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PROJECT REPORT

BREAKAGE IN MANUALLY-FELLED CLEARFELL RADIATA PINE

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Project Report

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BREAKAGE IN MANUALLY-FELLED CLEARFELL RADIATA PINE

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ABSTRACT

To investigate regional variations in manual felling breakage of radiata pine, a total of one thousand trees of clearfell age 25 to 30 years, from managed stands, were felled at 20 different sites around New Zealand (50 trees per site). Detailed measurements were made of breakage, tree characteristics and site topography. Felling methods, and the time to fell the sampled trees were noted. One qualified faller was used for the complete study.

Mean Relative Break Height, and Relative Break Diameter for all broken trees was 0.67 and 0.43 respectively. A tree was deemed to have broken if the diameter at the first break exceeded 10cm. The range of percentage broken trees per site varied from 10% to 98%. The most significant variable affecting the probability of a tree breaking was tree height. Tree height, followed by Site, explained the most variation in first break height. The number of merchantable (length > 1.2m, SED > 10cm) broken top pieces was found to increase with tree height. The overall distribution of piece lengths was: 1.2 to 2.4m : 38%, 2.4 to 3.6m : 36%, 3.6 to 4.8m : 10%, 4.8 to 6.0m : 7%, and > 6.0m : 9%.

The most common known causes of breakage were topography and crossed stems. However, most trees broke for unknown causes. Mean stump height was 10.13 cm, but mean effective stump height was 23.41 cm. Variation in effective stump height was best explained by tree lean, and butt diameter.

Average felling time varied from 1.3 min for a conventional scarf and back-cut tree, to 2.7 min for a quarter-cut tree felled with the aid of a wedge. Variation in felling time was largely due to DBH, followed by felling technique.

1.0 INTRODUCTION

Most mature radiata pine break on felling. Over the years, rules of thumb, largely based on observation, have become apparent. For instance: "smaller trees have a relatively higher break point; most trees tend to break at 2/3 tree height, and break diameter is usually about 1/2 DBH".

The breakage pattern for an individual tree on felling is believed to be determined by many factors, often difficult to quantify, but including:

Terrain - irregularities in the "landing zone" such as stumps, pre-felled trees and uneven ground.

Operator - skills, techniques and motivation.

Harvest System - manual felling (chainsaw).
-mechanised felling (varying with machine type and operator factors as above).

Tree Characteristics
- tree height
- tree diameter
- stocking
- branching
- density/strength

Breakage patterns are believed to vary regionally, so region-specific breakage equations have been developed to more accurately predict tree breakage. Accuracy is greatest when applied to comparable stands, felled in a similar way to the sample trees used to develop the equation.

The reasons for regional variation in breakage patterns are not clear. Tree density/strength may have a significant influence on radiata breakage patterns but this link has not yet been determined. A recent study by McConchie et al, 1994 reported no significant relationship between outerwood density and any breakage parameters, measured or calculated.

Breakage equations are required as input into Pre-harvest Inventory Assessments (MARVL) where estimates of the average relative break height (Break height/Tree height), asociated standard deviation, and the probability of a tree not breaking, for a range of tree height classes, are applied to sample plot data. Many forest owners have developed breakage equations to reflect the different characteristics of their forests. These results are usually confidential.

Practical research into variables affecting tree breakage is hindered by the nature of the task. Manley (1977) found that difficulty in defining stumps, terrain, tree falling skills, and tree variables other than tree size, meant that the break point could only be predicted in terms of normally distributed values of Relative Break Height (RBH).

The last published tree breakage work was carried out in 1987 (Twaddle, 1987), and almost all previous published work relates to studies undertaken in the Central North Island (Hall, 1990; Manley, 1977;Murphy, 1982a, 1982b; Murphy, 1984a, 1984b; Terlesk, 1990. Lees, 1969) carried out research into breakage in the Nelson area. Few studies involved a single, qualified faller, and controlled study conditions.

It is desirable to reduce the incidence and (if possible) extent of felling breakage. This issue has largely been addressed by efforts to promote directional felling (Murphy and Gaskin, 1982). Directional felling aims to reduce the severity of breakage by felling in such a way that stumps, terrain obstacles, and pre-felled trees have a minimal effect.

Allied to the issue of the "quality" of manual felling, is that of butt log value loss, mostly due to poor felling technique, which often results in butt damage (slabbing, splitting and drawwood) and therefore higher "effective" stump heights. This loss of volume can result in a value loss per stem to the forest owner. Butt log damage can lead to a penalty volume loss when detected by the customer.
The number, and size of broken pieces is another important attribute of tree breakage. For instance, Twaddle (1987), stated that: in manually felled, 30 year old managed radiata pine in the Bay of Plenty region, merchantable pieces above the first break will typically comprise 45% of the total number of logs to be extracted, but will make up only 4% of the volume and 1% of the value. These conclusions are probably still valid, ten years later.

Because it was felt that many questions regarding breakage remain unanswered, it was decided to investigate manually felled tree breakage patterns on a regional basis, and also to research the effects of felling technique on butt log quality. The project was given timely impetus by the growing trend to mechanised felling, and the desire to quantify its benefits relative to manual felling.

2.0 METHOD

2.1 Site selection and sample size

Twenty sites throughout New Zealand were chosen. Fifty trees from each site were felled and measured, this sample size was assumed to be sufficient to validate existing breakage functions. Samples were taken from existing harvesting operations in tended new crop radiata, aged between 25 to 35 years old. Sites were rejected if their topography (for example, broken or steeply dissected terrain) was severe to the extent that breakage would be "uncharacteristically excessive". The first sample of 50 trees was felled in early 1994, and the last in mid-1996. A list of sites, and a description of the stands sampled is shown in Table 1.

Table 1 - Site descriptions (based on MARVL summaries)

	Region	Forest	Age (yrs)	Stocking (stems/ha)	Merch Piece Size (m^3)	Total Recoverable Volume (m^3/ha)	Mean Slope (°)
1	Northland	Glenbervie	27	236	2.19	428	9
2	Auckland - Site 1	Riverhead	26	395	1.59	498	8
3	Auckland - Site 2	Woodhill	29	428	0.87	372	3
4	Coromandel	Tairua	30	255	2.46	616	5
5	Bay of Plenty - Site 1	Rotoehu	29	270	1.96	638	3
6	Bay of Plenty - Site 2	Tarawera	27	300	2.14	643	11
7	Bay of Plenty - Site 3	North Kaingaroa	31	227	2.8	687	18
8	Bay of Plenty - Site 4	South Kaingaroa	33	193	2.62	533	4
9	Waikato	Kinlieth	26	346	1.43	495	6
10	East Coast	Mangatu	29	324	2.1	680	13
11	Hawke's Bay - Site 1	Mohaka	28	345	1.74	599	11
12	Hawke's Bay - Site 2	Kaweka	27	301	1.75	507	8
13	Hawke's Bay - Site 3	Gwavas	32	810	1.16	924	2
14	Wairarapa	Ngaumu	34	304	1.96	596	2
15	Nelson - Site 1		27	667	0.93	617	12
16	Nelson - Site 2	Golden Downs	29	211	2.22	426	17
17	Canterbury	Ashley	27	159	1.92	302	8
18	Southland-Site 1	Otago Coast	27	225	1.99	449	8
19	Southland-Site 2	Tapanui	31	317	1.59	503	2
20	Southland-Site 3	Invercargill	27	239	1.78	366	5

2.2 Data collection

One experienced faller was used for all felling (LFITB, FIRS Module 3.3 :Tree Felling - Stage Two certification). Felling was not carried out in an actual "production" situation due to the intensive measurement required, and this may have impacted on the breakage recorded. Actual felling time, from the first saw cut, to the tree hitting the ground was however carried out as if under "production pressure". Site and tree variables measured included: felling slope,tree height, DBH, first break height and first break diameter as well as length of "merchantable" broken top pieces. A complete listing of measured variables can be found in Appendix 1. Malformed trees (for example, forked, broken tops, dead spars etc.) were excluded from all samples.

2.3 Data analysis

The most significant or useful independent variables were selected for inclusion in predictive or descriptive models or equations (Appendix 10).

Dependent Variables

Unbroken y/n (UBC)
First break height (BH1)
First break diameter (BD1)
Time to fell (FT)
Draw wood depth (DWD)
Shatter zone length (SHZ)
Effective stump height (ESH)
Total no. of merch. pieces above first break (PCT)

Independent variables

Tree Height (TH)
DBH
Region (SIT)
Crown Size (CRS)
Crown Height (CRH)
Felling Arc (FLA)
Dia. of branches at break (WB)
Dia. 1st green whorl (DGW)

Fell Slope (FSL)
Age
Stocking

Height to 1st Green Whorl (HGW)
Fell Technique (FLT)
Tree Lean (TL)
Fell direction rel. to lean (FL)
Diameter at 1st break (BD1)
Cause of break (CBK)
Butt diameter (BUT)

3.0 RESULTS AND DISCUSSION

One thousand trees were felled at 20 sites (50 trees per site) over a two year period. Most sites were on ground-based terrain.

Two datasets were used in the data analysis, one comprised the variable values for all broken trees, and the second, a reduced dataset included only values for trees judged to have broken for no apparent reason, that is. Cause of Break (CBK) = unknown.

3.1 Stump heights (STH)

Mean stump height for the entire study was 10.1 cm (st. dev. 5.3 cm) varying between 0 and 39 cm. Mean stump heights for the different sites are tabled in Appendix 9. Effective stump heights were calculated for every tree. These values take into account felling damage such as draw wood, splitting or slabbing, and the removal of the sloven (scarf height). Mean effective stump height was 23.4 cm (st. dev. 17.6 cm) and varied from 1 to 214 cm. A summary of felling damage for each site is also given in Appendix 9. Variation in effective stump height was best explained by tree lean and butt diameter, and to a lesser extent, site.

3.2 Draw wood depth (DWD)

Draw wood occcurred in 41% of trees felled. Average depth or length was 9.3 cm (St. dev. 6.8 cm) ranging from 1 to 60 cm. Draw wood depth was found to be weakly, but significantly related to DBH, and to a lesser extent, site. One site appeared to be prone to this kind of damage (Ngaumu). This problem is described in detail in the faller's notes (Appendix 11.)

3.3 Scarf height (SCH)

Mean scarf height was 10.9 cm (St. dev. 4.9 cm) ranging from 1 to 29 cm. Scarf height tended to increase with DBH.

3.4 Split/Slab length (SSB).

Only 4% of trees felled were damaged by splitting or slabbing. Mean length of damage was 710 cm (St. dev. 56 cm) ranging from 9 to 210 cm. Some sites appeared to be prone to this kind of damage, eg. Woodhill. This problem is described in detail in the faller's notes (Appendix 11.)

3.5 Broken trees

Of the 1000 trees felled, 686 (69%) were deemed to have broken (that is, first break diameter > 10cm). The mean values for measured variables such as total tree height (TH), first break height (BH1), first break diameter (BD1), DBH, Relative Break Height (RBH) and Relative Break Diameter (RBD) for each site are given in Appendix 2.

The range of these values for all trees is shown in Table 2.

Table 2 - Range of data (all sites)

Variable	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
All trees (1000)				
DBH (cm)	**47**	**11.5**	**18**	**79**
Tree Height (m)	**34.6**	**6.2**	**16.1**	**49.7**
Unbroken trees (314)				
DBH (cm)	**41**	**12.5**	**18**	**73**
Tree Height (m)	**29.8**	**5.8**	**16.1**	**47.7**
Broken trees (686)				
DBH (cm)	**50.0**	**9.7**	**22**	**79**
Tree Height (m)	**36.8**	**4.9**	**23.1**	**49.7**
First break height (m)	**24.5**	**4.6**	**9.8**	**36.9**
RBH	**0.67**	**0.11**	**0.22**	**0.89**
RBD	**0.43**	**0.12**	**0.16**	**0.82**

3.6 Cause of breakage

The most common cause of breakage was not identified, that is, the tree broke for unknown reasons (Figure 2), but of the identified causes, topography and crossed stems accounted for most breakage.

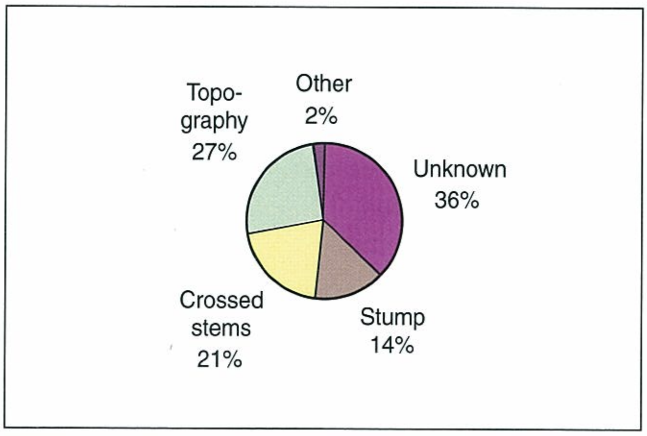

Figure 2 - Distribution of cause of breakage (CBK)

3.7 Unbroken trees

As can be seen in Figure 4. (and more fully reported in Appendix 3), the different sites showed a wide range of probabilities for a tree to break (from 10% at Woodhill to 98% broken at Ngaumu).

The most significant variable affecting the probability of a tree breaking was found to be total tree height. Having accounted for the effect of tree height, individual site characteristics explained some further variation. Equations relating break probability to tree height were developed (Equations A1, A2, B1, Appendix 10).

Smaller trees tended not to break, and the effect of tree height can be seen in Figure 3, showing that trees under about 25m in height had only a 20% chance of breaking. The variation in the percentage of broken trees in different sites is shown in Figure 4. Some breakage probabilities differed significantly, notably Kaweka, Glenbervie, Woodhill, Riverhead, Tairua, Tarawera and Invercargill.

Other tree characteristics may have been influential in reducing breakage. For instance, at Kaweka, 50% of the trees were classed as heavily branched, and all trees were felled uphill. The felling angle of 30% of the Kaweka trees was <80°. Other samples with low breakage (for example, Woodhill, Glenbervie, Riverhead) had combinations of either large branching or low felling angle.

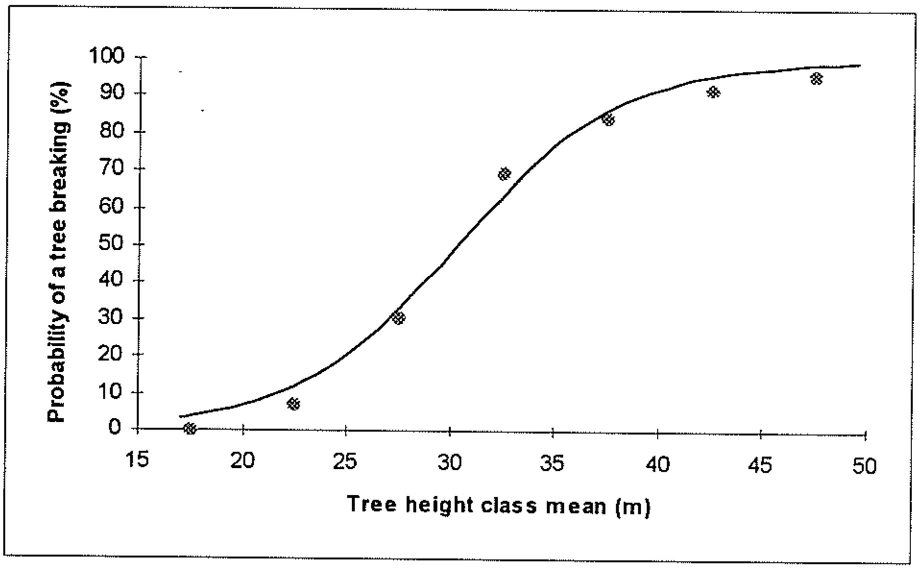

Figure 3 - The effect of tree height on the probability of a tree breaking (actual, and fitted values) (Equation A1, Appendix 10)

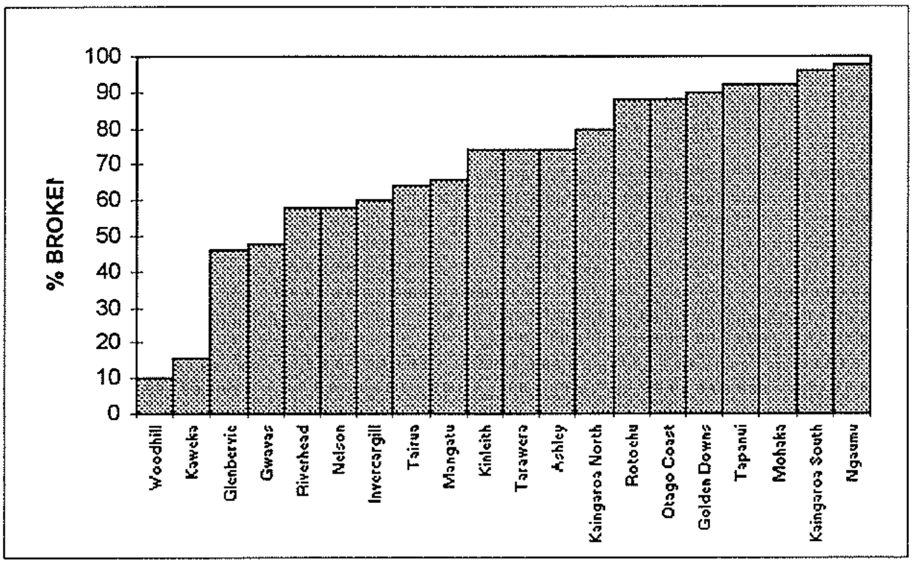

Figure 4 - Variation in percentage of broken trees at different sites

3.8 Relative Break Height (RBH) and Relative Break Diameter (RBD)

These two calculated ratios can provide a means of comparison of breakage patterns between different sites or stands. Appendix 3 gives RBH values and breakage values in the formats used by MARVL. The range of RBH and RBD means for different sites is shown in Figures 5 and 6. The 95% Confidence Intervals for Kaweka and Woodhill are large, owing to the small sample of broken trees, that is, eight and five trees respectively.

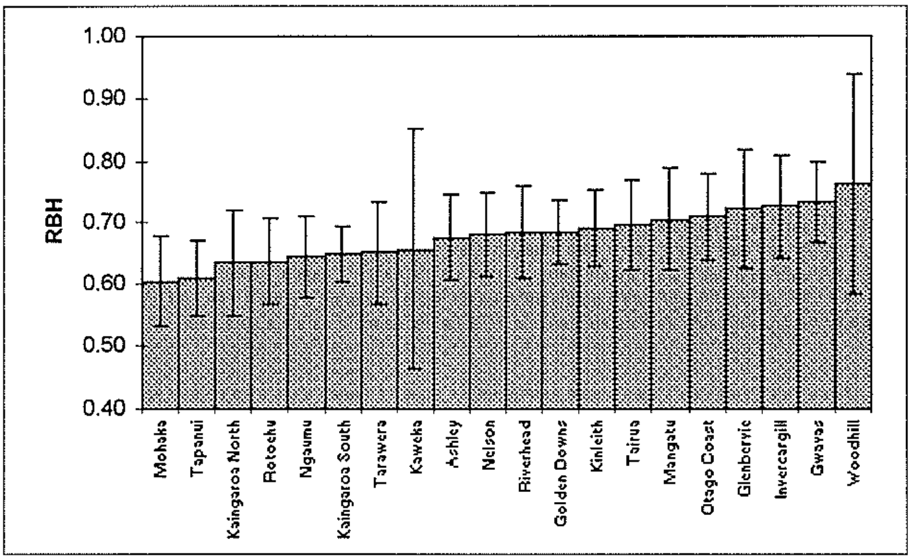

Figure 5 - Mean RBH values for different sites (error bars show 95% Confidence Limits)

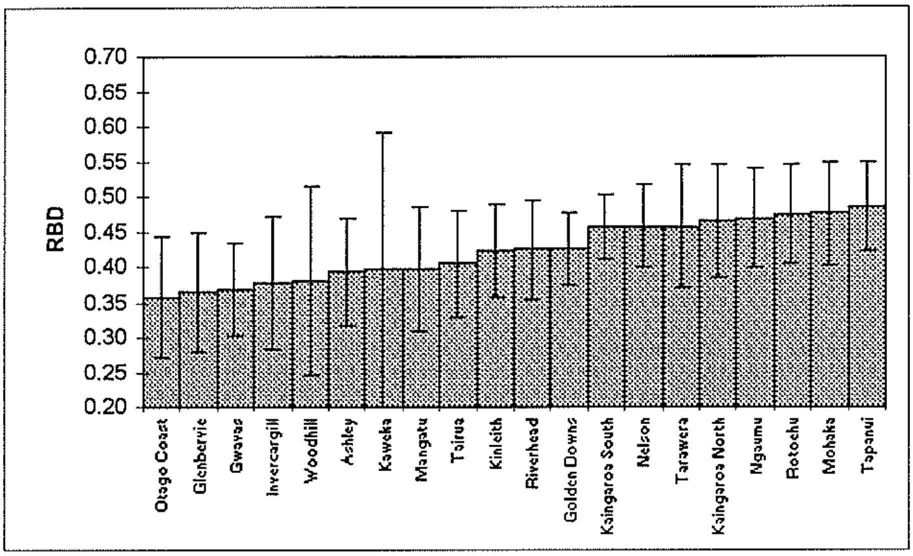

Figure 6 - Mean RBD values for different sites (error bars show 95% Confidence Limits)

There is an apparent trend to decreasing site RBH with mean tree height. This is shown in Figure 7. RBH was found to be significantly ($p<0.05$) negatively correlated with tree height, DBH, crown height and stem diameter at the first green whorl.

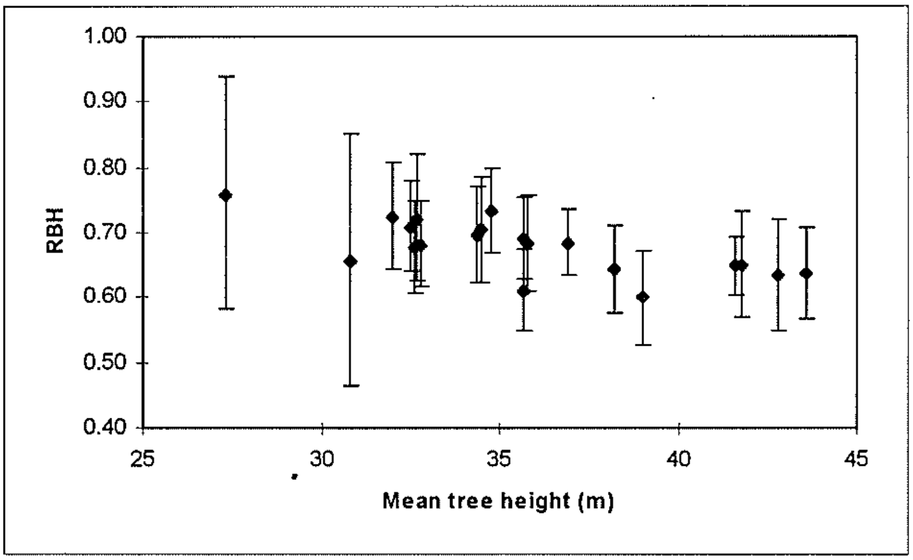

Figure 7 - RBH values by site and mean tree height per site

3.9 First Break Height (BH1)and First Break Diameter (BD1)

A range of site, stand and tree variables were tested for their effect on First Break Height (BH1) and First Break Diameter (BD1). Site and tree height were found to be the most significant variables for estimating BH1. Equations were developed to express this relationship (Equations A3, A4, B2, B3 Appendix 10). Tree height explained the most variation. An LSD test indicated there was no significant difference ($p<0.05$) between mean first break heights for any of the sites but Tapanui.

The reduced dataset (Cause of break = unknown) was analysed. This dataset excluded breakage due to known causes such as stumps or uneven terrain, and was therefore assumed to more accurately reflect the effects of measured variables. The models developed explained about 20% more variation ($r^2 = 0.5$) in BH1, and gave no improvement for BD1. Site factors explained about 5% of variation in BH1 for the enlarged dataset, and 13% in the reduced dataset.

Variation in First Break Diameter (BD1) was mostly explained by DBH, site, and tree height (TH). Site, and tree height, though significant, had less effect than DBH. Equations were developed to express this relationship (Equations A4, A5, B4, B5 Appendix 10).

3.10 Shatter zone length (SHZ)

The damaged portion of the tree at the first break was described as the shatter zone. Average shatter zone length was 0.86 m (St. dev. 0.61 m) and ranged from 0.1 to 5.3 m. Shatter zone length variation was best explained by, and shatter zone length tended to increase with, first break diameter. An equation (A7) was developed to reflect this relationship (Appendix 10). The intercept value is very small. Shatter zone length expressed in cm was equal to four times the first break diameter.

3.11 Number of merchantable broken top pieces (PCT)

The 68.6% broken trees produced 900 merchantable top pieces, averaging 1.3 pieces per tree and varying from 0 to 6 pieces per tree. Figure 8. shows the distribution of number of top pieces. Sixty-eight percent of all sampled trees produced either one or two merchantable top pieces. Seventy-four percent of all merchantable top pieces were less than 3.6 m long (Figure 9).

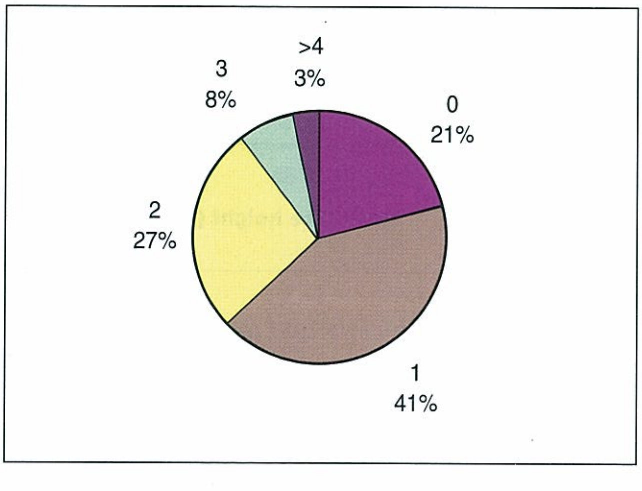

Figure 8 -Distribution of number of merchantable top pieces per tree

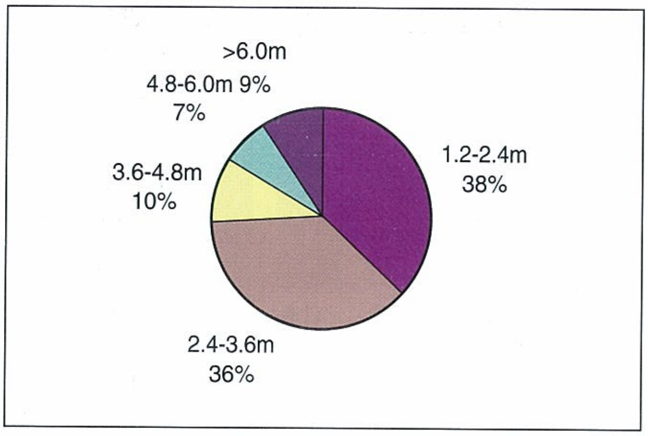

Figure 9 - Distribution of all merchantable piece lengths

The number of broken top pieces was found to increase with total tree height, with an apparent increase in the percentage of broken trees with two merchantable pieces per tree occurring at around 40m (Figure 9.) This may be due to the fact that 80% of data in this height range comes from just five sites, and one-third of these data from the Kaingaroa South site. This site, together with Tapanui, had a high percentage of breakage. The distribution of piece lengths appears to be relatively constant with tree height. (Figure 11.).

Regression analysis showed that tree height was the best predictor for the number of merchantable pieces produced for a given tree-height class (equation A8 - Appendix 10).

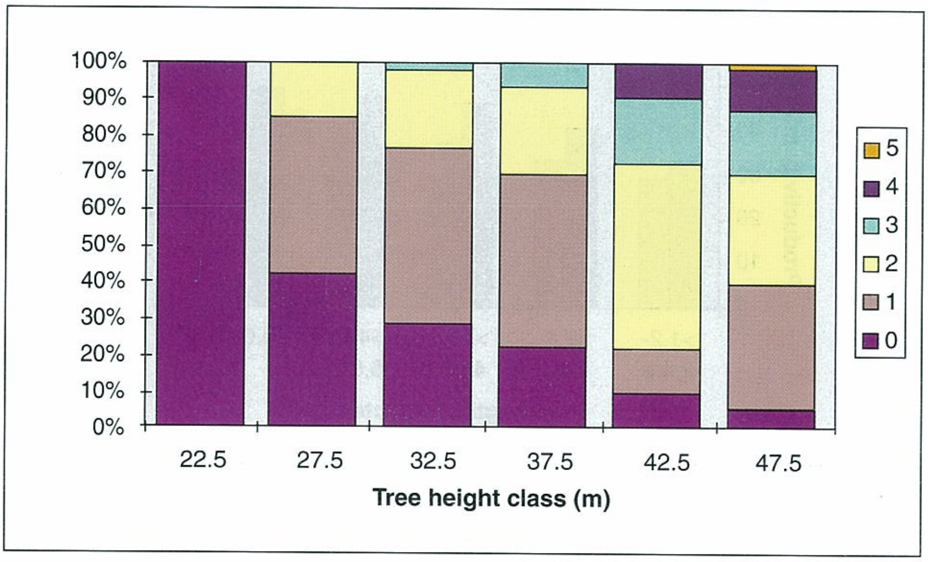

Figure 10 - Distribution of the number of merch. broken top pieces per tree by tree height class (min SED 10 cm, min. length 1.2 m)

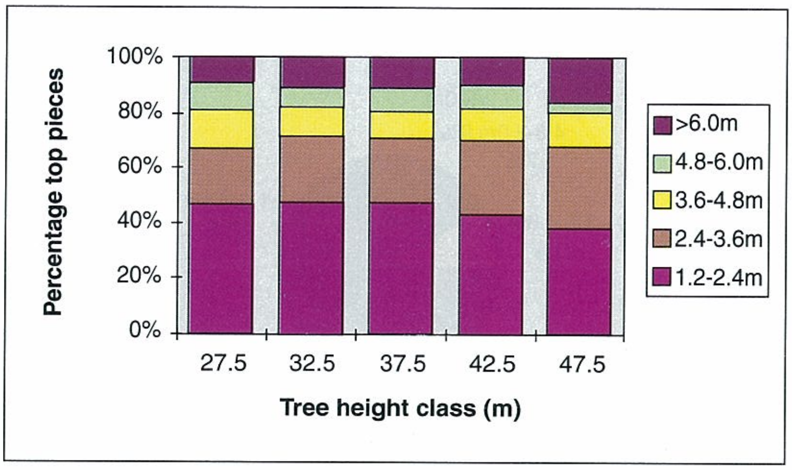

Figure. 11 - Distribution of top piece lengths by tree height class

Effect of breakage on extraction productivity

The effect on mean extracted piece size of extraction of different piece lengths is shown in Appendix 6. Specified recovery of the shortest lengths would reduce mean extracted piece size by 8% to 66%, depending on site factors and tree height distribution.

The effect on actual skidder productivity is illustrated in Figure 12. In two sites, Kaingaroa North and Riverhead, hourly productivity would be reduced by 34% and 27% respectively if recovery of the shortest top pieces was prescribed.

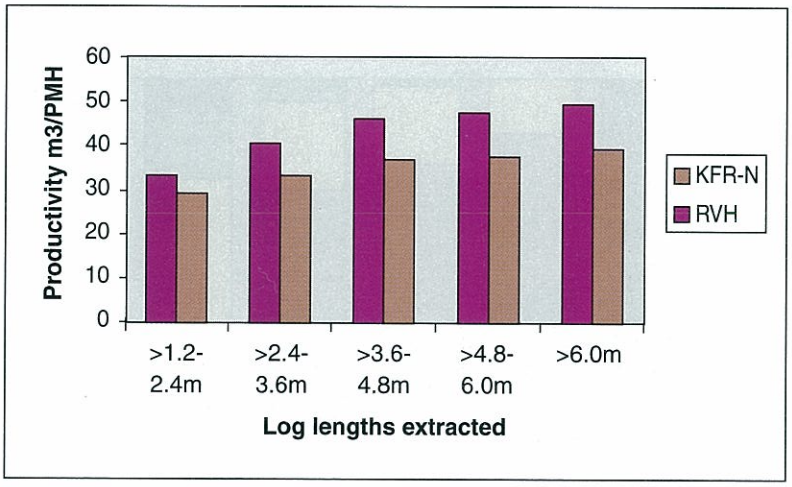

Figure 12 - An indication of the effect on skidder productivity of the extraction of merchantable top pieces of varying length (Cat 518, AHD 150m, 6.23m^3 average haul size, flat terrain) for two different sites

3.12 Felling times and techniques

Most trees were felled by the "Normal " felling technique, the bore and release method was used the least (Table 3.). Felling methods (3, 4) involving the use of wedges took on average 96% longer than for the normal method. The 1/4 cut method (2) took 65% longer, and the bore and release method (7) 76% longer. Mean felling times for the different methods were compared and results are shown in Table 3. There is, for instance, no significant difference between mean felling times for methods 3 and 4, and 2 and 7, when the times are corrected for DBH variation.

Table 3 - Mean felling times for different felling techniques

Felling technique	No.	%	Mean time (min)	St. Dev.	LSD*
1 = Normal felling technique, without aids.	508	52	1.28	0.61	a
2 = 1/4 cut (walk around to other side of tree).	122	12	2.11	0.63	b
3 = Normal technique, and use of wedge.	105	11	2.33	1.11	c
4 = 1/4 cut and use of wedge.	142	14	2.69	1.24	c
5 = Driver tree.	9	1	1.77	0.81	-
6 = Driven tree.	22	2	5.47	6.11	-
7 = Bore and release.	84	8	2.25	0.80	b
8 = Other.	2	-	-	-	-

***Least Significant Differences (LSD) between mean felling times: same letter = no difference at p=0.05**

Table 4 - Main felling method (and percentage use) used for different felling conditions

Tree Lean		Fell Direction to Lean: Forward	Sideways	Backwards	n/a
None		1 (75%)	-	-	1 (64%)
Light		1 (65%)	1 (51%)	4 (61%)	1 (100%)
Moderate		7 (61%)	4 (41%)	4 (55%)	1 (100%)
Heavy		7 (80%)	4 (37%)	6 (75%)	-

Regression analysis showed that variation in felling time (FT) was found to be largely due to DBH, the felling technique (FLT) used, and to a lesser extent site. An equation to predict felling time (equation A9) is given in Appendix 10. Table 4 shows the predominant technique used for felling trees with varying degrees of lean, and lean to the intended felling direction. For instance, most heavy forward leaners were felled using the bore and release method (7), while heavy side leaners tended to be felled using a 1/4 and wedge technique (4). Heavy back leaners were mostly driven.

4.0 CONCLUSIONS

Analysis of tree breakage data from manually felled trees of clearfell age, at a number of geographically dispersed sites, showed that of the 1000 trees felled, 686 (69%) were deemed to have broken (that is, first break diameter > 10cm). Most trees broke for unknown reasons. Of the remainder, topography and crossed stems accounted for most breakage.

The most significant variable affecting the probability of a tree breaking was found to be total tree height. Having accounted for the effect of tree height, individual site characteristics explained some further variation. Trees of total height <25m had only a 20% chance of breaking.

Mean Relative Break Height, and Relative Break Diameter for all broken trees was 0.67 and 0.43 respectively. There was no significant difference ($p<0.05$) between any of the mean first break height values for the various sites, except for that from Tapanui. However, total tree height was found to be the best predictor for estimating first break height of individual trees.

In broken trees the number of merchantable top pieces appeared to increase with tree height. Above 25m, the proportions of different top piece lengths remained approximately the same.

Felling time was found to increase with DBH, and varied with the felling technique used. Effective stump height was found to be influenced by tree lean, butt diameter and to a limited extent, site factors. Mean stump height for the entire study was 10.1 cm, varying between 0 and 39 cm. Shatter-zone length of broken trees was found to be approximately four times the break diameter. Break diameter was, in turn, found to be affected by tree height and DBH.

Much research remains to be carried out in this area, and further enquiry into the physiological basis for tree breakage may explain more of the variation in break height than that achieved as a result of this small sample. A trend to mechanised felling in ground-based operations may lead to greater reduction in breakage through directional felling, uphill felling, lowering of smaller trees, and felling into standing timber to slow the descent of the felled tree.

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Appendix 1

Measured variables, and Measurement methodology: Abbreviations and definitions

Tree Number: A unique tree number given to each tree sampled at any given site.

DBH: DBHob: Breast Height Diameter over bark, measured at 1.4m above ground level. Measured from the high side on sloping ground. If measured using calipers, the average of 2 measurements taken at right angles was used. Diameter was recorded to the nearest centimetre. Measurement point marked with a paint spot.

BUT: Butt Diameter: Measured across the large end of the butt log prior to sloven removal. The average of two readings taken at right angles. Measured over bark - bark thickness estimated, and include where appropriate (eg. if it has broken away during felling). Diameter recorded to the nearest centimeter.

STH: Stump Height: Determined by measuring from the DBH paint spot directly down to the back cut on the butt log, then subtracting this length from 1.4m. Recorded to the nearest centimetre.

FT: Felling Time: Only the direct felling time was recorded for each tree i.e. any time spent clearing undergrowth for safe felling, or pre-trimming was excluded. Fell Time began when the saw was revved up to begin the scarf cut and ended when the tree hit the ground (or was effectively hung up, or was left standing in a safe state, to be driven down by another tree).

FLT: Felling Technique (or method):

1 = Normal felling technique, without aids.
2 = 1/4 cut (walk around to other side of tree).
3 = Normal technique, and use of wedge.
4 = 1/4 cut and use of wedge.
5 = Driver tree.
6 = Driven tree.
7 = Bore and release.
8 = Other.

 # 1, 3. Normal felling technique, (with and without wedging): Scarf and single back cut (used when the bar length was sufficient to cut right through stem).

 # 2. Quarter cut: For large diameter trees, used because the bar was too short to complete the back cut with a single cut from one side.

 # 4. Quarter cut with wedges: Used for back leaning or side leaning trees, wedges being inserted on the compression side, to help direct the tree.

 # 7. Bore and release: For forward leaning trees.

Chainsaws used for study:

288 Husqvarna 20" bar
066 Stihl 20" bar

Felling tools:

Faller always carried four wedges and
a felling hammer.

FSL: Fell Slope: The slope angle of the felled tree.

TL: Tree Lean:

N = No detectable lean.
L = Light lean.
M = Moderate lean.
H = Heavy lean.

FL: Fell Direction in Relation to Tree Lean: Determined from the relationship of the scarf cut, to the direction of tree lean.

1 = Forward (315 - 45°).
2 = Sideways (45 - 135° or 225 - 315°).
3 = Backwards (135 - 225°).
4 = Not Applicable.

CR: Crown Structure:

1 = Light - Few branches >7cm, None >14cm.
2 = Moderate - Some branches >7cm, Few >14cm.
3 = Heavy - Many branches >7cm.

HGW: Height to the1st Green Whorl: Measured from the back cut directly up the stem to the first whorl where all branches on that whorl had green foliage. Recorded in metres to the nearest decimetre.

DGW: Stem Diameter at the 1st Green Whorl: Measured at mid-internode directly below first green whorl. Recorded to the nearest centimetre.

STB: Butt Distance from the Stump: Measured from the centre of the stump to the centre of the butt log and recorded to the nearest decimetre.

TH: Total Tree Height: Measured from the back cut directly up the stem to the apical shoot. Tree tops were broken in most cases, and care was taken in reassembling the top portion. Recorded in metres to the nearest 0.5m (Stump height was then added to this value).

Note: If Total Tree Height could not be measured with reasonable accuracy, then the tree was excluded from the sample.

BH1: Height to the 1st Break: Measured from the back cut directly up the stem to the first break. A flush cross cut at the measurement point was assumed. Recorded in metres to the nearest decimetre (Stump height was then added to this value).

BD1: Diameter at the 1st Break: Measured directly below the first break but clear of any splitting or nodal swelling. If measured using calipers, the average of 2 measurements taken at right angles was taken. Recorded to the nearest centimetre.

NB: A tree was deemed UNBROKEN if diameter at the first break was <= 10cm.

SHZ: Shatter Zone: The length of stem between clean / flush crosscuts directly below and above the break point. Recorded in metres to the nearest decimeter.

CBK: Cause of Break:

1 = Unknown.
2 = Across a stump.
3 = Across other felled stems.
4 = Due to uneven ground (topography).
5 = Other e.g. felled into stand

PCT: No. of Merchantable Pieces Above the first Break: The total of the number of merchantable top pieces (recorded in 5 length classes). Note, pieces had flush-cut ends with minimum SEDs of 10cm.

Length classes:

PC1: 1.2 - 2.4m
PC2: 2.4 - 3.6m
PC3: 3.6m - 4.8m
PC4: 4.8m - 6.0m
PC5: >6m

DWD: Draw Wood Depth: Measured from the stump to the top of any draw wood pulled from the butt log. Recorded to the nearest centimetre.

SSB: Butt Splitting / Slabbing: The length of any splitting / slabbing extending up the butt log. Recorded to the nearest centimetre.

SCF: Scarf Face: The height (not the length) of the scarf face on the butt log. Recorded to the nearest centimetre.

Stand Details: Stocking (sph), age (yr), mean merchantable piece size (m^3), Total Recoverable Volume (m^3/ha).

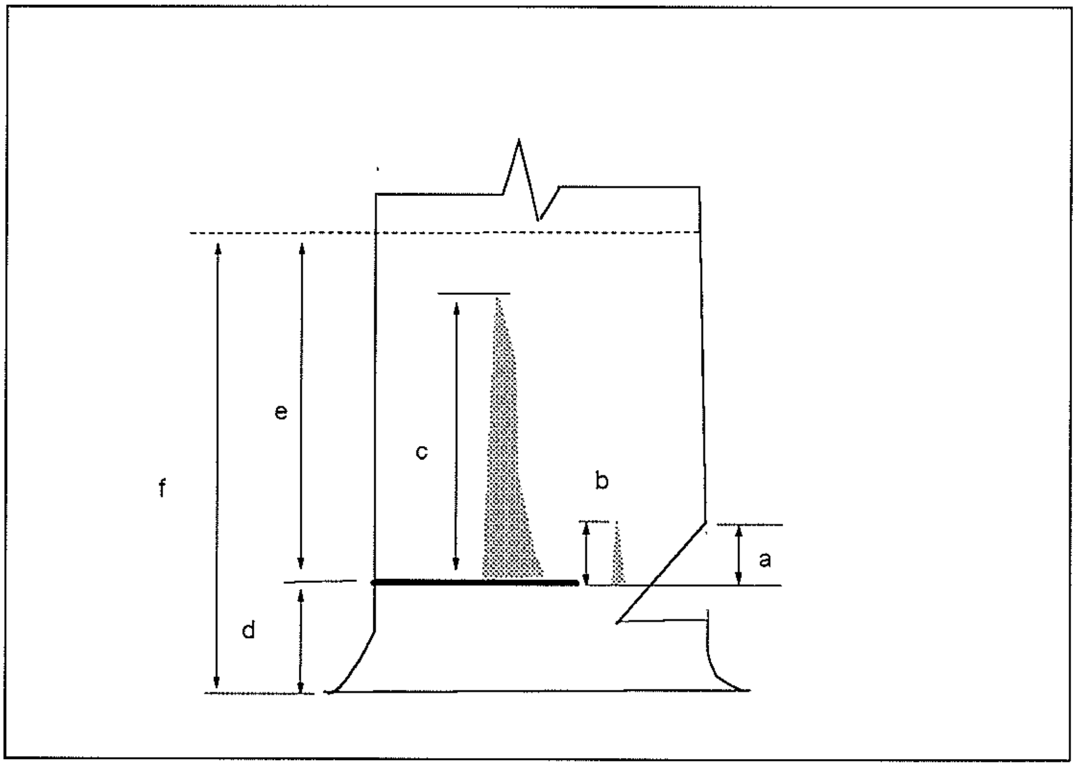
SIT: Location: Site identification.

WI : First Break, At a Whorl or Internode?:

1: Whorl
2: Internode

WB: Average branch diameter in the whorl: (see WI) in cm.

WN: Number of branches in the whorl: (see WI).



a = scarf height (SH)
b = draw wood depth (DWD)
c = split or slab length (SSB)
d = stump height = f - e (SH)
f = breast height (1.4m)

Effective stump height (ESH) = d + (a or b or c, whichever is the greater)

Figure 1 - Stump and butt measurements

Calculated Variables: Abbreviations and definitions

RBH: Relative Break Height: *First Break Height* divided by *Total Tree Height* (m). Both height values incorporate stump height, that is, comprise height above ground, not from the back-cut.

RBD: Relative Break Diameter: First Break Diameter divided by DBH (cm).

ESH: Effective Stump Height: Stump height plus: Draw wood length or Scarf height or Split or Slab length, whichever is the greater.

BLL: Butt Log Loss: Loss to the butt log length from Draw wood, Scarf height or Splitting or Slabbing.

FLA: Felling angle: A calculated angle from vertical (90°) to the fell slope.

UBC: Unbroken Code: Percentage of the trees in the sample that did not break.

CRH: Crown Height: Tree Height (TH) minus Height to the first Green Whorl (HGW).

FLA: Felling Arc: 90 degrees minus the slope angle of the felled tree (FSL).

Appendix 2 -Average Break diameters and heights

No.	Location	DBH All trees (cm)	Tree Height (m)	Unbroken trees %	DBH (cm)	Tree Height (m)	Broken trees DBH	Tree Height (m)	1st Break Height (m)	RBH	1st Break Diameter (cm)	RBD
1	Glenbervie	49	32.3	54	48	31.9	49	32.7	23.6	0.72	18	0.36
2	Riverhead	42	34.1	42	41	31.8	43	35.8	24.4	0.68	18	0.43
3	Woodhill	34	26.1	90	33	26.0	39	27.3	20.8	0.76	15	0.38
4	Tairua	52	34.1	36	51	33.6	52	34.4	23.9	0.70	21	0.41
5	Rotoehu	49	43.3	12	42	40.4	51	43.6	27.7	0.64	24	0.48
6	Tarawera	46	40.5	26	38	36.5	48	41.8	27.3	0.65	22	0.46
7	KFR North	55	42.0	20	46	39.0	57	42.8	27.1	0.64	27	0.46
8	KFR South	52	41.2	4	28	31.6	53	41.6	27.0	0.65	24	0.46
9	Kinleith	42	34.1	26	34	29.7	44	35.7	24.7	0.69	19	0.42
10	Mangatu	55	33.3	34	50	31.1	57	34.5	24.3	0.71	23	0.40
11	Mohaka	53	38.5	8	37	31.8	54	39.0	23.6	0.60	26	0.47
12	Kaweka	46	27.3	84	45	26.6	53	30.8	20.3	0.66	20	0.40
13	Gwavas	41	31.0	52	35	27.6	47	34.8	25.7	0.73	17	0.37
14	Ngaumu	50	38.1	2	44	29.8	50	38.2	24.5	0.64	23	0.47
15	Nelson	32	29.0	42	26	23.7	37	32.8	22.2	0.68	17	0.46
16	GoldenDowns	47	36.8	10	46	36.0	47	36.9	25.2	0.69	20	0.43
17	Ashley	52	31.7	26	48	29.2	54	32.6	22.0	0.68	21	0.39
18	OtagoCoast	56	32.3	12	57	31.4	56	32.5	23.1	0.71	20	0.36
19	Tapanui	44	34.9	8	25	25.6	46	35.7	21.7	0.61	22	0.49
20	Invercargill	45	31.6	40	42	30.9	46	32.0	23.2	0.73	17	0.38

Appendix 3 - Breakage equation components

No.	Location	Probability of breaking %	Height to break point % tree height (m)	Standard Deviation (m)
1	Glenbervie	46	0.7228	0.1113
2	Riverhead	58	0.6850	0.0965
3	Woodhill	10	0.7629	0.0697
4	Tairua	64	0.6972	0.1036
5	Rotoehu	88	0.6382	0.1173
6	Tarawera	74	0.6520	0.1246
7	KFR North	80	0.6355	0.1353
8	KFR South	96	0.6498	0.0786
9	Kinleith	74	0.6918	0.0935
10	Mangatu	66	0.7060	0.1153
11	Mohaka	92	0.6046	0.1225
12	Kaweka	16	0.6572	0.1176
13	Gwavas	48	0.7345	0.0776
14	Ngaumu	98	0.6449	0.1189
15	Nelson	58	0.6825	0.0877
16	GoldenDowns	90	0.6854	0.0850
17	Ashley	74	0.6770	0.1072
18	OtagoCoast	88	0.7098	0.1151
19	Tapanui	92	0.6108	0.1063
20	Invercargill	60	0.7260	0.1090
Average	All sites	69	0.6697	0.1128

Appendix 4 - Broken trees: Top Pieces above the first break

No.	Location	Broken trees	Shatter Zone	Trees with 0 Pieces	Trees with 1 Piece	Trees with 2 Pieces	Trees with 3 Pieces	Trees with >3 Pieces	% Increase in Pieces to extract (ie. >50 stems)
		%	(m)	%	%	%	%	%	
1	Glenbervie	46	0.54	17	65	13	5	0	48
2	Riverhead	58	0.79	15	50	35	23	0	80
3	Woodhill	10	0.32	40	40	20	0	0	8
4	Tairua	64	0.72	19	66	12	3	0	64
5	Rotoehu	88	1.07	11	32	34	16	7	154
6	Tarawera	74	1.12	11	51	19	19	0	108
7	KFR North	80	1.04	5	35	30	17	13	164
8	KFR South	96	1.04	11	21	52	8	8	176
9	Kinleith	74	0.81	19	51	22	8	0	88
10	Mangatu	66	0.81	46	39	12	0	3	50
11	Mohaka	92	0.88	7	22	43	17	11	190
12	Kaweka	16	0.78	38	62	0	0	0	10
13	Gwavas	48	0.67	38	58	4	0	0	32
14	Ngaumu	98	1.14	18	37	37	4	4	136
15	Nelson	58	0.49	48	35	10	7	0	44
16	GoldenDowns	90	0.72	31	53	16	0	0	76
17	Ashley	74	0.78	27	38	35	0	0	80
18	OtagoCoast	88	0.68	18	45	30	7	0	110
19	Tapanui	92	1.17	13	39	35	11	2	138
20	Invercargill	60	0.59	37	40	23	0	0	52

Appendix 5 - Distribution of Top piece lengths

No.	Location	Broken Trees %	Total No. of top pieces	Top Piece Lengths : % of total 1.2 - 2.4m	2.4 - 3.6m	3.6 - 4.8m	4.8 - 6.0m	>6.0m
1	Glenbervie	46	24	54	12	12	5	17
2	Riverhead	58	40	50	23	20	0	7
3	Woodhill	10	4	75	25	0	0	0
4	Tairua	64	33	27	36	12	10	15
5	Rotoehu	88	77	35	31	16	9	9
6	Tarawera	74	54	44	11	11	8	26
7	KFR North	80	82	45	24	11	8	12
8	KFR South	96	88	51	24	14	3	8
9	Kinleith	74	42	48	38	9	0	5
10	Mangatu	66	24	46	8	13	25	8
11	Mohaka	92	95	40	31	9	13	7
12	Kaweka	16	5	20	0	40	20	20
13	Gwavas	48	16	43	19	19	19	0
14	Ngaumu	98	68	44	25	12	9	10
15	Nelson	58	22	54	14	14	18	0
16	GoldenDowns	90	38	50	16	13	16	5
17	Ashley	74	40	42	25	12	13	8
18	OtagoCoast	88	55	61	22	4	4	9
19	Tapanui	92	69	64	20	6	4	6
20	Invercargill	60	26	57	8	12	4	19

Appendix 6 - Extraction of piece lengths : Effect on mean piece size of minimum lengths extracted

No.	Location	Broken Trees %	Minimum Top Piece Lengths extracted: 1.2 - 2.4m	2.4 - 3.6m	3.6 - 4.8m	4.8 - 6.0m	>6.0m	Nominal Mean Piece Size (m^3)
			Effective Mean extracted piece size, % of nominal mean extracted piece size					
1	Glenbervie	46	69	83	88	93	94	2.19
2	Riverhead	58	56	71	82	94	94	1.59
3	Woodhill	10	93	98	100	100	100	0.87
4	Tairua	64	60	68	81	86	91	2.46
5	Rotoehu	88	39	50	66	78	88	1.96
6	Tarawera	74	48	63	68	74	78	2.14
7	KFR North	80	38	53	67	76	83	2.8
8	KFR South	96	36	54	69	83	88	2.62
9	Kinleith	74	54	69	89	96	96	1.43
10	Mangatu	66	68	79	82	86	96	2.1
11	Mohaka	92	34	47	64	72	88	1.74
12	Kaweka	16	91	93	93	96	98	1.75
13	Gwavas	48	76	85	89	94	100	1.16
14	Ngaumu	98	42	57	70	79	88	1.96
15	Nelson	58	69	83	88	93	100	0.93
16	GoldenDowns	90	57	72	79	86	96	2.22
17	Ashley	74	56	68	79	86	94	1.92
18	OtagoCoast	88	48	70	85	88	91	1.99
19	Tapanui	92	42	67	82	88	93	1.59
20	Invercargill	60	66	82	85	89	91	1.78

Appendix 7 - Mean values, Felling Times, Techniques

No.	Location	Butt Dia (cm)	DBH (cm)	Stump height (cm)	Mean Felling Time (min)	Felling techniques: Normal %	1/4 cut %	Wedge %	1/4 cut +wedge %	Driver %	Driven %	Bore +release %	Other %
1	Glenbervie	62	49	8.7	2.53	26	36	2	34	0	2	0	0
2	Riverhead	51	42	8.0	1.65	28	26	8	28	0	2	8	0
3	Woodhill	43	34	7.0	1.60	52	0	14	32	0	2	0	0
4	Tairua	62	52	8.3	2.71	20	24	10	36	2	4	4	0
5	Rotoehu	56	49	13.2	1.81	56	0	28	0	8	8	0	0
6	Tarawera	51	46	9.3	1.51	70	4	14	2	2	4	4	0
7	KFR North	63	55	15.9	2.14	70	4	24	0	0	0	2	0
8	KFR South	60	52	14.6	1.61	84	2	8	0	2	4	0	0
9	Kinleith	48	42	8.5	1.50	34	20	12	24	0	0	10	0
10	Mangatu	67	55	7.4	3.59	24	4	12	39	0	4	14	3
11	Mohaka	65	53	9.1	1.99	12	24	0	4	0	0	60	0
12	Kaweka	56	46	8.0	2.27	34	22	8	20	0	0	16	0
13	Gwavas	51	41	9.0	1.44	58	18	4	12	0	0	8	0
14	Ngaumu	60	50	10.9	2.32	14	32	8	36	0	2	8	0
15	Nelson	40	32	3.6	1.41	60	0	28	4	0	6	0	2
16	GoldenDowns	55	47	7.8	1.44	86	2	2	4	0	2	4	0
17	Ashley	65	52	8.8	2.52	28	26	4	12	0	2	28	0
18	OtagoCoast	71	56	15.5	1.39	96	0	4	0	0	0	0	0
19	Tapanui	56	44	14.4	1.07	86	0	10	0	2	0	2	0
20	Invercargill	57	45	14.4	1.24	80	0	12	2	2	2	2	0

Appendix 8 - Breakage : Cause of Break

No.	Location	DBH (cm)	Tree Height (m)	Unbroken %	Unknown %	Topography %	Crossed %	Stump %	Other %
1	Glenbervie	49	32.3	54	4	8	24	10	0
2	Riverhead	42	34.1	42	18	22	12	6	0
3	Woodhill	34	26.1	90	2	2	4	2	0
4	Tairua	52	34.1	36	26	22	10	6	0
5	Rotoehu	49	43.3	12	36	4	16	30	2
6	Tarawera	46	40.5	26	26	14	12	22	0
7	KFR North	55	42.0	20	26	12	8	32	2
8	KFR South	52	41.2	4	42	4	34	12	4
9	Kinleith	42	34.1	26	32	14	10	18	0
10	Mangatu	55	33.3	34	8	10	6	42	0
11	Mohaka	53	38.5	8	34	28	4	26	0
12	Kaweka	46	27.3	84	6	4	0	6	0
13	Gwavas	41	31.0	52	30	4	10	4	0
14	Ngaumu	50	38.1	2	18	10	54	16	0
15	Nelson	32	29.0	42	4	4	8	42	0
16	GoldenDowns	47	36.8	10	38	0	32	20	0
17	Ashley	52	31.7	26	48	4	18	4	0
18	OtagoCoast	56	32.3	12	34	4	4	44	2
19	Tapanui	44	34.9	8	56	12	4	20	0
20	Invercargill	45	31.6	40	26	2	14	6	12

Appendix 9 - Felling Damage : Mean values

No.	Location	DBH (cm)	Scarf Height (cm)	Draw Wood % trees	Draw Wood Depth (cm)	Split/Slab % trees	Split/Slab Length (cm)	Effective Stump Height (cm)	Butt Log Loss (Inc.scarf) (cm)
1	Glenbervie	48.9	11.3	28	8.3	8	101	27.2	19
2	Riverhead	42.2	11.8	26	8.6	0	0	20.0	12
3	Woodhill	34.0	10.8	40	9.1	6	148	26.3	19
4	Tairua	51.7	11.6	42	10.9	8	45	23.7	15
5	Rotoehu	49.5							
6	Tarawera	45.9	7.6	44	9.7	2	75	19.4	10
7	KFR North	54.8	6.8	68	11.8	4	18	27.7	12
8	KFR South	51.7							
9	Kinleith	41.6	10.2	56	8.0	0	0	19.5	11
10	Mangatu	55.0	9.7	34	11.4	2	180	21.7	14
11	Mohaka	53	8.7	28	14.6	12	51	24.3	15
12	Kaweka	46.5	14.6	24	5.8	8	36	24.2	16
13	Gwavas	40.9	11.2	30	10.2	2	48	21.3	12
14	Ngaumu	50.2	14.3	50	12.2	8	97	32.6	22
15	Nelson	32.2	5.0	58	9.9	4	115	15.9	12
16	GoldenDowns	46.7	8.3	50	8.0	0	0	17.4	10
17	Ashley	52.1	13.5	32	6.5	2	26	22.7	14
18	OtagoCoast	56.3	14.1	60	8.5	0	0	30.1	15
19	Tapanui	44.2	9.5	32	5.1	4	15	24.5	10
20	Invercargill	44.7	7.9	30	6.0	0	0	22.7	8

Appendix 10

Models were developed using SAS (Statistical Analysis System) GLM and GENMOD statistical procedures. All models were highly significant ie. p value=0.0001

The equations are valid only for the range of the data from which they were derived ie.

TH: 16.1 to 49.7 m
DBH: 18 to 79 cm
BD1: 10 to 52 cm

A. Using the complete dataset of 1000 broken and unbroken trees (n=686 broken trees)

A1

$$\% \, Broken = \frac{100 \times \exp(-7.71 + 0.255 \times TH)}{1 + \exp(-7.71 + 0.255 \times TH)}$$

where TH is tree height in metres

	Est.	**Std.Err.**
TH	0.255	0.017

A2

$$\% \, Broken = \frac{100 \times \exp(SITE + 0.271 \times TH)}{1 + \exp(SITE + 0.271 \times TH)}$$

where TH= tree height in metres	**Est.**	**Std.Err.**
TH	0.271	0.023
SITE=		
Glenbervie	-8.9	0.8
Riverhead	-8.9	0.8
Woodhill	-9.4	0.8
Tairua	-8.6	0.8
Rotoehu	-9.4	1.0
Tarawera	-9.7	1.0
KFR North	-9.7	1.0
KFR South	-7.6	1.1
Kinleith	-8.0	0.8
Mangatu	-8.3	0.8
Mohaka	-7.3	0.9
Kaweka	-9.4	0.8
Gwavas	-8.7	0.8
Ngaumu	-5.8	1.2
Nelson	-7.4	0.7
GoldenDowns	-7.6	0.9
Ashley	-7.4	0.8
OtagoCoast	-6.6	0.8
Tapanui	-6.5	0.9
Invercargill	-8.1	0.8

A3 $BH1 = 9.0 + 0.42 \times TH$ **r^2=0.20**

Where BH1 =First break height in metres	**Est.**	**Std.Err.**
TH	0.420	0.032

A4 $BH1 = SITE + 0.418 \times TH$ **r^2=0.25**

where BH1= First break height in metres	**Est.**	**Std.Err.**
TH	0.418	0.050
SITE=		
Glenbervie	9.9	1.8
Riverhead	9.4	1.9
Woodhill	9.3	2.3
Tairua	9.5	1.9
Rotoehu	9.4	2.3
Tarawera	9.8	2.2
KFR North	9.2	2.2
KFR South	9.6	2.2
Kinleith	9.7	1.9
Mangatu	9.9	1.9
Mohaka	7.3	2.0
Kaweka	7.4	2.1
Gwavas	11.1	1.9
Ngaumu	8.5	2.0
Nelson	8.5	1.8
GoldenDowns	9.8	1.9
Ashley	8.4	1.7
OtagoCoast	9.5	1.7
Tapanui	6.8	1.9
Invercargill	9.8	1.8

A5 $BD1 = -8.7 + 0.408 \times TH + 0.304 \times DBH$ **r^2=0.33**

where BD1= First break diameter in cm and DBH is diameter at 1.4 m in cm.	**Est.**	**Std.Err.**
TH	0.407	0.051
DBH	0.304	0.026

A6 $BD1 = SITE + 0.252 \times TH + 0.336 \times DBH$ **r^2=0.36**

where BD1= First break diameter in cm	**Est.**	**Std.Err.**

and DBH is diameter at 1.4 m in cm.

TH	0.252	0.089
DBH	0.336	0.033

	Est.	Std.Err.
SITE =		
Glenbervie	-6.8	2.7
Riverhead	-5.3	2.9
Woodhill	-4.9	2.7
Tairua	-4.9	2.7
Rotoehu	-3.6	3.4
Tarawera	-4.6	3.3
KFR North	-3.2	3.3
KFR South	-4.1	3.2
Kinleith	-5.3	2.8
Mangatu	-5.4	2.7
Mohaka	-2.4	3.0
Kaweka	-5.2	3.1
Gwavas	-7.6	2.8
Ngaumu	-3.1	2.9
Nelson	-3.7	2.7
GoldenDowns	-5.1	2.9
Ashley	-5.2	2.6
OtagoCoast	-7.2	2.6
Tapanui	-2.3	2.8
Invercargill	-6.2	2.6

A7 $SHZ = 0.006 + 0.040 \times BD1$ **r^2 =0.23**

where SHZ = Shatter zone length in metres
and BD1 = first break diameter in cm

	Est.	Std.Err.
BD1	0.039	0.003

A8 $PCT = \exp(-2.304 + (0.070 \times TH))$

where PCT = total number of merchantable broken pieces

	Est.	Std.Err.
TH	0.078	0.006

A9 $FT = PLT + 0.047 \times DBH$ **r^2=0.43**

where FT= felling time per tree in minutes
and FLT=

	Est.	Std.Err.
	0.047	0.003
1 = Normal felling technique, without aids.	-0.84	0.15
2 = 1/4 cut (walk around to other side of tree).	-0.43	0.19
3 = Normal technique, and use of wedge.	-1.03	0.18
4 = 1/4 cut and use of wedge.	-1.21	0.18
5 = Driver tree.	-0.53	0.39
6 = Driven tree.	3.41	0.27
7 = Bore and release.	-0.23	0.20
8 = Other.	-0.42	0.77

B. Using the reduced dataset of trees that broke for no apparent reason (n=257 broken trees)

B1 $\% \, Broken = \frac{100 \times \exp(-8.31 + 0.244 \times TH)}{1 + \exp(-8.31 + 0.244 \times TH)}$

	Est.	Std.Err.
TH	0.244	0.022

B2 $BH1 = 4.6 + 0.578 \times TH$ **r^2=0.37**

	Est.	Std.Err.
TH	0.58	0.05

B3 $BH1 = SITE + 0.526 \times TH$ **r^2=0.50**

	Est.	Std.Err.
TH	0.526	0.071
SITE=		
Glenbervie	9.0	3.2
Riverhead	7.2	2.7
Woodhill	8.8	3.9
Tairua	7.4	2.6
Rotoehu	8.4	3.1
Tarawera	7.8	3.1
KFR North	7.2	3.2
KFR South	5.9	3.0
Kinleith	7.1	2.7
Mangatu	7.6	3.0
Mohaka	4.8	2.7
Kaweka	5.9	2.8
Gwavas	8.2	2.7
Ngaumu	7.7	2.9
Nelson	5.4	3.0
GoldenDowns	6.7	2.7
Ashley	4.5	2.5
OtagoCoast	7.4	2.4
Tapanui	3.5	2.6
Invercargill	8.3	2.4

B4 $BD1 = -4.6 + 0.293 \times DBH$ **r^2=0.21**

	Est.	Std.Err.
DBH	0.293	0.035

B5 $BD1 = 6.62 + SITE + 0.285 \times DBH$ **r^2=0.36**

	Est.	Std.Err.
DBH	0.285	0.038
SITE=		
Glenbervie	-1.4	4.0
Riverhead	4.0	2.2
Woodhill	1.7	5.2
Tairua	4.5	2.5
Rotoehu	5.3	2.2
Tarawera	4.7	2.3
KFR North	5.9	2.4
KFR South	7.7	2.2
Kinleith	4.0	2.1
Mangatu	2.5	3.3
Mohaka	6.6	2.3
Kaweka	3.2	3.3
Gwavas	2.7	2.2
Ngaumu	3.7	2.6
Nelson	3.5	3.7
GoldenDowns	5.4	2.1
Ashley	6.3	2.3
OtagoCoast	1.0	2.4
Tapanui	8.4	2.0
Invercargill	1.1	2.2

Appendix 11 - Faller's Notes

Details of individual felling sites

Note: The faller had no prior knowledge of any of the specific felling techniques which may have been regionally developed to cater for particular forest characteristics. Therefore, trees at each site were felled using L & FITB approved methods. However, in some cases, if those methods produced undesirable results, slightly different methods were used, and these are described in the following notes.

1. Glenbervie

A confined study area which made it difficult to fell all the trees onto a clear cutover, subsequently a few trees were felled into standing timber.

Butts of trees were quite buttressed, making the effective diameter to cut at ground-level quite large. This led me to work from both sides of the stem so as to complete the cuts accurately (ie. the quarter cut method).
A high perportion of the trees required wedging to directionally fell because of the variability of tree lean throughout the stand.

2. Riverhead

The perfect felling site (Cover photo).

Felling accuracy (within 1-2metres) was very important in this site so as to reduce breakage resulting from high stumps, which were prevalent in the cutover.

3. Woodhill

Conventional felling methods did not achieve desired results. The hinge often remained attached to the stump of felled trees. The resulting tension in the butt of the stem caused the stem to slab.

The instances of slabbing were reduced initially by making a very shallow top cut of the scarf. This was because the scarf would close before the tree hit the ground forcing the hinge to break. Secondly, the hinge was made thinner (feather thick) than conventionally taught (ie. 10% diameter of the stem). Thirdly, the step was made slightly higher.

The modified felling methods reduced slabbing in most instances, but it should be noted these felling methods have not been officially approved.

The worst instances of slabbing occurred when felling into the prevailing wind, and wedging was necessary. A (conventional) 10 % hinge diameter was required to ensure the hinge would not break before the tree was wedged over, and consequently, the tree always slabbed.

The small uniform crop made it very easy to achieve accurate felling cuts but the sand, wind blown on to the butts of trees, made it difficult to maintain a sharp saw.

4. Tairua

Excellent felling site.

5. Rotoehu

No unusual stand characteristics.

6. Tarawera

Limbed the trees before realising there was a Waratah processor on the skid.

7. KFR North

No unusual stand characteristics.

8. KFR South

No unusual stand characteristics.

9. Kinleith

Perfect felling site, unpruned stand. Quite a lot of hindrance from undergrowth ie. native vines.

10. Mangatu

We had a strong wind blowing directly toward us which held the trees up, often preventing them from immediately falling. This situation required me to do a lot more wedging than normally required. In a production situation the faller would normally move to another felling face where the wind was not such a hindrance. However we were restricted to the one felling face for this study.

Malformed tree tops were prevalent in the stand, possibly due to snow or wind damage.

11. Mohaka

This forest had the most pronounced predominant tree lean of the twenty forests we studied. A large percentage of trees had to be felled using the bore & release method to minimise butt damage. This method did not eliminate all butt damage, as the heavy forward lean of some trees caused the holding wood (at the back/tension side of the tree) to break before the release cut was complete.

Trees were often quite buttressed and had large branches in the upper portion of the stems.

12. Kaweka

Very heavily limbed trees, these limbs appeared to cushion the falling impact.

Tree form varied dramatically within the site. Short trees with large butt diameters and heavy limbs were found on the tops of ridges, while small diameter, suppressed trees tended to occupy the shaded gullies.

13. Gwavas

No unusual site characteristics.

14. Ngaumu

On day one, we were felling on to other stems already felled. (hauler setting, rolling-flat contour). This caused many trees to break due to cross-overs. Moved to a different site to collect the remainder of sample.

These trees proved very difficult to fell without some butt wastage from draw-wood occurring. Reducing hinge width, increasing the step and making the wing cuts very deep reduced the draw-wood. This was the most distinctive site out of all felling sites regarding difficulties in reducing butt wastage due to draw wood.

15. Nelson

Across slope felling for a hauler crew. The small piece-size of this stand made directional felling (eg. turning trees by angling the hinge diameter, using wedges etc.) relatively easy. Wing cuts were used to reduce butt wastage although this was not always necessary.

16. Golden Downs

Pruned, low stocking, very uniform stand. The felling site required some trees to be felled into the standing timber. However the relatively low stocking allowed trees to be felled between the standing trees.

17. Ashley

Snow damaged heads were prevalent. Trees were short, with large butt diameters and quite buttressed.

A small chainsaw was being trialled at this time, some felling times may be longer than would be expected from the use of a larger saw.

18. Otago Coast

The butts of trees were often very buttressed which made it difficult for me to make accurate felling cuts, and so minimise stump height.

Strong gusts of wind occasionally assisted trees to fall before I expected them to, resulting in some trees being felled with a larger than desirable hinge.

19. Tapanui

Trees which were felled over stumps, other stems or obstacles, often did not break, in contrast to Northern sites.

20. Invercargill

There was an apparent variation in tree form. On the ridge tops, trees were shorter, with large butt diameters. While in the the gullies, they were taller and had less taper.

Most trees were also heavily buttressed, extending the felling time.

The site had many high native stumps, with large native logs lying amongst thick native regeneration. It was inevitable that some felled trees would hit them. Surprisingly, many felled stems did not break.

Stumps of felled trees often appeared high, although the felling cuts were made as close to ground level as practically possible. This was because the trees had been planted on mounds.