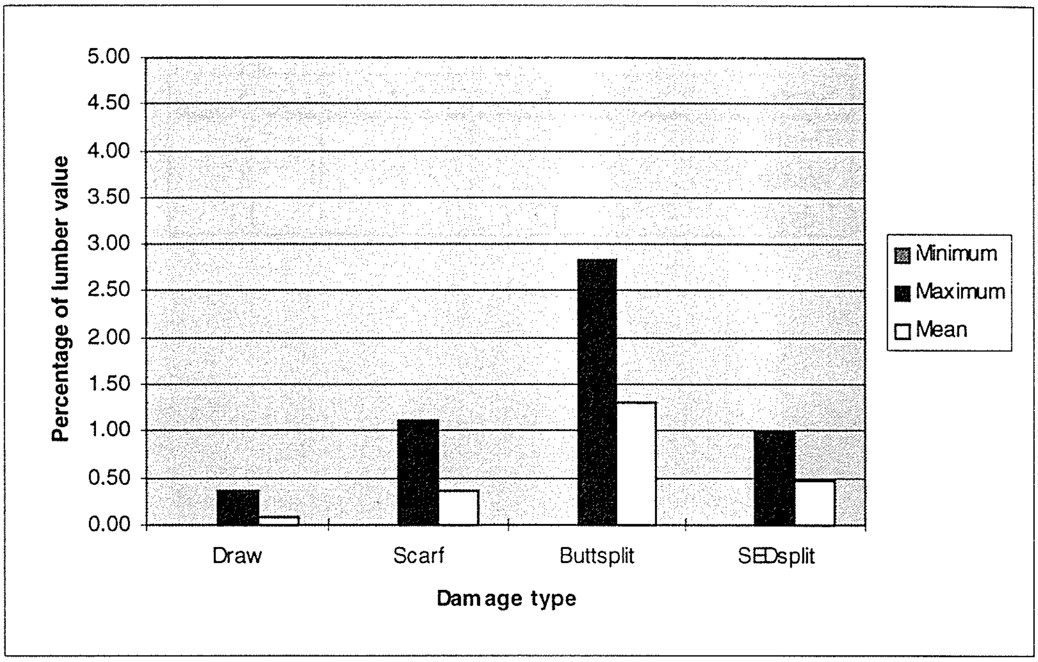


*Figure 15. Large logs*

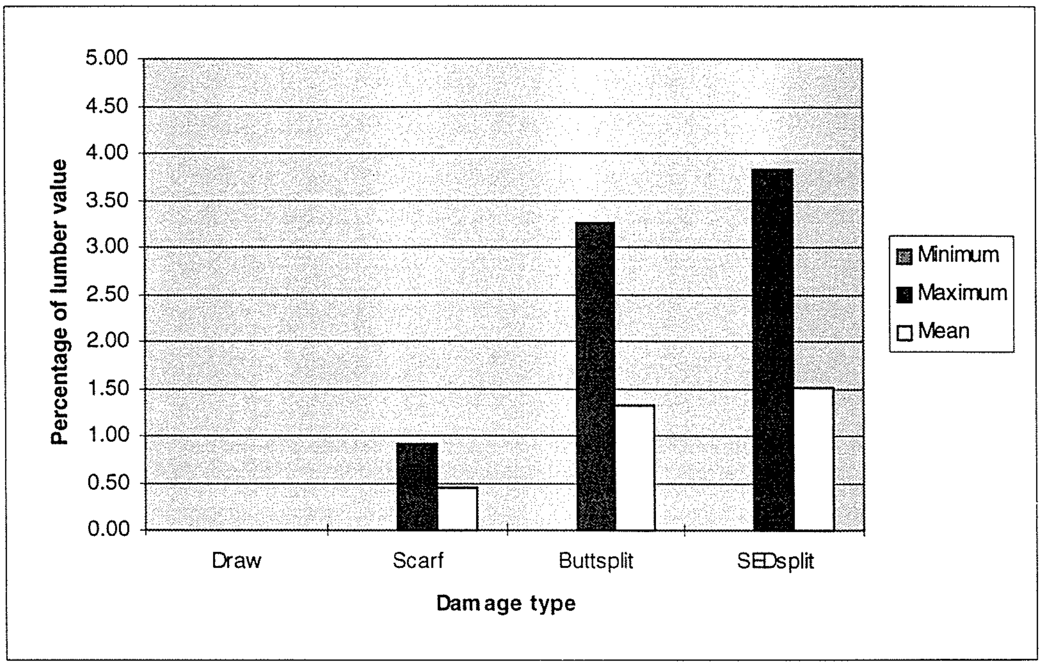


*Figure 16. Medium logs*

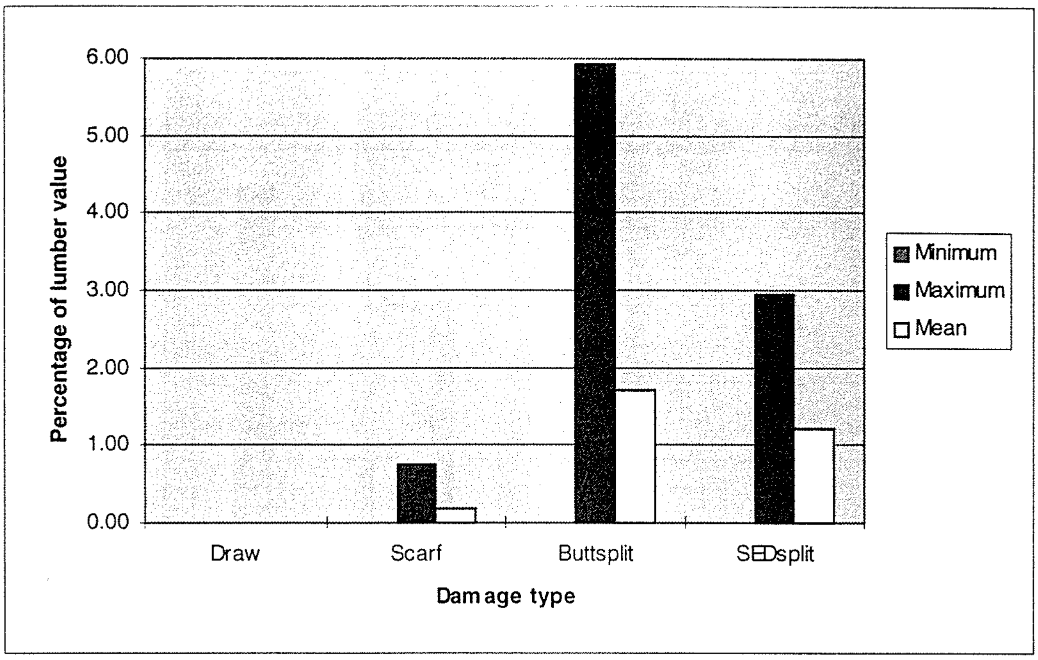


*Figure 17. Small logs*

## Unpruned logs - Type 1 damage

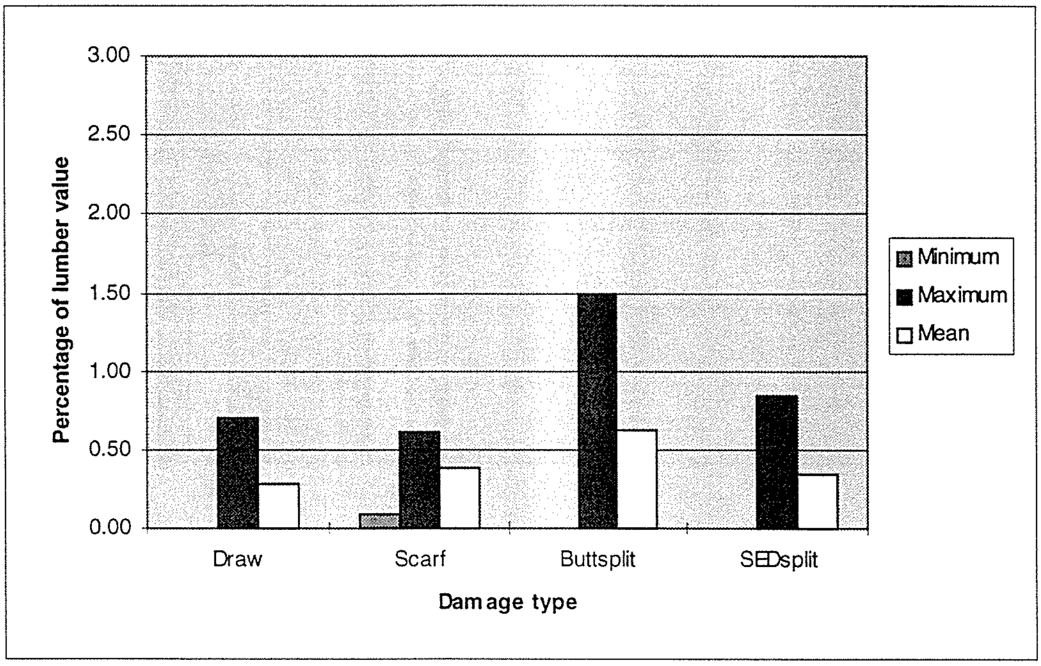


*Figure 18. Large logs*

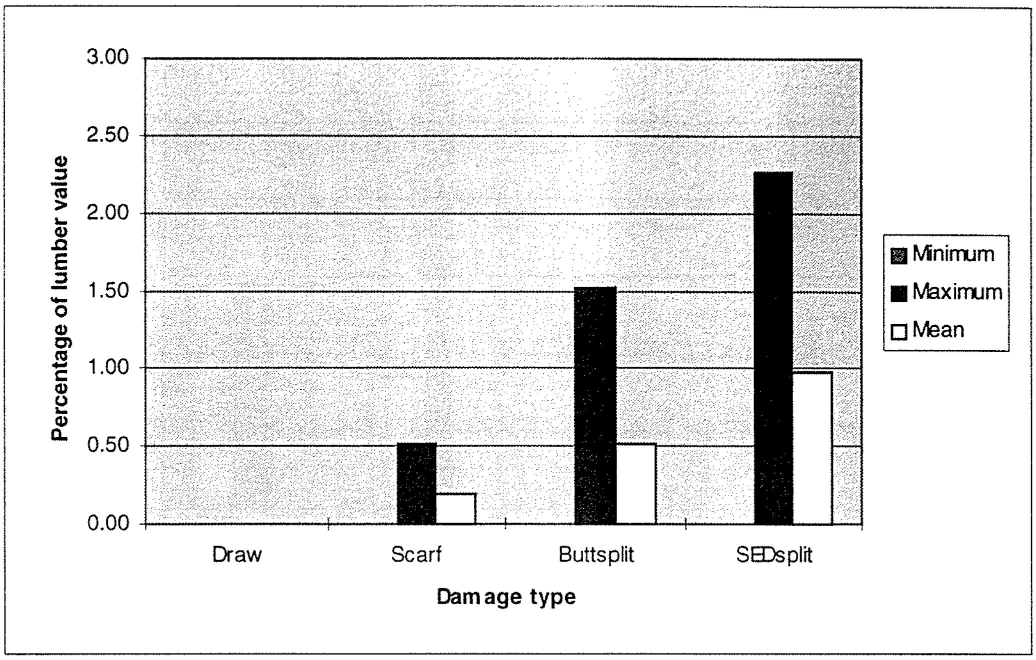


*Figure 19. Medium logs*

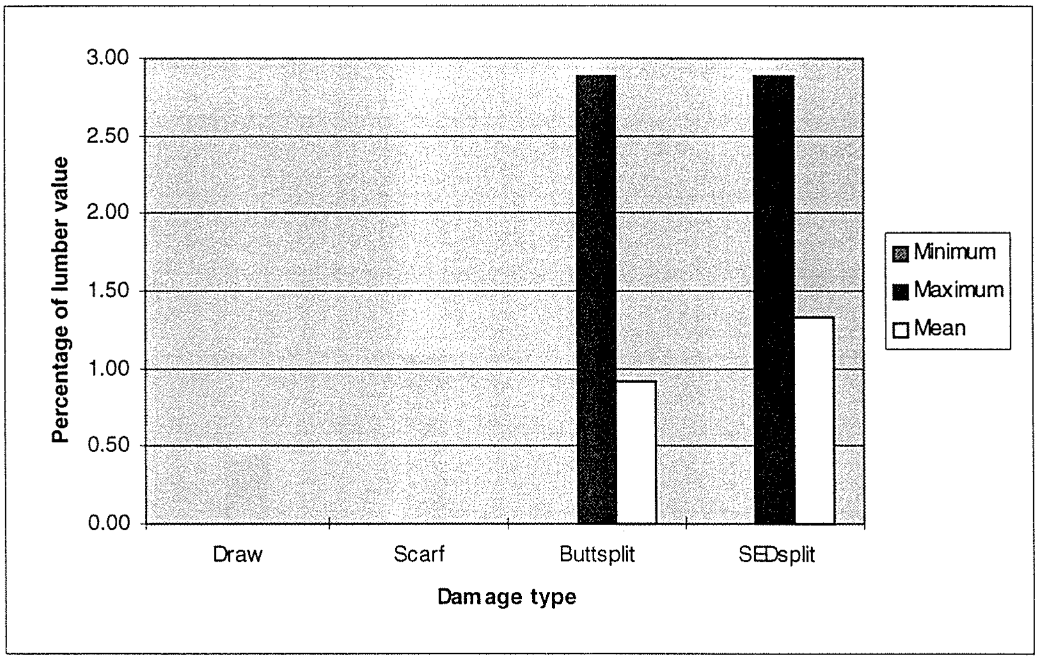


*Figure 20. Small logs*

## Pruned logs - Type 2 damage

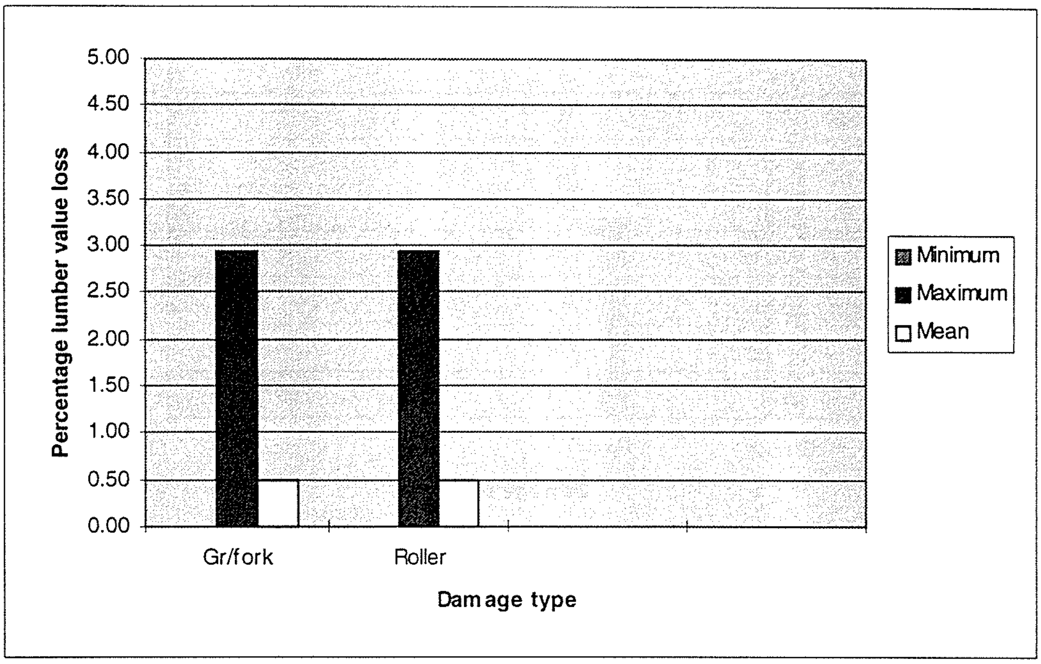


*Figure 21. Large logs*

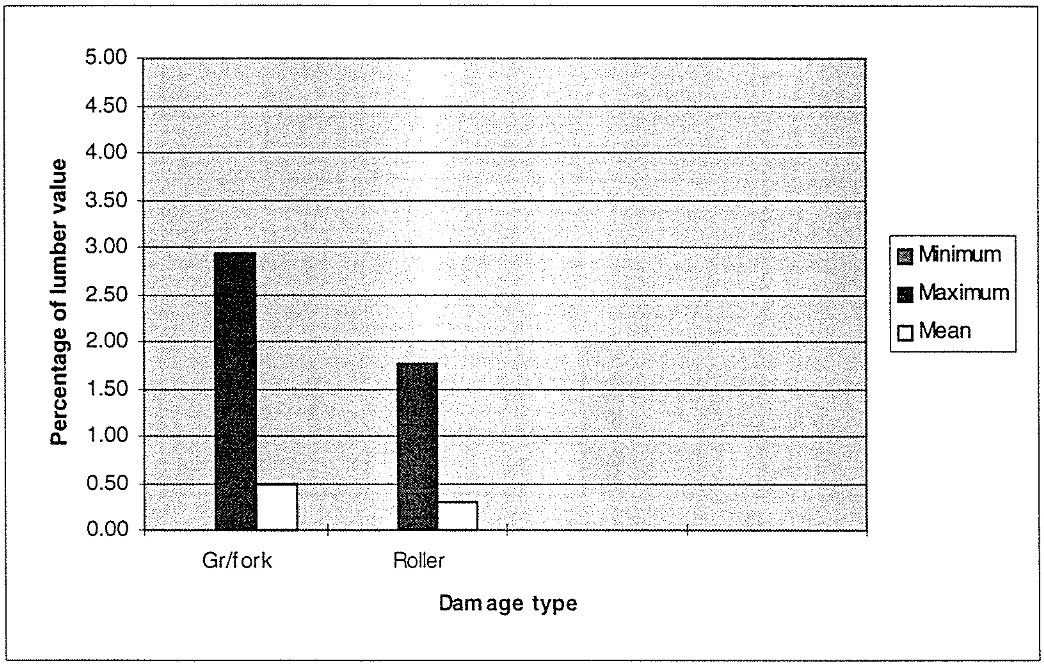


*Figure 22. Medium logs*

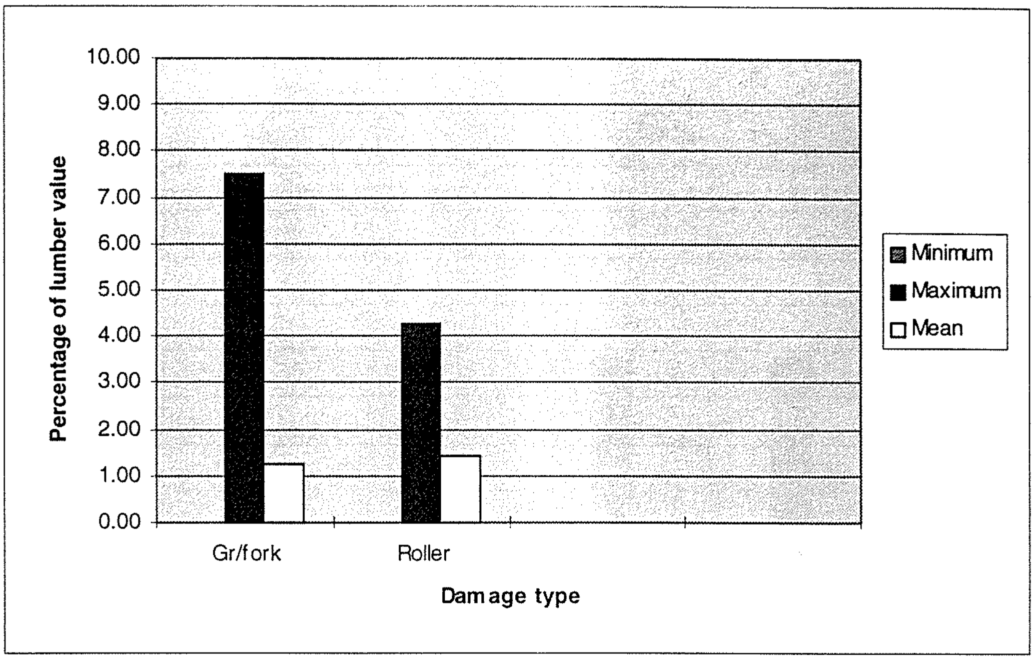


*Figure 23. Small logs*

# Unpruned logs - Type 2 damage

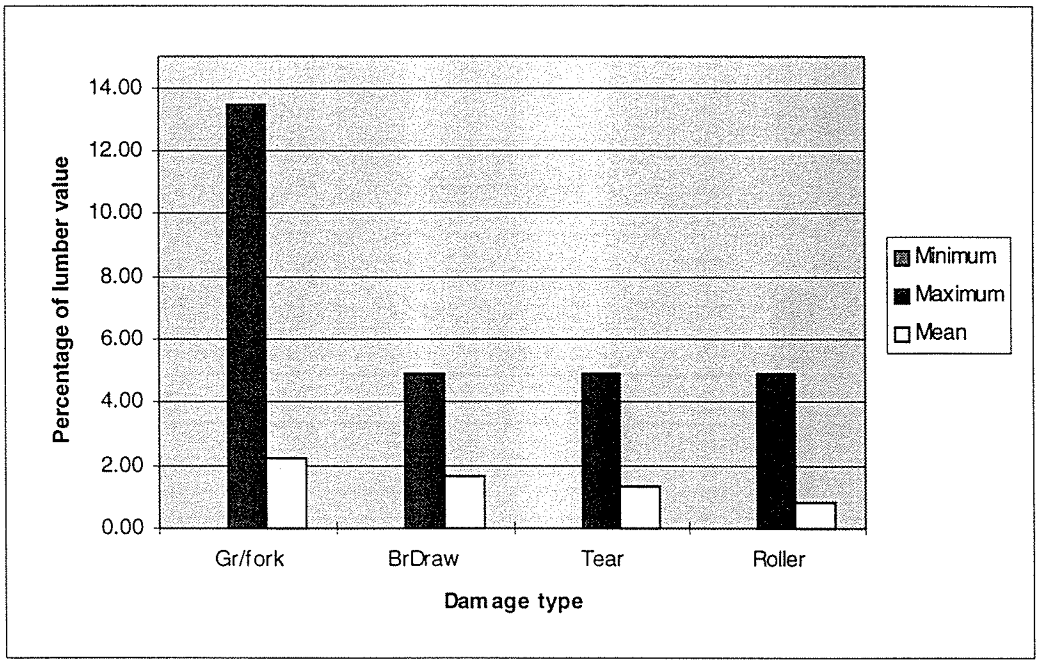


*Figure 24. Large logs*

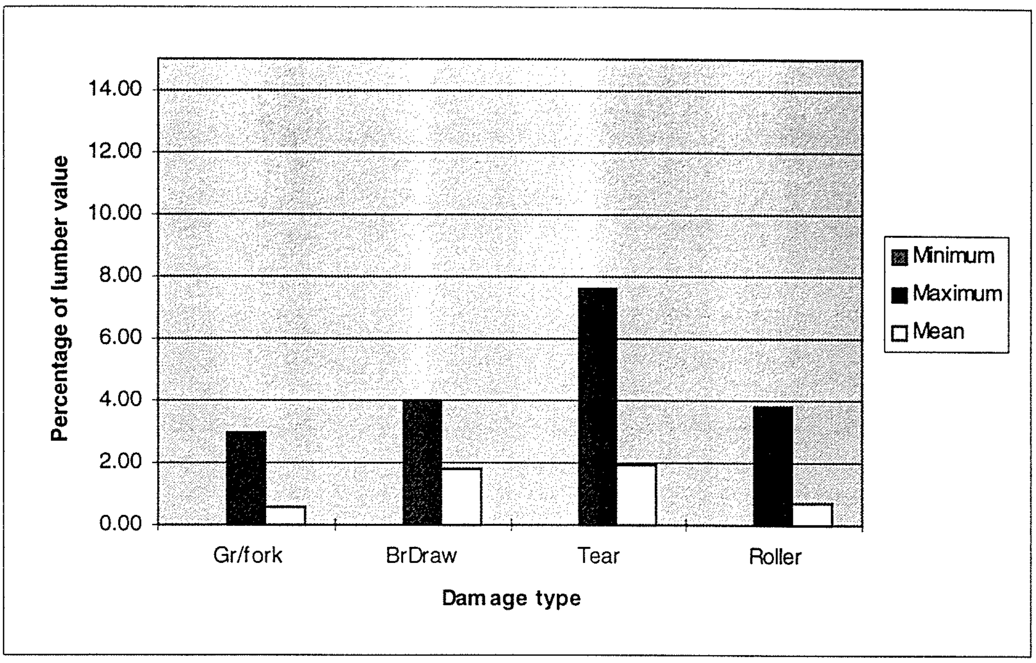


*Figure 25. Medium logs*

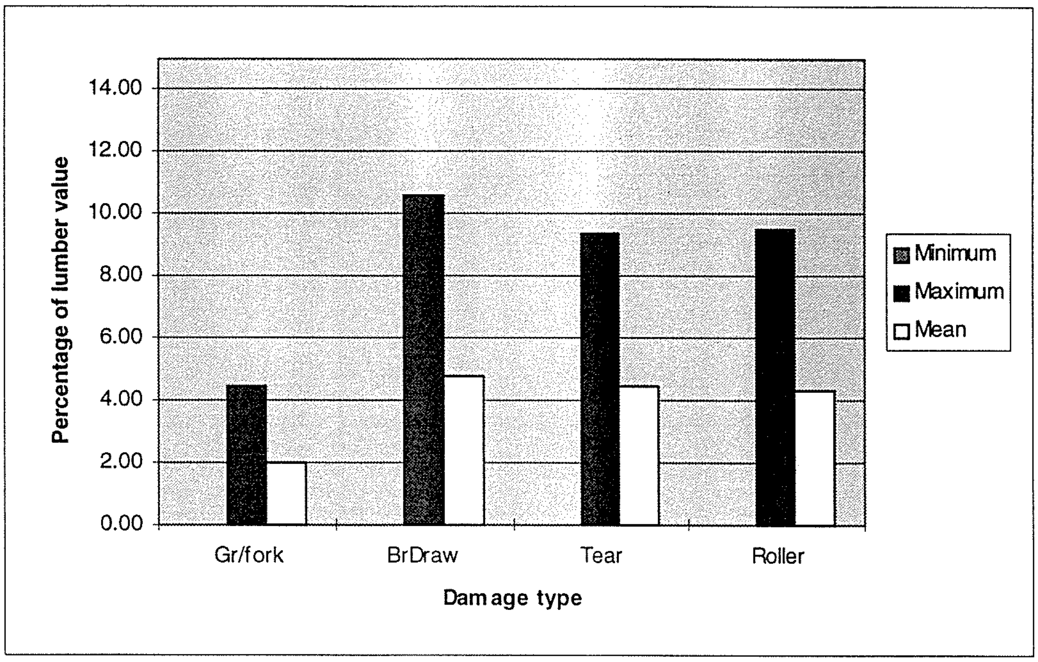


*Figure 26. Small logs*

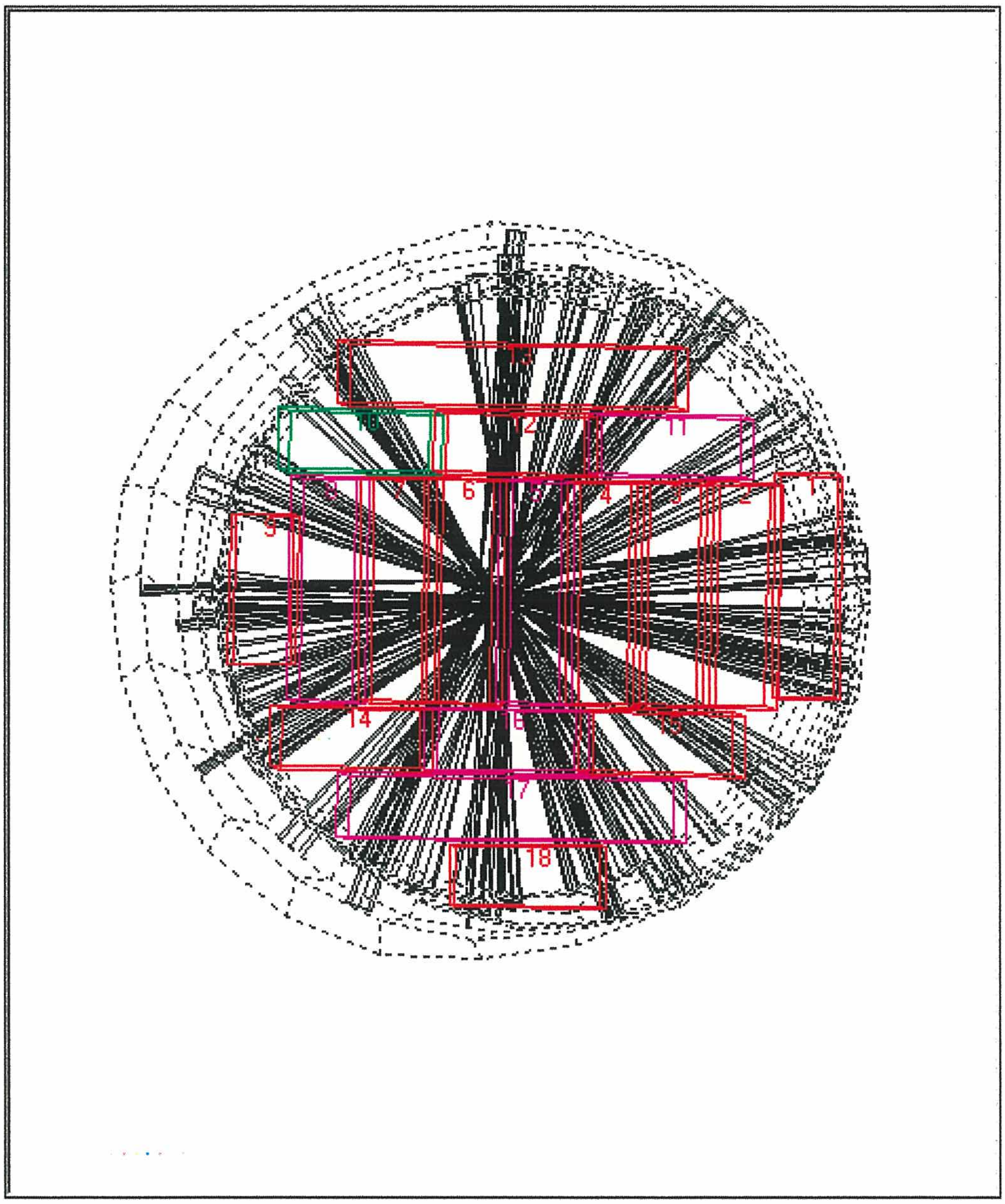


*Figure 27. Treemaps example - view from the small end*

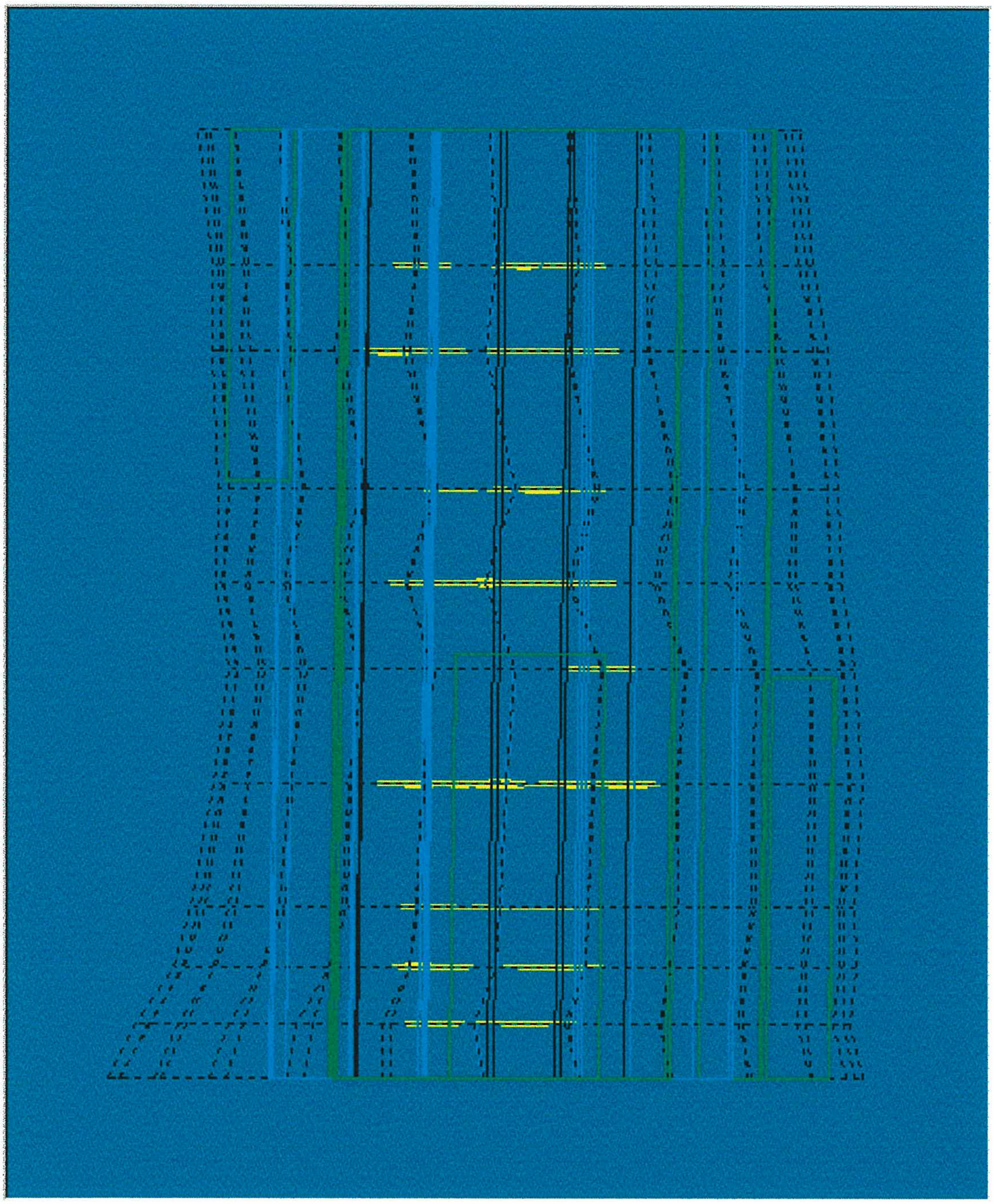

*Figure 28. Treemaps example - side view*

# APPENDIX 5 – Example of Treemaps™ outturn

Large log, pruned

| | | | | | |
|---|---|---|---|---|---|
| Nominal thickness 1 [mm] | 25 | | Width 1 [mm] | 75 | 78 |
| Actual thickness 1 [mm] | 28 | | Width 2 [mm] | 100 | 103 |
| Nominal thickness 2 [mm] | 40 | | Width 3 [mm] | 125 | 128 |
| Actual thickness 2 [mm] | 43 | | Width 4 [mm] | 150 | 153 |
| | | | Width 5 [mm] | 200 | 205 |
| | | | Width 6 [mm] | 225 | 228 |
| | | | Width 7 [mm] | 250 | 255 |
| | | | Width 8 [mm] | 300 | 306 |
| | | | Width 9 [mm] | 325 | 331 |
| | | | Width 10 [mm] | 350 | 356 |

| | | |
|---|---|---|
| Saw clears price [$/m^3] | Clear | 600 |
| Saw clear-1-face price [$/m^3] | Clear1X | 550 |
| Saw dressing price [$/m^3] | Dress | 275 |
| Saw shop price [$/m^3] | Shop | 450 |
| Saw factory price [$/m^3] | Fact | 400 |
| Saw merchant price [$/m^3] | Merch | 250 |
| Saw box price [$/m^3] | Box | 200 |
| Saw engineering price [$/m^3] | Eng | 500 |
| Saw no. 1 frame price [$/m^3] | Frame1 | 350 |
| Saw no. 2 frame price [$/m^3] | Frame2 | 275 |

| | Log volume | 0.7955 | | | | | | Docked length | Docked $/board | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Length | Width | Th. | Name | Volume | $/vol | $ | | $ | Vol |
| 1 | 2.4 | 10.3 | 4.3 | Clear | 0.0106296 | 600 | 6.37776 | 2.4 | 6.37776 | 0.0106296 |
| 2 | 5 | 15.5 | 4.3 | Clear | 0.033325 | 600 | 19.995 | 4.8 | 19.1952 | 0.031992 |
| 3 | 5 | 15.5 | 4.3 | Clear1X | 0.033325 | 550 | 18.32875 | 4.8 | 17.5956 | 0.031992 |
| 4 | 5 | 15.5 | 4.3 | Box | 0.033325 | 200 | 6.665 | 4.8 | 6.3984 | 0.031992 |
| 5 | 5 | 15.5 | 4.3 | Box | 0.033325 | 200 | 6.665 | 4.8 | 6.3984 | 0.031992 |
| 6 | 5 | 15.5 | 4.3 | Box | 0.033325 | 200 | 6.665 | 4.8 | 6.3984 | 0.031992 |
| 7 | 5 | 15.5 | 4.3 | Box | 0.033325 | 200 | 6.665 | 4.8 | 6.3984 | 0.031992 |
| 8 | 5 | 15.5 | 4.3 | Clear1X | 0.033325 | 550 | 18.32875 | 4.8 | 17.5956 | 0.031992 |
| 9 | 5 | 7.8 | 4.3 | Clear1X | 0.01677 | 550 | 9.2235 | 4.8 | 8.85456 | 0.0160992 |
| 10 | 4.1 | 10.3 | 4.3 | Clear | 0.0181589 | 600 | 10.89534 | 3.9 | 10.36386 | 0.0172731 |
| 11 | 5 | 15.5 | 4.3 | Clear1X | 0.033325 | 550 | 18.32875 | 4.8 | 17.5956 | 0.031992 |
| 12 | 3.5 | 7.8 | 4.3 | Clear | 0.011739 | 600 | 7.0434 | 3.3 | 6.64092 | 0.0110682 |
| 13 | 5 | 15.5 | 4.3 | Clear | 0.033325 | 600 | 19.995 | 4.8 | 19.1952 | 0.031992 |
| 14 | 5 | 7.8 | 4.3 | Clear | 0.01677 | 600 | 10.062 | 4.8 | 9.65952 | 0.0160992 |
| 15 | 4.2 | 10.3 | 4.3 | Clear | 0.0186018 | 600 | 11.16108 | 4.2 | 11.16108 | 0.0186018 |
| 16 | 5 | 15.5 | 4.3 | Clear1X | 0.033325 | 550 | 18.32875 | 4.8 | 17.5956 | 0.031992 |
| 17 | 2.7 | 7.8 | 4.3 | Clear | 0.0090558 | 600 | 5.43348 | 2.7 | 5.43348 | 0.0090558 |
| 18 | 5 | 15.5 | 4.3 | Clear | 0.033325 | 600 | 19.995 | 4.8 | 19.1952 | 0.031992 |
| 19 | 2.5 | 7.8 | 4.3 | Clear | 0.008385 | 600 | 5.031 | 2.4 | 4.82976 | 0.0080496 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | 0 | 400 | 0 | | | 0 |
| | | | | | | | | | 216.88254 | 0.4587885 |
| | | | | Total | 0.4766851 | | 225.18756 | | 0 | 0 |
| | | | | Conversion | 0.599227027 | | | | 0.7955 | 225.18756 |
| | | | | Chipper | 0.3188149 | | | | 0 | 0 |

| Stem name | Start | Length | LED | SED | Volume | CVol | CP | DC | PLI | Taper | Sweep |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Seed log LP | 0 | 5.3 | 511 | 413 | 0.7955 | 0.6653 | 3.101 | 210 | 7.82 | 9 | 4.2 |