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MODELLING THE POSITION OF BRANCH CLUSTERS IN RADIATA PINE PROGRESS REPORT

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EXECUTIVE SUMMARY

A model of crown development is being constructed. The model requires 11 separate functions to be developed.

Two of the functions are:

The number of branch clusters within an annual shoot
The relative position of the branch clusters within the annual shoot.

This report contains a detailed account of the analyses undertaken to derive prototypes of these functions.

MODELLING THE POSITION OF BRANCH CLUSTERS IN RADIATA PINE PROGRESS TO END OF JUNE 1995

J. C. GRACE

INTRODUCTION

The position and size of branches affect the quality of timber obtained at the end of a rotation. It has been suggested that an improved estimation of stand log outturn could be achieved by developing a methodology for growing quality variables forward in time from a mid-rotation inventory (Rawley and Hayward, 1990). Grace (1992) suggested that two components of such a model should be equations to predict number of branch clusters (whorls) formed per year and equations to predict the relative positions of these branch clusters within the annual shoot. The advantage of this approach is that these equations can be directly linked with the current suite of growth models developed at NZFRI.

A major study of branch cluster position in radiata pine was carried out by Bannister (1962). From this study the following conclusions were obtained. Radiata pine produces between 1 and 6 branch clusters per year. The number produced is influenced by genetics, environment and tree age. The average number of branch clusters formed per year increases with age until about 15 years and then remains approximately constant. Fewer branch clusters are produced per year the further south one goes in New Zealand.
From comparing his data with data collected in Australia, Bannister (1962) concluded that the position of branch clusters within the annual shoot varied between the two countries and that the differences may be related to the distribution of rainfall within the year.

The objective of the current study is to develop a prototype simulation model for the number of branch clusters within the annual shoot and the relative positions of the branch clusters within the annual shoot.

STEP 1 - METHOD AND RESULTS

Data on the position and age of branch clusters were collected when a 26 year old radiata pine with DBH close to the plot average was felled from a plot at 500 SPH in experiment RO905 in Kaingaroa Forest (see Grace (1994) for further details).

The number of clusters formed per year were calculated for tree ages 6 to 23 years inclusive. Younger ages were not available due to pruning. Data for the last three years could not be calculated due to breakage at felling.
The relative position of branch clusters within the annual shoot was also calculated.

The number of branch clusters in the annual shoot was plotted against tree age. However, there did not appear to be a trend in the number of branch clusters with tree age. This is in contrast to the results of Bannister (1962, Fig. 6). It was decided to develop a prototype model for the number of branch clusters within the annual shoot by assuming the the number of branch clusters within the annual shoot was not a function of age but was random. The probability distribution for number of branch clusters within the annual shoot was therefore calculated (see Table 1).

Table 1. Probability distribution for number of branch clusters within the annual shoot for 1 tree in Experiment RO905

Number of branch clusters in annual shoot	Probability of occurrence
1	0.00
2	0.22
3	0.33
4	0.33
5	0.06
6	0.06

The average relative position of branch clusters within an annual shoot were calculated for shoots with 2, 3, 4, 5 and 6 branch clusters (see Table 2).

Table 2. Relative position of branch clusters within the annual shoot for 1 tree in RO905

Number of branch clusters	2	3	4	5	6
Relative position of branch clusters					
branch cluster 1	0.35	0.31	0.30	0.07	0.23
2	1.00	0.62	0.54	0.22	0.33
3		1.00	0.79	0.52	0.43
4			1.00	0.85	0.64
5				1.00	0.86
6					1.00

STEP 1 - PROTOTYPE MODEL

The data in these two tables were used to generate a prototype model of branch cluster position as follows:

1. calculate the height increment for a given age using a height age curve.
2. generate a random number between 0 and 1. This is used to determine the number of branch clusters formed that year according to probability distribution in Table 1.
3. position of the whorls within the annual shoot according to the data in Table 2.

The model was run to generate the position of branch clusters for 25 trees with a height of 33 m at age 20 years. The height of 33 m is an estimate of the average mean crop height for stands with site index 33 m and 36 m (see below). The height model used was NZ1. The internode lengths below 16.7 m were then calculated assuming whorl depth of 0.15 m and grouped into 0.2 m zones and the proportion of internodes in each class calculated (see Fig. 1). A whorl depth of 0.15 was considered to be realistic for stands with a site index between 33 m and 36 m.

The correspondence between class (in the figures) and internode length is given below:

Class	Internode Length
1	0 m to 0.2 m
2	0.2 m to 0.4 m
3	0.4 m to 0.6 m
4	0.6 m to 0.8 m
5	0.8 m to 1.0 m
6	1.0 m to 1.2 m
7	1.2 m to 1.4 m
8	1.4 m to 1.6 m
9	1.6 m to 1.8 m
10	1.8 m to 2.0 m
11	greater than 2.0 m

In order to see how realistic this "first attempt" model is, the proportion of internodes in the same classes were calculated using data from stands in the Central North Island with site indices of 33 m and 36 m collected by C. Inglis (see Fig. 2).

By comparing the two figures it is concluded that the model is reasonable for a first attempt. The really long internodes have not be predicted. Possible causes are:

a. all trees were assumed to be the same size.
b. no shoots were allowed to have one branch cluster.
c. the average positions of branch clusters within the shoot were used.
d. the number of branch clusters per year was not assumed to be less at young ages as has been shown by the data of Bannister (1962).

Figure 1.

25 simulated trees using model from Step 1, whorl depth 0.15 m

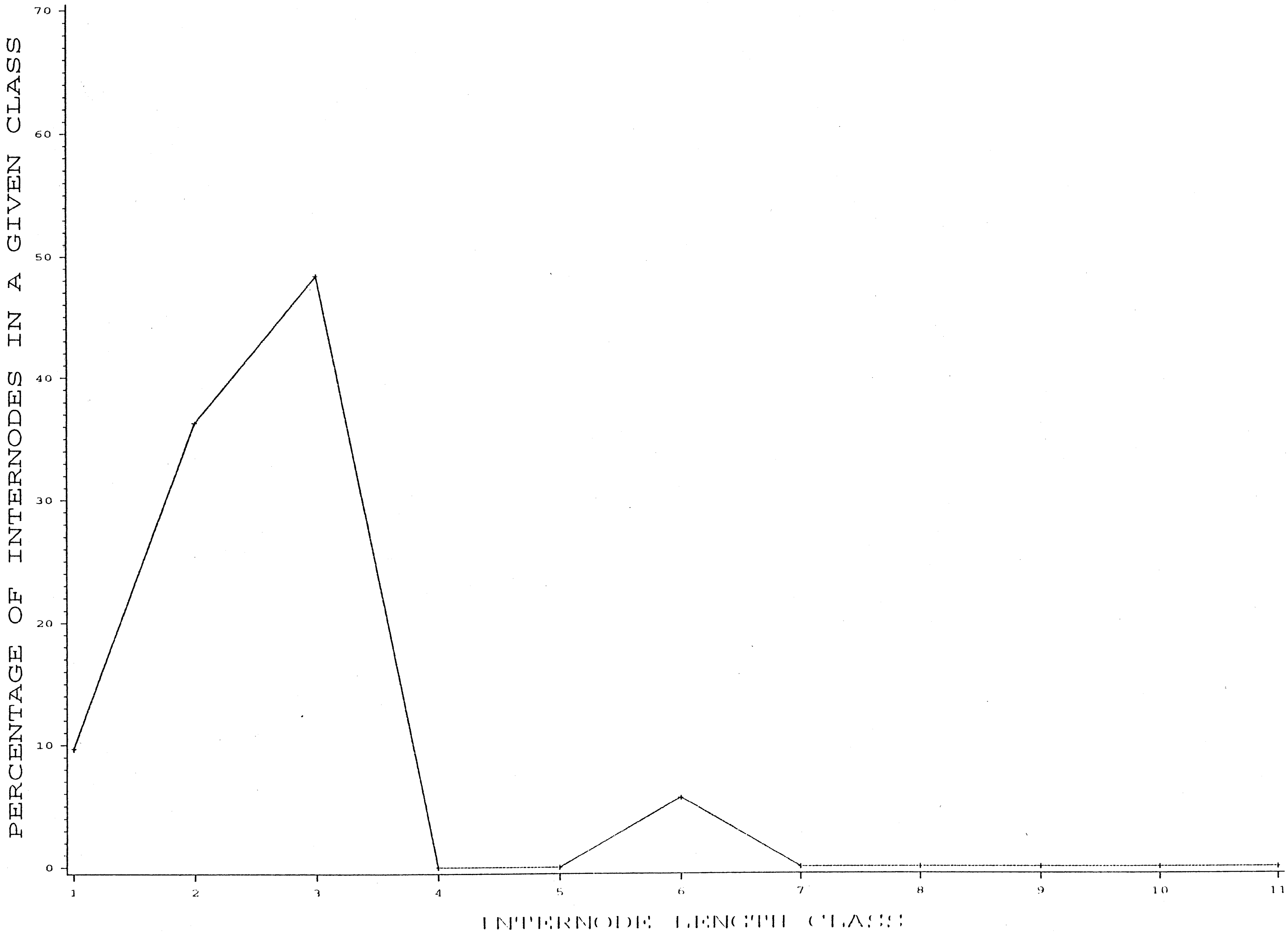
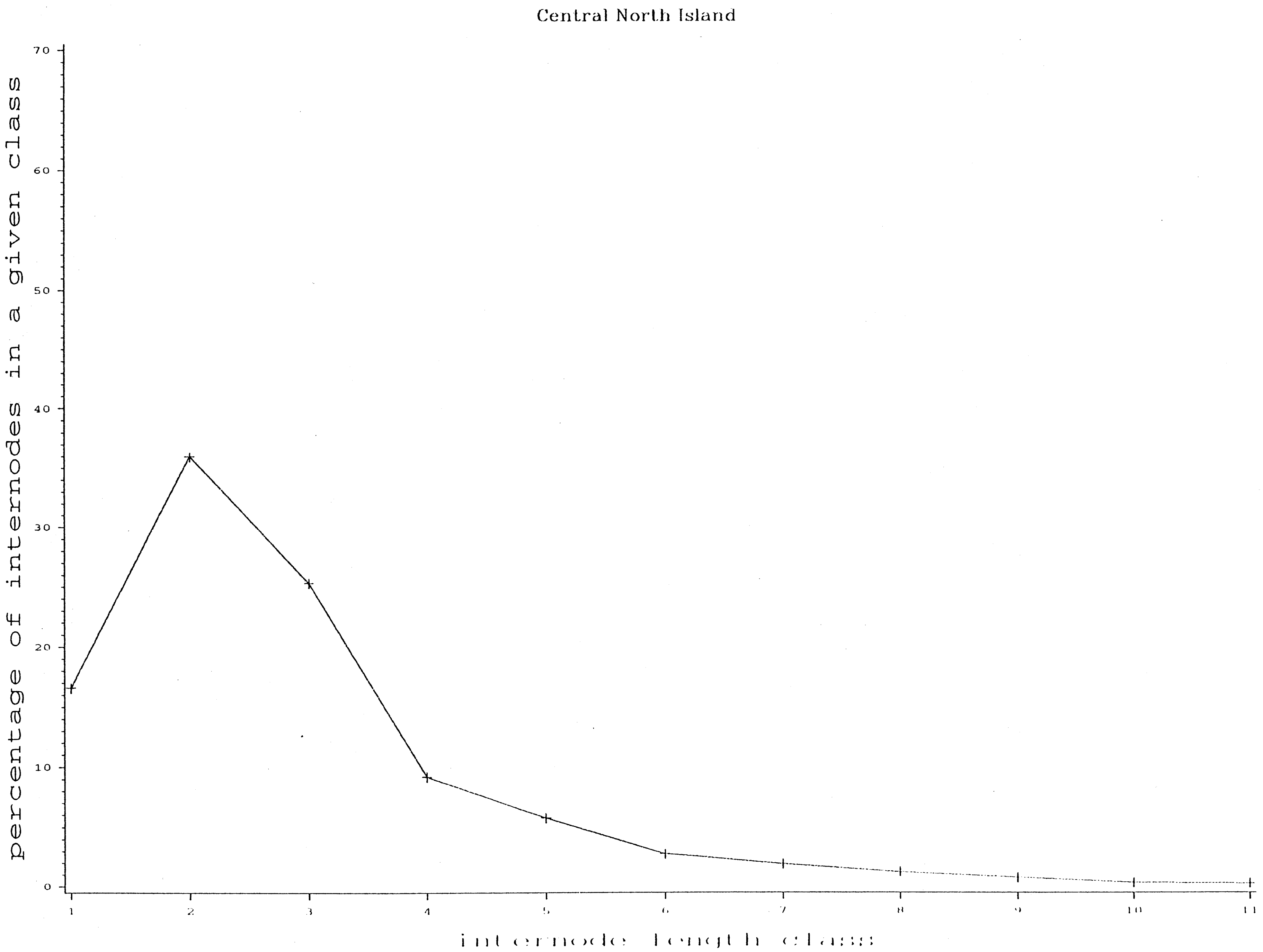


Figure 2


Central North Island
percentage of internodes in a given class
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
internode length class

STEP 2 - METHODS AND RESULTS

During spring 1994, twelve 26-year-old radiata pine were felled from a spacing experiment (RO696) in Kaingaroa Forest. These were trees with a small, average and large DBH from plots at 200 SPH, 400SPH, 600 SPH and 800SPH. The heights to the base and top of each branch cluster were measured . Also the number of growth rings were counted in the stem below the branch cluster. One branch per branch cluster was also measured for branch diameter growth. In some instances the ring count taken below the branch cluster did not agree with the ring count taken when the branch was measured for diameter growth. This usually occurred where there was a change in the number of stem growth rings, and occurred more often on the trees with small DBH.

A data set was prepared containing data on only those annual shoots that were unlikely to have any errors in the number of branch clusters formed per year. The trees with small DBH at 400SPH, 600 SPH and 800 SPH were excluded as there were few shoots which were unlikely to have errors.

The number of branch clusters in the annual shoot was plotted against number of stem growth rings below the branch cluster for each tree and for the whole data set.
Apart from the largest tree at 200 SPH, there was no obvious pattern when the number of branch clusters in the annual shoot was plotted against number of stem growth rings below the cluster. However there was a significant correlation between number of branch clusters in the annual shoot and number of stem growth rings below the branch cluster for the whole dataset (see Table 3). The significant correlation appeared to be caused by the small number of shoots with one or six branch clusters. When these annual shoots were excluded from the dataset, the correlation between number of branch clusters and number of stem growth rings below the branch cluster was not significant.

Data collected on maritime pine (Coudurier et al, 1994) indicated that longer annual shoots tended to have more branch clusters than the shorter ones. In order to see if the same was true for radiata pine, the correlation between shoot length and number of branch clusters was calculated for the whole data set and for each tree individually (see Table 3).

Table 3. Correlation between shoot length, number of stem growth rings and number of branch clusters in the annual shoot

Tree	Correlation between shoot length and number of branch clusters	Correlation between number of stem growth rings and number of branch clusters
18 - large tree at 200 SPH	0.31 (ns)	-0.82 (p=0.05)
21 - medium tree at 200 SPH	0.85 (p=0.03)	0.17 (ns)
30 - small tree at 200 SPH	0.67 (p=0.02)	-0.14 (ns)
33 - large tree at 400 SPH	0.92 (p=0.0001)	0.03 (ns)
35 - medium tree at 400 SPH	0.71 (p=0.004)	0.07 (ns)
71 - large tree at 600 SPH	0.18 (ns)	-0.30 (ns)
76 - medium tree at 600 SPh	0.59 (p=0.07)	-0.06 (ns)
56 - large tree at 800 SPH	-0.18 (ns)	0.54 (p=0.1)
63 - medium tree at 800 SPH	0.42 (ns)	-0.44 (p=0.1)
whole dataset	0.49 (p=0.0001)	-0.20 (p=0.04)

From the above analysis, it is clear that the number of branch clusters within the annual shoot is not random. The number of branch clusters within the annual shoot appears to depend on shoot length. From the data collected in this study, it is less clear whether the number of branch clusters within the annual shoot is dependent on the tree age when the whorl was formed.

For comparison with Table 1, the probability distribution for the number of branch clusters within the annual shoot has been calculated (Table 4).

Table 4. Probability distribution for number of branch clusters within the annual shoot in Experiment RO696.

Number of Branch Clusters in Annual Shoot	Probability of having a shoot with x branch clusters
1	0.06
2	0.12
3	0.31
4	0.31
5	0.17
6	0.03

There are some differences between Tables 1 and 4. These are likely to be due to the small sample size. However it is clear that annual shoots with 3 or 4 branch clusters are the most common.

There are also several options for ways to model the relative positions of the branch clusters within the annual shoot.

The simplest way is to assume average positions. These values are shown in Table 5.
As can be seen from comparing Tables 2 and 5, there are some differences between the two data sets. These differences are likely to be due to the small size of the data sets.

Table 5. Average position of branch clusters within annual shoots from Experiment RO 696

Number of Branch Clusters	1	2	3	4	5	6
Relative Position of Branch Clusters						
Cluster Number 1	1.00	0.60	0.32	0.25	0.21	0.11
2		1.00	0.71	0.50	0.40	0.30
3			1.00	0.79	0.56	0.48
4				1.00	0.82	0.62
5					1.00	0.86
6						1.00

H. Madgwick (pers comm) suggested that a model of the relative position of branch clusters within the annual shoot should take account of the variability in branch cluster position. This variability is illustrated by Bannister (1962, Fig. 11).

The number of first branch clusters within the annual shoot positioned in each tenth of the annual shoot was calculated for shoots with 2, 3, 4, 5 and 6 branch clusters. In each case there was clearly a preferred position for the first branch cluster.
The correlation between the relative position of one branch cluster and the relative position of the previous branch cluster was also generally positive and significant.
These results indicate that a model which uses the average position of branch clusters within annual shoots may be quite realistic. With more data a more sophisticated probability model could be developed.

STEP 2 - PROTOTYPE MODEL

The prototype model used in Step 1 was run with the data in Tables 4 and 5 used to give the number and position of branch clusters within the annual shoot. The model results are shown in Fig. 3.

More long internodes are simulated using this model. One reason is that annual shoots were allowed to have one branch cluster.

The analysis of the data during step 2 indicated that the number of branch clusters within the annual shoot is related to tree variables. This will be taken into account in the next version of the model. Equations that can be tested have been derived (see below).

A linear regression equation was developed to predict number of branch clusters from shoot length and number of growth rings in the stem.

The regression equation is:

Number of branch clusters = 1.98
+ 1.64 * (shoot length (m))
- 0.09* (number of rings in stem below branch cluster)

$R^2 = 0.38$

There was a significant correlation between the residuals and SPH.

A regression equation including SPH was then developed:

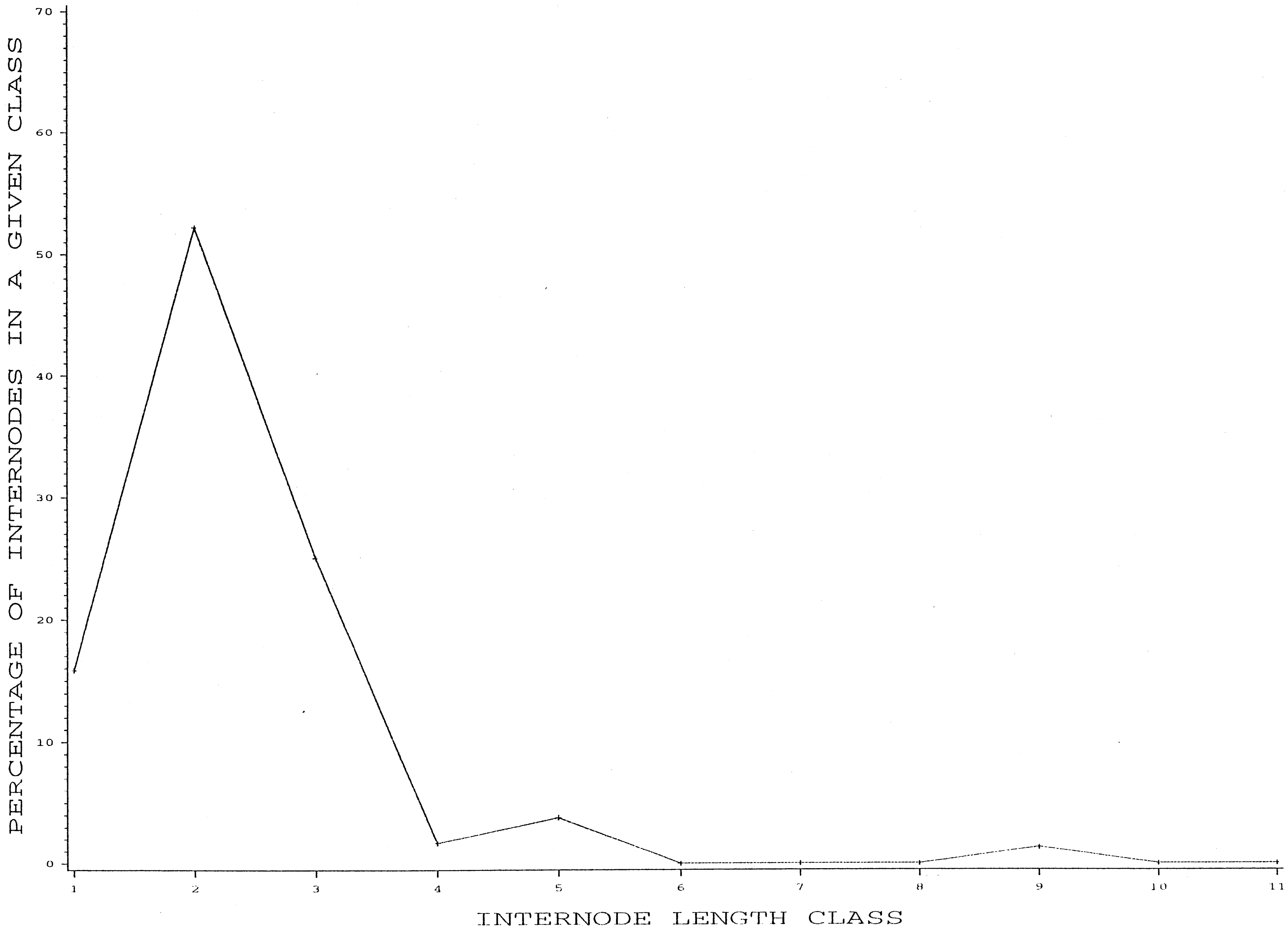
Number of branch clusters = 2.74
+ 1.5 * (shoot length (m))
- 0.08 * (number of rings in stem below branch cluster)
- 0.001* (SPH)

$R^2 = 0.45$

It needs to be realised that these are preliminary equations developed with a very small data set.

Figure 3

25 simulated trees using model from Step 2, whorl depth 0.15 m



STEP 3 - METHODS AND RESULTS

The data collected at Pigeon Valley near Nelson, (see Bannister, 1962) can be analysed in a similar manner. Table 6 shows the probability distribution for number of branch clusters within the annual shoot and Table 7 shows the relative position of branch clusters within the annual shoot.

Table 6. Probability distribution for number of branch clusters within the annual shoot for shoots from Pigeon Valley near Nelson

Number of branch clusters within the annual shoot	Probability of occurrence
1	0.02
2	0.14
3	0.27
4	0.41
5	0.15
6	0.01

Table 7. Relative position of branch clusters within annual shoots from Pigeon Valley

Number of Branch Clusters	1	2	3	4	5	6
Relative Position of Branch Clusters						
Cluster Number 1	1.0	0.75	0.40	0.25	0.20	0.10
2		1.00	0.80	0.50	0.40	0.17
3			1.00	0.80	0.62	0.50
4				1.00	0.87	0.72
5					1.00	0.92
6						1.00

A comparison of the numbers in Table 6 with those in Tables 1 and 4 indicates that there are more shoots with 4 branch clusters in Pigeon Valley than in the Central North Island. The relative position of branch clusters within the annual shoot are similar between Pigeon Valley and Central North Island. One of the larger differences is in the position of the 1st branch cluster in annual shoots with two branch clusters.

Figure 4

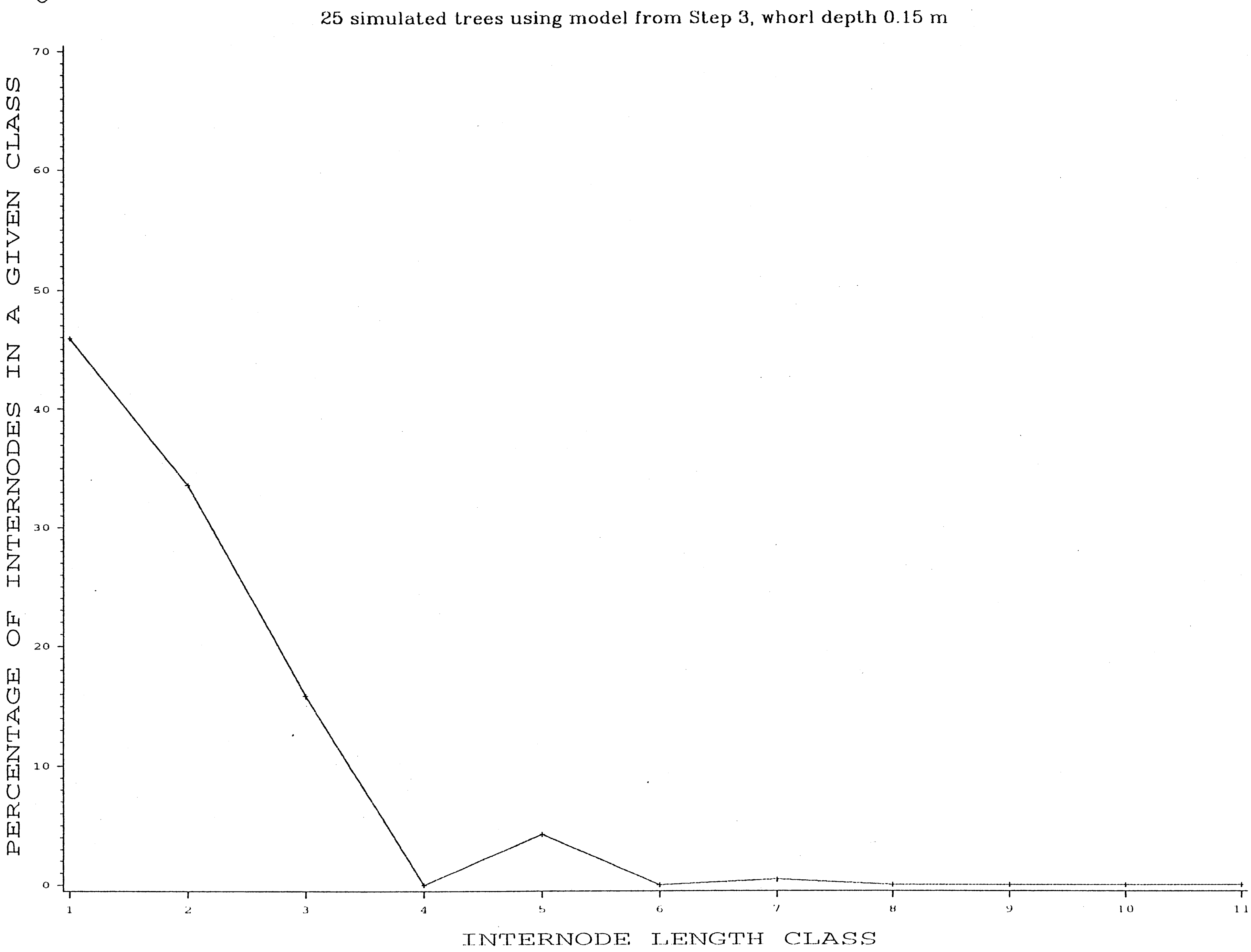
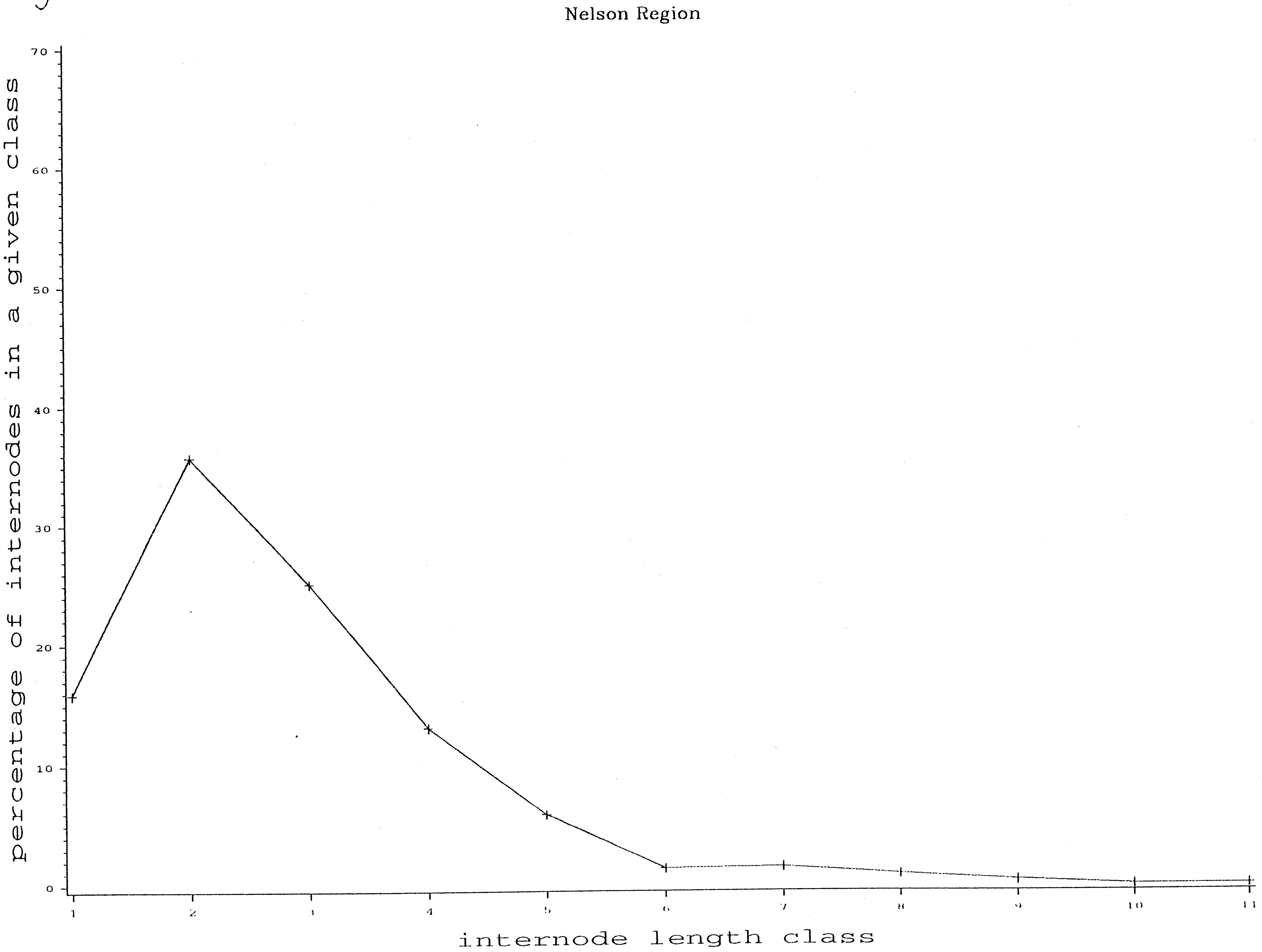

25 simulated trees using model from Step 3, whorl depth 0.15 m
PERCENTAGE OF INTERNODES IN A GIVEN CLASS
0
10
20
30
40
50
60
70
1
2
3
4
5
6
7
8
9
10
11
INTERNODE LENGTH CLASS

Figure 5



Nelson Region
percentage of internodes in a given class
internode length class
0
10
20
30
40
50
60
70
1
2
3
4
5
6
7
8
9
10
11

STEP 3 - PROTOTYPE MODEL

The prototype model in Step 1 was run with the data in Tables 6 and 7 used to give the number and position of the branch clusters within the annual shoot. The simulated trees had a height of 25.6 m at age 20 years. This is the estimated mean crop height for stands with a site index of 27 m. The distribution of internodes using a whorl depth of 0.15 m is shown in Fig. 4.

These data were compared with data collected by C. Inglis in Golden Downs Forest (site index 27 m) (see Fig. 5).

The data in both figures are for branch clusters between 5.7 and 16.7 m.

The longer branch clusters are not well predicted. This may the number of branch clusters formed per year at Pigeon Valley varied with tree age (Bannister, 1962).

FUTURE RESEARCH

The above analyses indicate that these prototype models for the position of branch clusters are realistic. The model should be improved by allowing the number of branch clusters in the annual shoot to depend on tree variables. It should also be improved by allowing a range of tree growth rates to be simulated. These ideas will be taken into account when the model is revised.

Further data need to be collected to expand the database. In any future data collection, the number of stem growth rings should be measured above and below the whorl, in order to minimise differences in ring counts.

This approach to modelling branch cluster position will be particularly useful for modelling branching patterns in improved seedlots as the branching pattern is under strong genetic control.

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