Liro
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PROJECT REPORT

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NODAL SWELLING AS AN INDICATOR OF KNOT SIZE

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EXECUTIVE SUMMARY

A sample of 31 pruned, clearfell-age stems were intensively measured for stem diameter (over bark) at 5cm increments of length, whorl or cluster centres, and branch sizes. The data was analysed and the following results obtained:

1. Clusters or whorls (nodal swellings) in the unpruned section of the tree were detected with successive 5cm diameter measurements made in a single plane.

2. Whorls with one or more branches >6cm were predicted with a 53% success rate using the data obtained in this study.

3. Detailed stem, or log profiling, using either scanners or grapple processor-based diameter sensing, could provide useful data for:

    - log optimisation
    - log differentiation on the basis of internodal lengths
    - accurate stem and log volumes

Recommendation

Harvester-based diameter profiles from a number of stands, in different geographical areas; and log profile data from sawmill scanners, should be analysed to see if the results from this study can be confirmed.

INTRODUCTION

Many clearfell logging operations in New Zealand involve the use of mechanised processors for log-making. A large number of these processors are single-grip grapple-processors.

The operators of these grapple processors are often restricted in their ability to logmake to an optimal degree by their physical location. The view from a cab, through windows and operator protection structures (OPS) does not help identification of critical tree parameters, such as sweep and branch size; that may be also be some 3 to 4 metres away from the operator-logmaker (Cummins, 1998).

Recently, software developments in processor controllers (logmaking computers) for grapple processors have enabled detailed models of stem surfaces to be constructed (Sondell, 1997). The models consist of successively recorded stem diameter measurements (by mechanical diameter sensing) at intervals as small as 10mm. These models have been used to construct taper equations, which are in turn used to optimise the assortment of logs cut from a stem by predicting SED ahead of the grapple position.

It may be that the detailed model of a stem that can be constructed using this software could be used to infer the nature of some log features, such as cluster location and branch size. This is partly because the structure of a tree tends to approximate a "pipe" model. As branches appear to deviate from the stem, there is a corresponding decrease in stem diameter (Shinozaki et al, 1964; Valentine, 1990). From observation, it can be seen that branches in a cluster also tend to produce nodal swellings, and these tend to be proportional to branch size. Knowledge of the probability of the occurrence of a large branch in a cluster could be useful to the processor operator, or an optimiser, for making log-making decisions.

Other research into branch size or stem features

Over the years, a great deal of research has been carried out into the morphology of radiata pine. Recently, there has been renewed interest in the development and application of various sensors for detecting and describing log or stem internal and external features. This is because of the development of optimising software for saw-patterns for logs, and log allocation in stems (eg. AVIS, TimberTech, AutoSaw, TreeMaps).

Several years ago, an initiative by Cedric Terlesk and Peter Hall of FRI's Harvest Planning Group (HPG) led to nodal swelling, and other tree feature measurements being made of samples of stems from a transition crop stand (Hall, 1991a), and an 18yr old agro-forestry stand Hall, 1991b). These measurement data were tested for correlations between nodal swelling measurements and largest branch size. The best r^2 value, 0.423, was obtained for a regression predicting branch size of greater than 6cm from a nodal swelling diameter - for the upper log (height >11m) in the transition crop sample.

It was concluded that although the presence of a large branch could be predicted from nodal swelling on a whorl by whorl basis, the presence of several whorls in any log, and the probability of being wrong, meant that nodal swelling was unlikely to be useful as a grade-predictive tool.

The use of surface features to grade logs at sawmills has also been a focus of wood processing research in New Zealand and Sweden (Nylinder and Grace, 1993; Van Wyk et al, 1997). In this research, lasers and shadow scanners have been used to describe the surface texture of the logs, and inferences made of the log's internal qualities for the purpose of sorting logs for different cutting patterns. The results of this research in New Zealand are confidential, but are said to be promising.

Recent research at Forest Research's Mensuration group (now working under the Value Realisation Project area) has obtained detailed tree branch and cluster measurements, through destructive sampling of near-rotation trees, as part of a Co-operative-funded project.

In a paper written for a soon-to-be-held conference (Grace and Pont, 1998) a description is given of some of the equations developed to predict the size of stem features, such as the largest branch diameter in a cluster. The data and details of the predictive equations are confidential to the research project co-operative members.

The inadequacy of research-to-date for correlating nodal swelling with branch size

All the quoted research has failed to measure nodal swelling or cluster shape in the detail that is now available via harvester heads - typically, two diameter measurements have been made at an indeterminate distance above and below the cluster. The wood processing-based research has obtained detailed diameter measurement, and branch size, but only after de-barking, and only of individual logs. The diameter measurements of the rest of the stem are, of course, not available.

Inquiries of mensuration-based research has shown that much interest has been focused on excluding the effect of nodal swelling in order to develop taper functions and thereby tree or log volume functions. These tend not to reflect "true" tree shape.

Project objective

Accordingly, it was proposed to measure a sample of stems in sufficient detail in an attempt to establish whether any branch parameters can be predicted from tree diameter (and associated) measurements, and with what level of confidence.

METHOD

Phase 1: Measure, in detail, a sample of stems.

A sample of 31 trees (Table 1) from a pruned and thinned clearfell block (Cpt. 171 Kaingaroa Forest) were manually felled and trimmed, and intensively measured.

Table 1. Description of sample stems (n=31)

	DBH cm	Height m
Average	51	24.8
St. Dev.	6.5	3.7
Maximum	68	35.6
Minimum	36	15.5

Diameter measurements were taken (over bark, in mm) every 50mm along the stem from butt to tip, in a single horizontal plane, using Haglof electronic callipers.

Butt diameter (under bark), cluster height (from the butt, subjectively marked), cluster length (branch start to branch finish within the whorl) and branch sizes greater than 40mm (length and width, in mm) were recorded. Branches in classes <1, 2 to 3, and 3 to 4 cm were counted.

Phase 2. Analysis

The dataset was analysed for correlation of branch parameters with stem measurements.

The purpose of this analysis was to assess how well whorls containing large branches could be identified from stem diameter traces. Specifically, the aim was to identify whorls containing one or more branches greater than a specified diameter, using stem diameter measurements obtained at 5cm intervals over the unpruned portions of radiata pine stems.

Method of predicting large branch whorls from stem diameter measurements

The following steps were used to predict whorls from the stem diameter data:

1. To eliminate the stem taper from the data, a high order polynomial regression of diameter against age was fitted to each stem. The residuals from this function were used in subsequent analysis.

2. A weighted moving average was then used to smooth out minor irregularities in the data values.

3. This moving average was then used to predict whorls. The peaks and troughs were identified. Several methods were used to assess the size of each peak. Whorls were predicted to occur when peaks were greater than a certain specified threshold.

Various options were tested at each of the above steps:

1. The degree of the polynomial in the first step was varied; quadratic and quartic equations were tested.

2. For each stem diameter measurement, the moving average in step 2 was based on up to 3 values above and 3 values below it. Thus, the moving average was based on up to 7 measurements covering up to 35cm of stem. Comparisons were made between using equal weights for each considered value, and giving greater weight to the more central measurements.

3. The size of each peak was classified in three different ways:

   - Peak height - the difference between the height of the peak and the average of the troughs on either side of it.

   - Peak height x length - the peak height multiplied by the length of the peak measured between the troughs on either side of the peak.

   - The sum of all values within the peak, between the two troughs on either side, above a straight baseline between the troughs

The accuracy of whorl prediction was assessed as follows:

The actual heights of all whorls with one or more branches of greater diameter than that specified were first identified. These were then compared with the predicted heights. A prediction was considered to be accurate if an actual whorl occurred within a specified distance (ie. either 10 or 20cm) on either side of a predicted whorl. The effect of increasing the specified "window" for prediction was tested.

ACKNOWLEDGEMENTS

The assistance of Wayne Gibbons with the data. The cooperation of Fletcher Challenge Forests Limited, and contractor Neil Clapperton is also noted.

RESULTS

During stem analysis, the effect of increasing the specified "window" for whorl prediction was tested. Results are shown in Figure 1. There was no appreciable advantage for prediction in using a 40cm (±20cm) window.

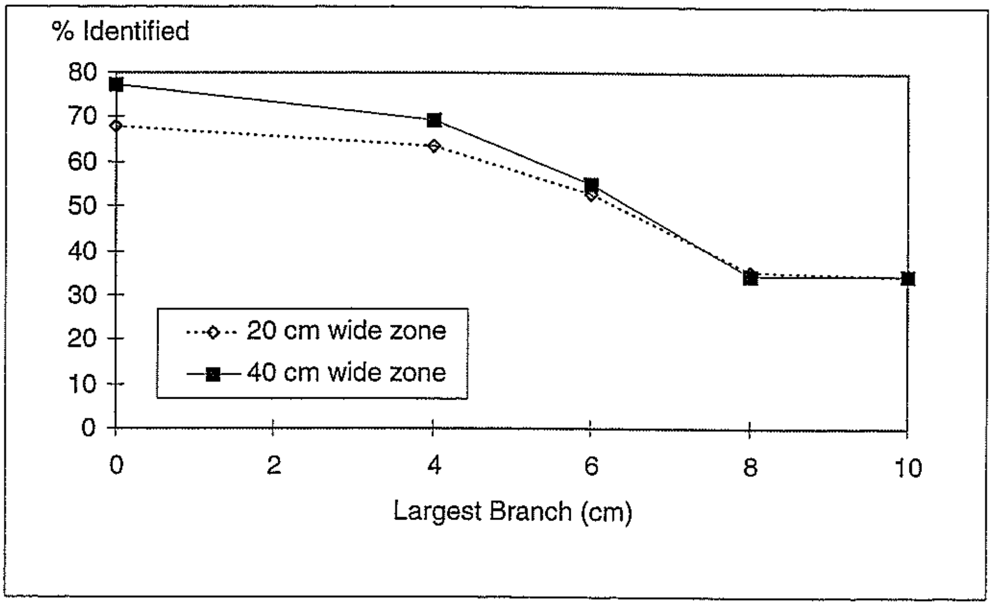

Figure 1. Effect on predictive efficiency of 20, 40cm windows

Prediction errors occurred when predicted whorls did not coincide with actual whorls (positive prediction error); or, when an actual whorl was predicted (negative prediction error).

To allow a comparison between the different prediction methods, the peak size threshold was adjusted so that there were an equal number of positive and negative prediction errors. Results of this analysis are shown in Table 2. It is apparent that weighting methods 2 or 7, combined with peak height, demonstrated the best predictive efficiency.

Table 2. Percentage correct predictions (predictive efficiency) against total predictions, 6cm branch whorls; for three different peak measurement methods, and seven different moving average weighting procedures.

Method	Weighting	Peak measurement method		
		height (%)	height x length (%)	sum of heights (%)
1	0,0,0,1,0,0,0	37	47	49
2	0.05,0.1,0.2,0.3,0.2,0.1,0.05	54	53	53
3	0.14,0.14,0.14,0.14,0.14,0.14,0.14	48	47	48
4	0,0.05,0.25,0.4,0.25,0.05,0	52	52	51
5	0,0,0.25,0.5,0.25,0,0	49	51	51
6	0,0.2,0.2,0.2,0.2,0.2,0	51	51	50
7	0,0.1,0.2,0.4,0.2,0.1,0	53	53	53

DISCUSSION AND CONCLUSIONS

Prediction of the occurrence of large branches

Of all the methods developed for the analysis of the profiles, method no. 2 (Table 2) using peak height of the smoothed waveform, was both the simplest and the most effective.

This method enabled the prediction of 54% of the whorls that actually contained branches greater than 6cm (determined by direct measurement). However, of the whorls containing smaller "largest" branches, eg. <4cm, 70 to 80% were successfully predicted. This was probably due to the larger number of sample whorls classified as such.

Application to mechanised processing

Grapple processors have the potential to sense diameter, at less than 5cm intervals, via the head's delimb arms. If profile data can be acquired through processor-based diameter sensing, and predictions are similarly valid, then this profiling method may have potential as an aid to logmaking.

Such a tool will probably be one of complementing the subjective assessment of the stem by the processor operator. This "aid" would perhaps take the form of a warning that a large branch "could" be present in a given section of log.

Indicator threshold

The predictive performance results relate to the entire unpruned whorl sample. For future individual stem samples, the threshold peak-height that indicated the presence of a target branch could be adjusted, where appropriate, to match the number of whorls "sensed" in the stem. This is because stems with fewer whorls are more likely to have large branches present, so the threshold indicator value could be increased. Threshold detection of target whorls might also be varied by whorl height on the stem, reflecting the changing nature of whorl geometry.

Other applications

Many sawmills dimensionally scan logs before primary breakdown in order to make the first cuts at optimum points. Profile analysis, before breakdown, could enable the prior sorting of logs into those more suitable for specific end products.

Further research

A number of stem profile samples, from different stands and geographic areas, need to be examined. The profile data obtained need to be analysed and compared to actual sample stem attributes to determine the extent to which these data reflect those attributes, and if variable threshold detection methods can be developed.

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APPENDIX

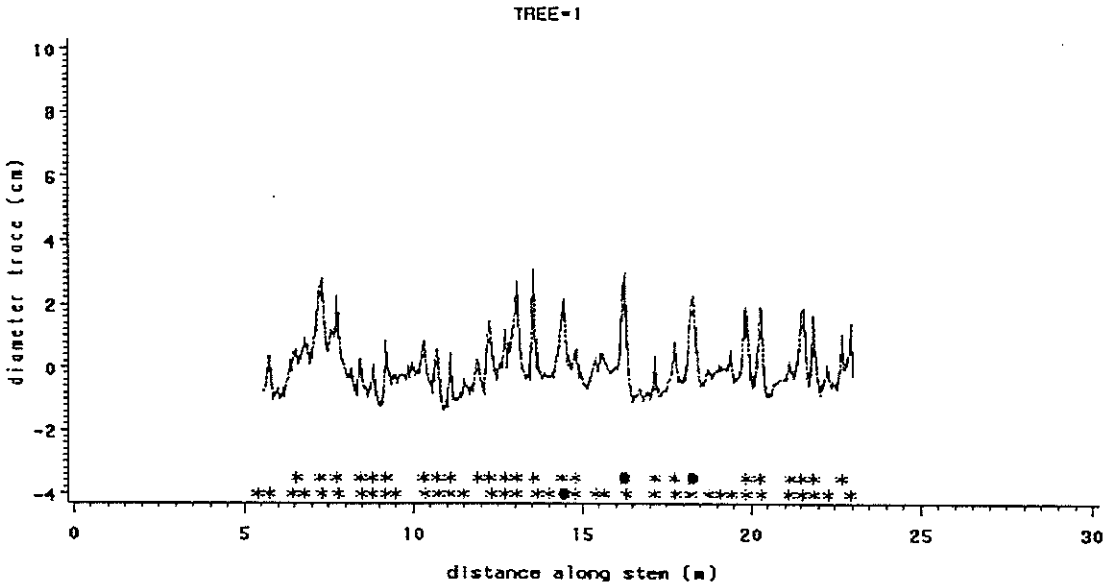
Stem profiles:

Lower code line

* = actual measured whorls
• = actual whorls with at least one branch 6cm or larger

Upper code line

* = predicted whorls
• = predicted whorls with at least one branch 6cm or larger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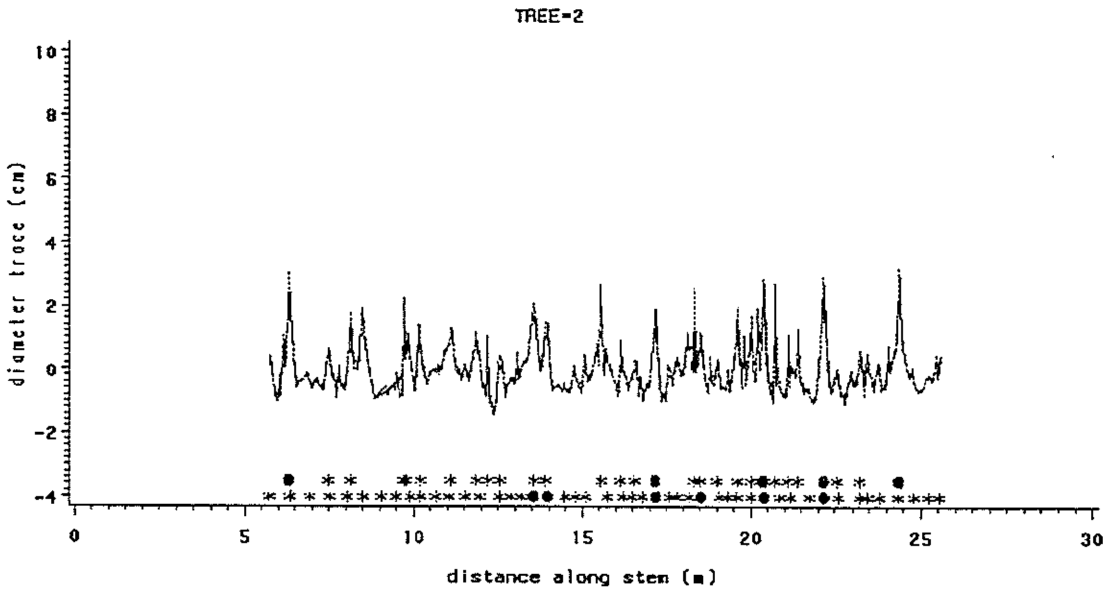
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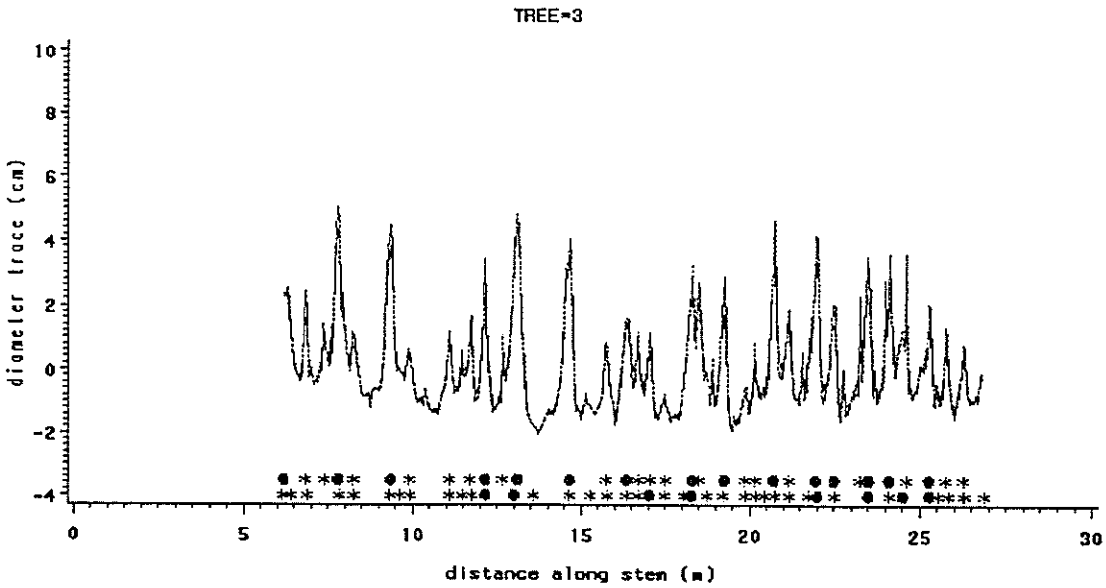
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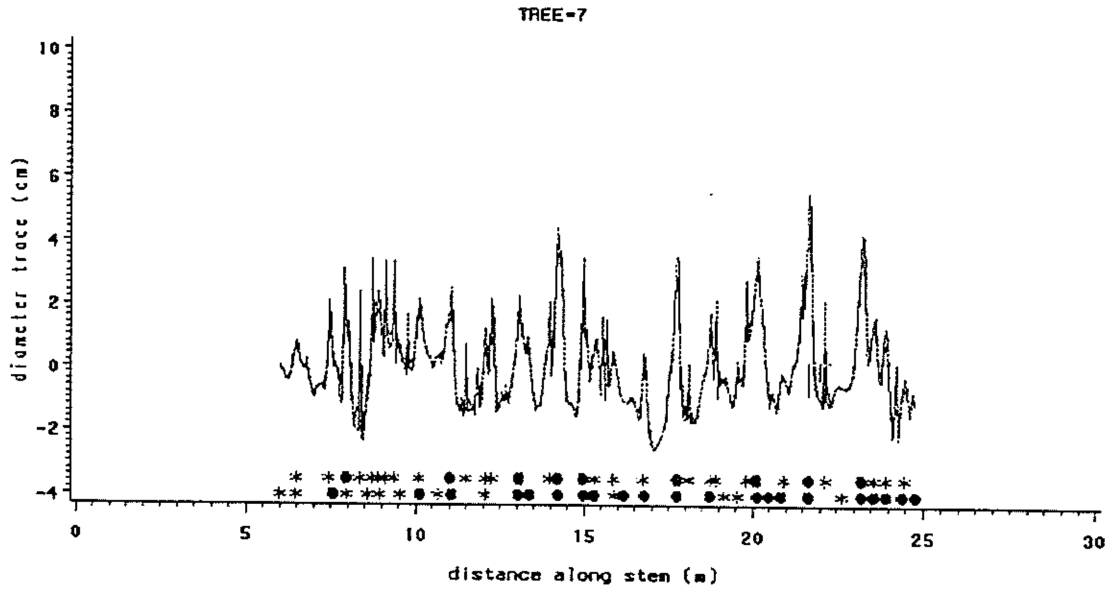
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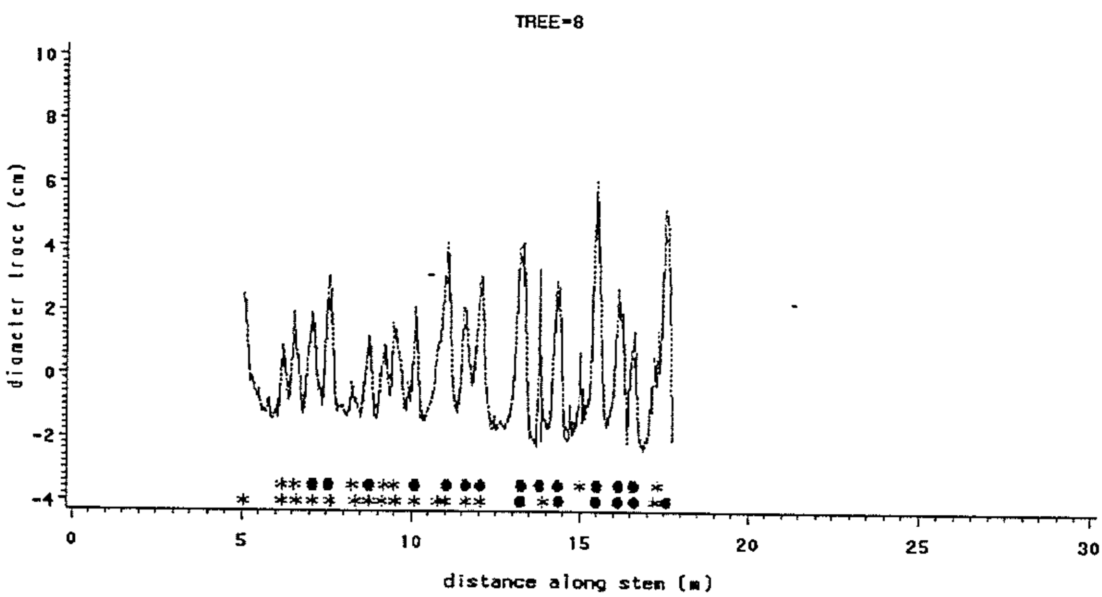
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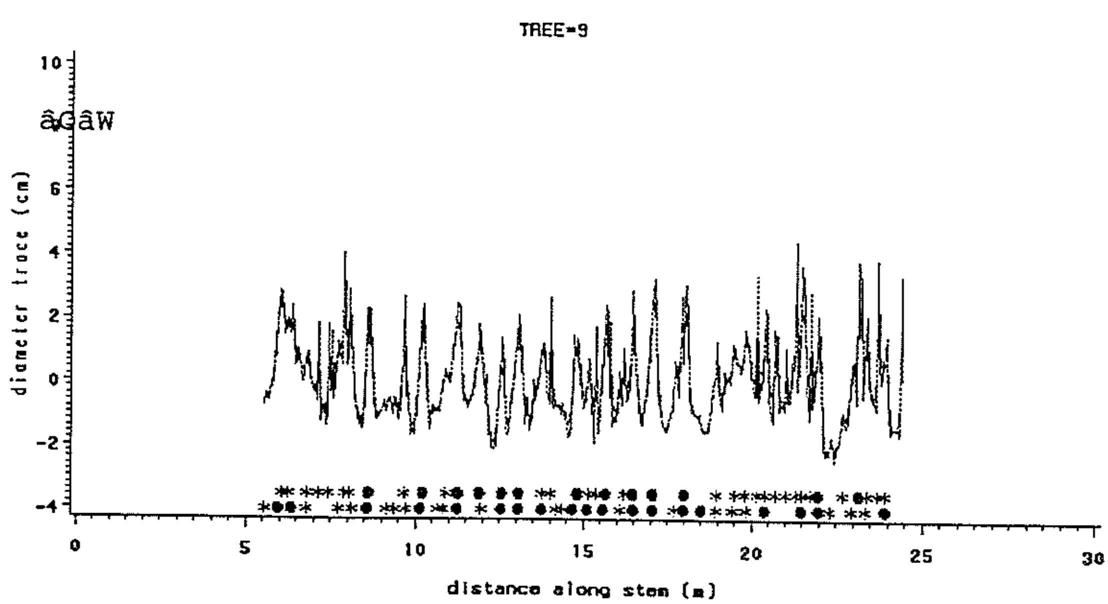
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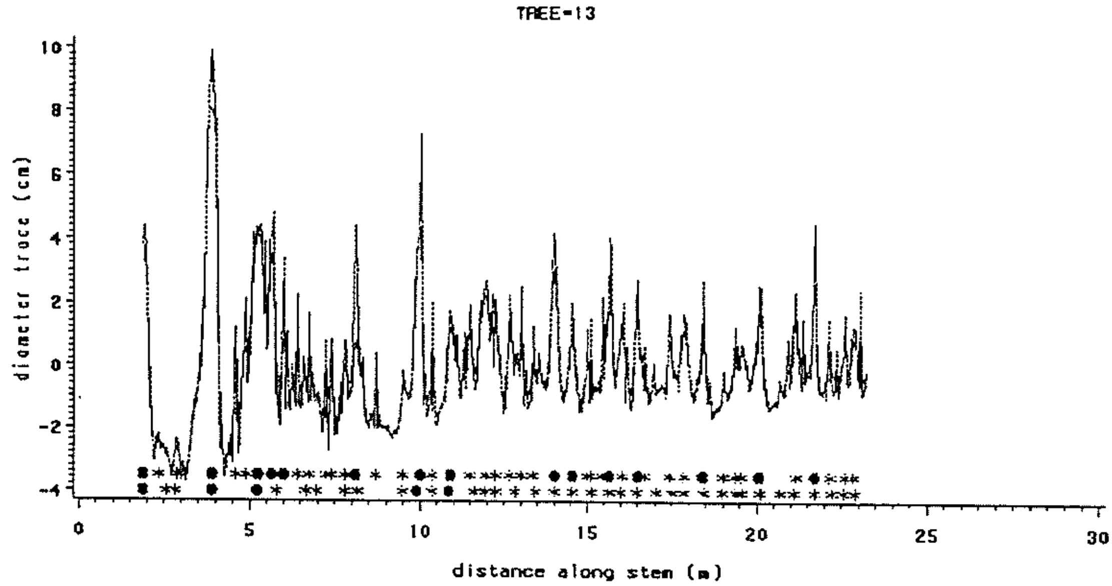
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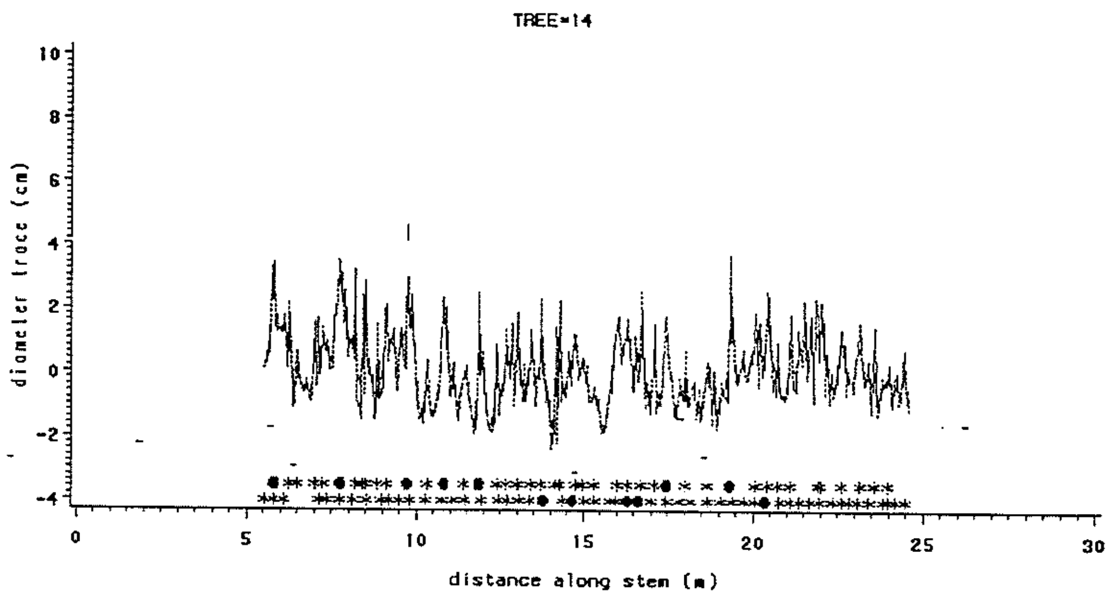
distance along stem (m)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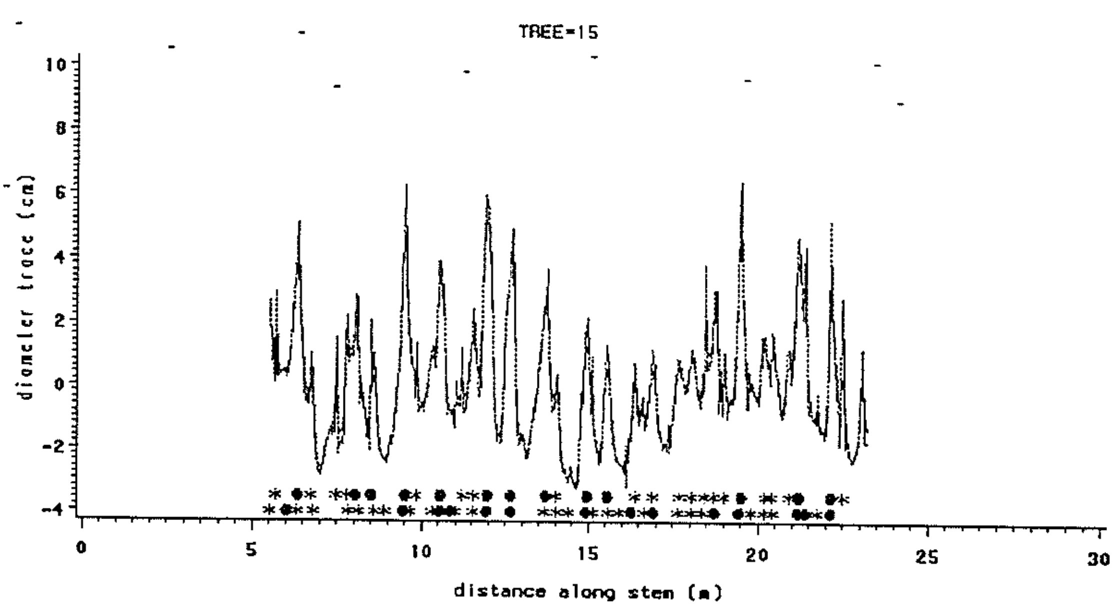
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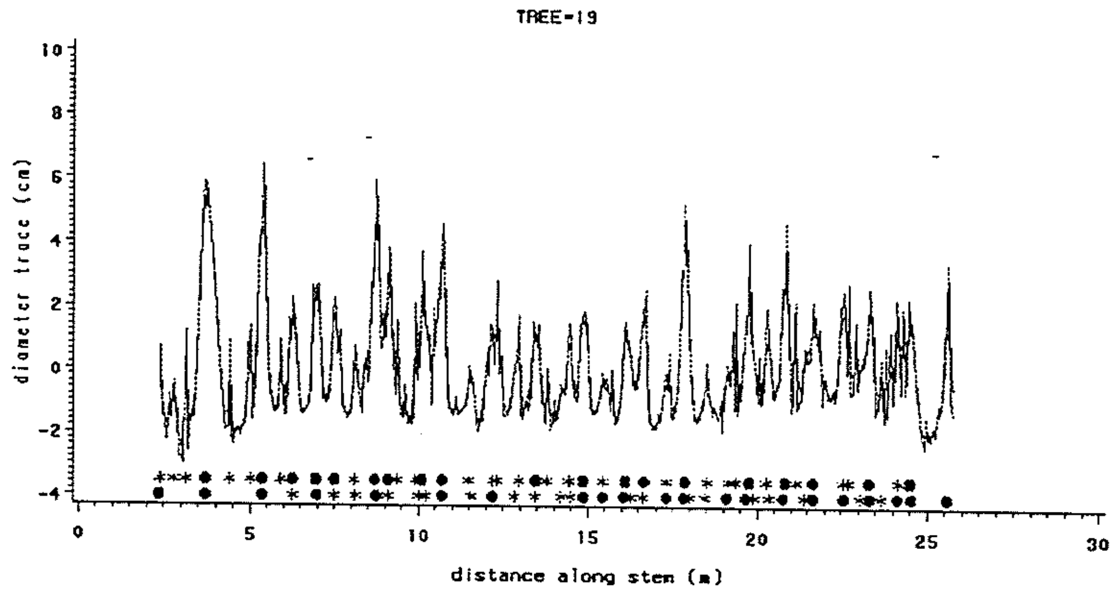
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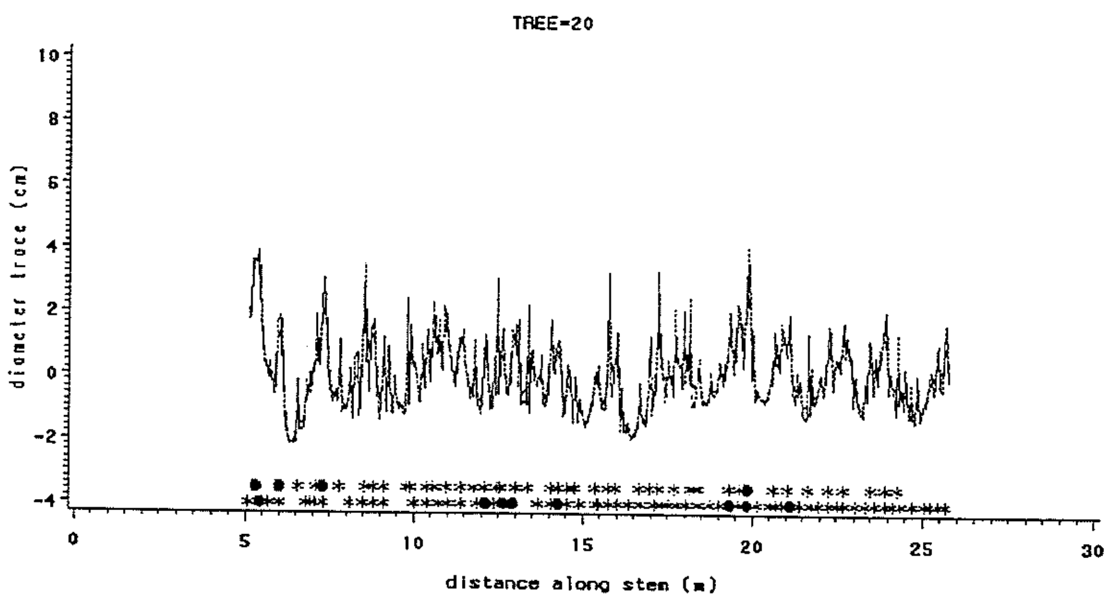
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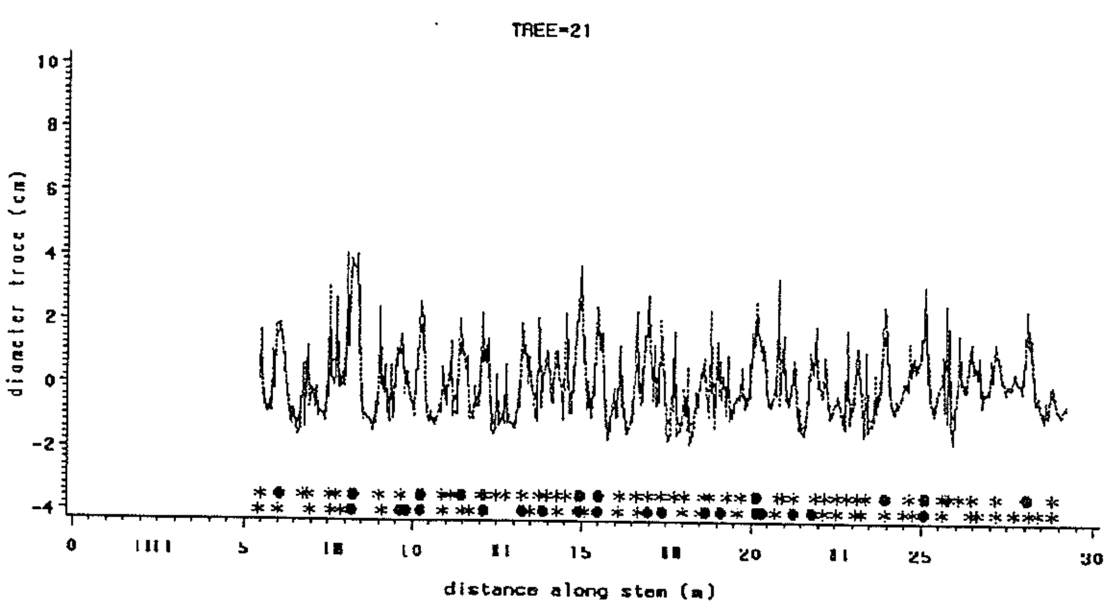
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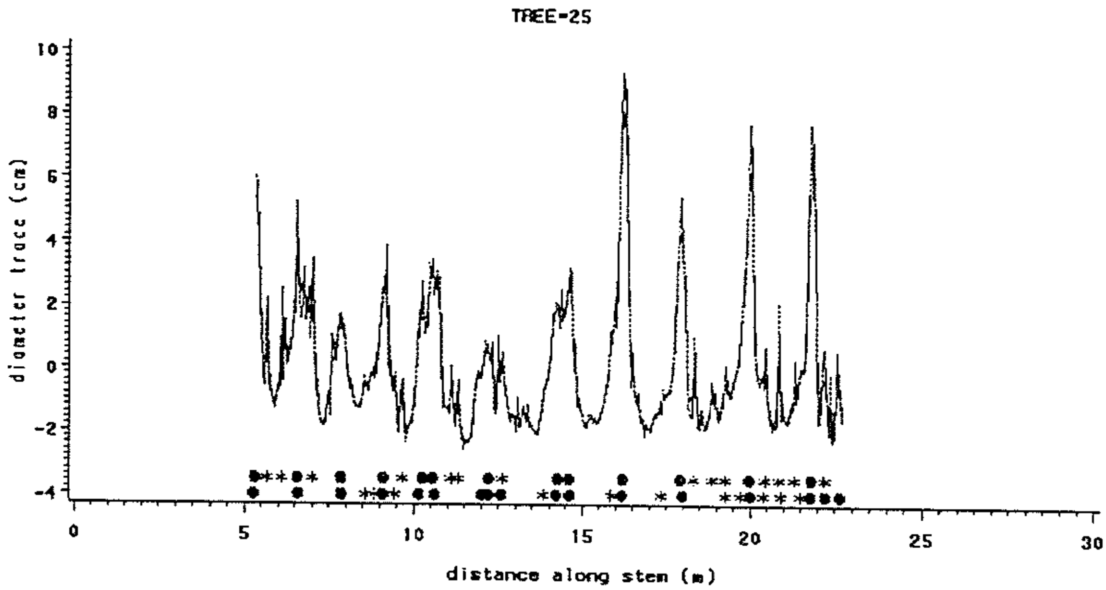
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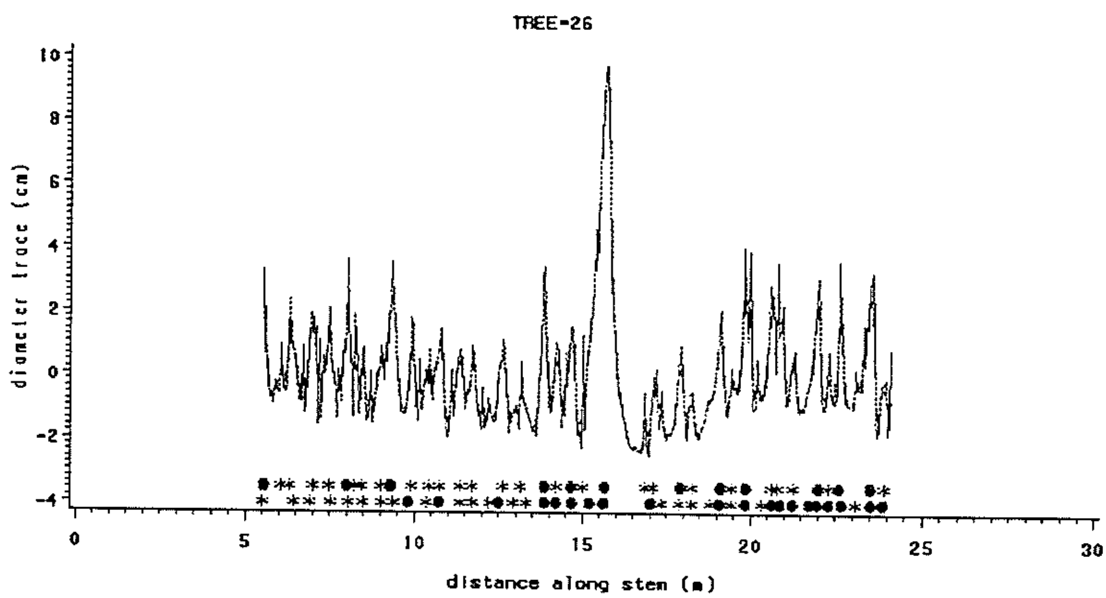
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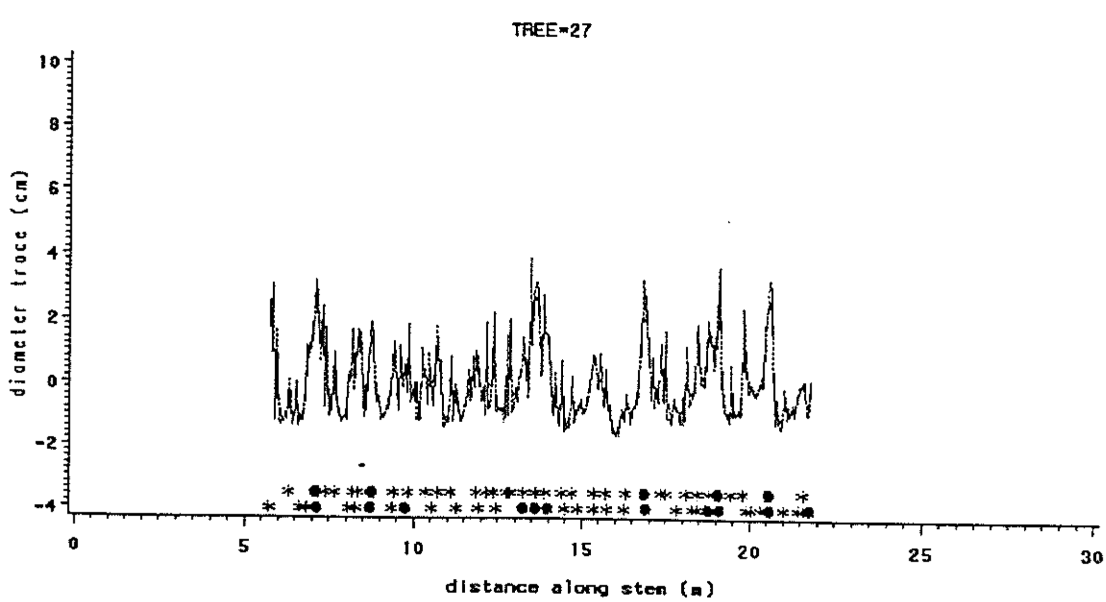
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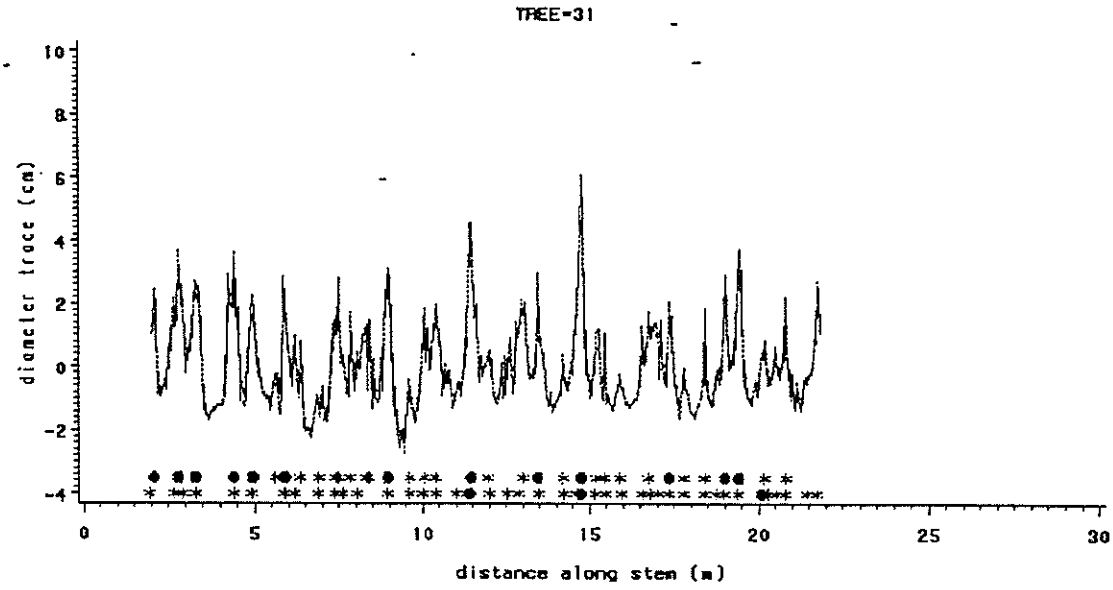
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diameter trace (cm)
10
8
6
4
2
0
-2
-4
0
5
10
15
20
25
30
distance along stem (m)